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Research Article

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Effects of Climate Change on Balıkesir Province: Investigation of Temperature Extremes for the Period 1975-2023

Muhammed Mustafa Özdel [1], Melike Durak [2], Dilek Aykır [3] & Alaattin Kızılçaoğlu [2]

[1] Non-affiliated, Kayseri, Türkiye
[2] Balıkesir University, Faculty of Science and Letters, Department of Geography, Balıkesir, Türkiye
[3] Izmir Kâtip Çelebi University, Faculty of Social and Human Sciences, Department of Geography İzmir, Türkiye

Abstract

This study aimed to analyse the changes and trends in the temperature extremes at the Ayvalık, Balıkesir, Bandırma, Burhaniye, Dursunbey, Edremit, and Gönen meteorological stations in Balıkesir province, all of which have long-term meteorological observation records. In this framework, 16 extreme temperature indices such as the maximum value of the daily maximum temperature (TXx), the minimum value of the daily minimum temperature (TNn), summer days (SU25), and tropical nights (TR20) were calculated using the daily temperature data from these stations for the 1975 to 2023 period. The temperature indices were evaluated in three main categories: degrees, days, and percentages. Trends in these extreme temperature indicators, calculated using the RClimdex package, were analysed with the Mann-Kendall trend test and slope estimate. The results indicate significant increases in the warming-related temperature indices at most stations, while the cooling-related indices generally show a decreasing trend. Over the 49-year period, the SU25 index increased by 25 days in Balıkesir and Edremit, while the TR20 index increased by 65 days in Bandırma and by 58 nights in Ayvalık. The percentage of warm nights (TN90p) increased between 5% and 19% across the stations, whereas the number of cold days (TX10p) decreased by 10% to 13%. These findings demonstrate that climate change has a substantial impact on temperature extremes in Balıkesir province, with both global climate change and urbanisation contributing to these changes.

Keywords Balıkesir · Climate Change · Extreme Temperature Indices

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Corresponding author: Muhammed Mustafa Özdel m.mustafaozdel@gmail.com

Introduction

While extreme weather events are partly linked to natural climate variability, anthropogenic global climate change has significantly increased their frequency, intensity, and duration (Stott et al., 2016). Human activities—such as the rise in fossil fuel consumption following the industrial revolution, unsustainable use of natural resources, improper land use, and deforestation—have led to a substantial accumulation of greenhouse gases in the atmosphere, including carbon dioxide, methane, and nitrous oxide (Filonchyk et al., 2024). This build-up has intensified pressure on the climate system, contributing to a global rise in the occurrence and severity of extreme weather events and related natural disasters (IPCC, 2021). These events, which directly affect human life, have increased markedly across the world in the 21st century (Carbon Brief, 2022). According to the report by EM-DAT (The International Disaster Database), 83% of the disasters recorded between 2000 and 2019 were directly linked to extreme weather events. These included floods (44%), storms (28%), extreme temperatures (6%), and droughts (5%). Notably, the number of disasters caused by extreme temperatures increased significantly—from 130 events between 1980 and 1999 to 432 events between 2000 and 2019, representing more than a threefold rise (UNDRR, 2020). Based on projections from current climate models (SSP scenarios), global mean surface temperatures are projected to increase by 1°C (optimistic, SSP1-1.9) to 5.7°C (pessimistic, SSP5-8.5) by the end of the century, compared to the 1850–1900 baseline period (IPCC, 2021).

Extreme weather events vary significantly depending on the geographical location. According to reports by the World Meteorological Organization (WMO) and the Intergovernmental Panel on Climate Change (IPCC), the Mediterranean Basin is among the regions projected to be most severely affected by this variability (IPCC, 2013; WMO, 2016). The Mediterranean Basin, identified as a significant climate change hotspot where the effects of global warming are relatively more pronounced (Giorgi, 2006), is experiencing increasingly important changes in extreme weather values. Summer temperatures along the North Aegean coasts are projected to increase by up to 3°C during the period 2013–2040. These temperature increases are expected to become more pronounced in the spring and summer seasons during the subsequent periods of 2041–2070 and 2071–2099 (Demir et al., 2013). Long-term daily meteorological observations play a crucial role in identifying extreme weather events. In recent years, the growing availability of such long-term data on a global scale, along with an increase in related research, has contributed to obtaining more objective and reliable results. Extreme weather events, which are considered one of the key manifestations of climate change (Erlat and Yavaşlı, 2009), directly or indirectly affect numerous sectors such as health, tourism, agriculture, food security, forestry, and water resources (Jahn, 2015). This situation underscores the importance of monitoring changes in the frequency, intensity, and duration of such events, as well as identifying emerging trends. Indeed, the literature contains numerous scientific studies that systematically analyse the spatial and temporal variations of extreme weather events (Alavinia and Zarei, 2020; Frimpong, Koranteng and Molkenthin, 2022; Aydın and Karabulut, 2022; Likinaw, Alemayehu and Bewket, 2023; Keskin and Saplıoğlu, 2023; Wang, Wu and Liu, 2024).

Some of these studies focused on regional analyses conducted in different countries and revealed noteworthy findings regarding changes in extreme temperature indices. For instance, in the Carpathian region (Romania), there was a marked increase in tropical nights, summer days, and both daily minimum and maximum temperatures during the period from 1961 to 2010. In contrast, significant decreasing trends were observed in the indices for frosty nights and days, as well as cold nights and days (Croitoru and Piticar, 2012). In a study evaluating the period from 1980 to 2012 in the Central Adriatic region (Italy), an increase was observed in the number of warm days and nights, tropical nights, summer days, and the duration of the warm spell duration index. Significant decreases were noted in cold-related extremes, such as cold nights and frosty and icy days (Scorzini, Bacco and Leopardi, 2018). A study conducted in Malawi for the periods 1961-2005 and 1982-2015 observed an increasing trend in extreme temperature indices, while a decreasing trend was noted for cold wave indices. Furthermore, attention was drawn to the trends in temperature increases during the more recent period (Mtewa et al., 2025).

Research undertaken in Türkiye also revealed similar trends. A study using temperature data from 100 stations in Türkiye between 1971 and 2004 found an increase in the number of tropical nights and summer days, along with a decrease in the number of frosty and icy days. A significant portion of these trends were statistically significant at the 95% level. Additionally, the study identified a significant increase in the frequency of warm days and nights, accompanied by a notable decrease in the occurrence of cold days and nights (Sensoy, Demircan and Alan, 2008). Erlat and Yavaşlı (2009) analysed the trends in tropical nights and summer days using data from 10 stations in the Aegean Region for the period between 1938 and 2008. The study findings revealed a statistically insignificant increasing trend until the 1970s, followed by significant increasing trends in most stations starting in the 1970s. Since the 1980s, an increasing trend in tropical nights and summer days has been observed, with significant increases in a large portion of the stations, particularly during the last decade of the dataset. Erlat and Yavaşlı (2011) analysed trends in temperature extremes in the Aegean region using the Mann-Kendall trend analysis with six different temperature indices (number of warm days and nights, number of cold days and nights, summer days, and tropical days). The analysis revealed statistically significant increases in warm days and nights across all stations over the last 35 years. A study using daily temperature data from 97 stations in Türkiye between 1970 and 2006 found an increasing trend in the number of warm and extreme warm days, along with a significant decreasing trend in the number of cold and extreme cold days (Acar Deniz and Gönençgil, 2015). Erlat and Türkeş (2017) identified a strong increasing trend in the number of annual tropical nights across a significant portion of Türkiye after 1985. Using data from 7 stations in the Marmara Region, Abbasnia and Toros (2018) found an increasing trend in warm nights and days, the warm spell duration index, summer days, and tropical nights, alongside a decreasing trend in cold nights and days, icy days, and the cold spell duration index. Similarly, Dün and Gönençgil (2021) observed an increase in summer days and warm days and nights, as well as a decrease in cold nights and days, cold spell duration, and daily temperature range in a significant portion of the Aegean Region.

On the other hand, urbanisation constitutes a critical factor impacting temperature trends. With the escalation of urban populations, alterations in land use and land cover, increased energy consumption, and heat emissions resulting from anthropogenic activities, the "Urban Heat Island" phenomenon has emerged. This phenomenon engenders a divergence in the temperature trends observed in urban locales compared to those in rural areas. An abundance of studies has scrutinised the ramifications of urbanisation on mean temperature series, and their conclusions consistently suggest that urbanisation significantly exacerbates warming trends (Aykır, 2017; Zhao et al., 2019; Sun et al., 2019; Manalo et al., 2021; Yılmaz and Özcanlı, 2021).

This research endeavour sought to elucidate the temporal and spatial changes in temperature extremes in Balıkesir province, which holds significant importance for tourism and agriculture in Türkiye, through statistical analyses. In this context, 16 different temperature indices were generated from daily temperature data obtained from 7 meteorological stations (Ayvalık, Balıkesir, Bandırma, Burhaniye, Dursunbey, Edremit, and Gönen), with a long observation period of 30 years. The Mann-Kendall Test was applied to these indices to assess the temporal and spatial changes in extreme air temperatures in the study area. The effect of climate change on Balıkesir province was analysed using daily maximum and minimum temperatures, and the direction of change in temperature extremes was determined.

Study Area

Balıkesir province is situated between the Marmara and Aegean regions of Türkiye, with a large part of its territory falling within the Marmara Region (Figure 1). The province's location along both the Marmara and Aegean Seas significantly influences its economic and commercial potential. Balıkesir city, the administrative centre of the study area, is the most developed and densely populated settlement in the area. According to the data of the Turkish Statistical Institute for the year 2023, approximately 29.4% of the province's total population (1,273,519 people) resides in the Karesi and Altıeylül districts in central Balıkesir, 13.5% in Edremit, and 13.1% in Bandırma (TurkStat, 2023). The temporal fluctuations in the populations of the localities housing the analysed stations are delineated in Table 1, which was compiled using data from Erel (1992) and TurkStat (2023).

Table 1

Population Data for the Years 1970–2023 (number of persons) (compiled using data from Erel, 1992 and TurkStat, 2023)

Settlement Name	1970	1990	2010	2023
Balıkesir (Centre)	85,004	170,589	334,893	374,304
Ayvalık	17,661	25,687	63,627	74,643
Bandırma	39,525	77,444	135,094	166,836
Burhaniye	11,908	21,805	51,089	65,790
Dursunbey	7,629	13,025	43,516	33,621
Edremit	24,115	35,486	120,955	171,700
Gönen	13,815	26,849	73,407	75,572

The annual mean temperatures recorded at the meteorological stations used in this study range from 12°C to 17°C. As one moves inland, a general decline in temperatures is observed; in Dursunbey, which is situated further inland, the annual mean temperature decreases to 12°C. The total annual precipitation spans from 525 mm to 720 mm, with a notable reduction observed in more inland areas (Table 2). According to the Erinç Precipitation Efficiency Index (Erinç, 1965) and De Martonne Drought Index (de Martonne, 1926), calculated using the observation records of the stations in the study, the region exhibits semi-humid and semi-arid to humid climate characteristics (table3). Based on the Köppen-Geiger Climate Classification, the study area largely falls under the Csa climate class, known as the Mediterranean climate, characterised by hot, dry summers and mild, rainy winters.

On the other hand, in areas of the study site exceeding 1000 metres in elevation, the Csb climate class—characterised by mild winters and warm, dry summers—can be observed (Taşoğlu, Öztürk and Yazıcı, 2024).

Table 2

Temperature and Precipitation Data from the Stations Used in the Study

Station Name	Annual Average Temperature (°C)	Annual maximum temperature average (°C)	Annual minimum temperature average (°C)	Annual total precipitation (mm)
Ayvalık	16.7	21.9	12.6	659.4
Balıkesir	14.8	21.2	8.9	604.5
Bandırma	14.4	18.8	10.4	715.9
Burhaniye	16.4	21.9	11.4	628.1
Dursunbey	12.3	18.7	7.2	525.3
Edremit	16.7	22.1	11.8	720.3
Gönen	14.4	20.1	9.0	678.5

Figure 1

Location Map of the Study Area

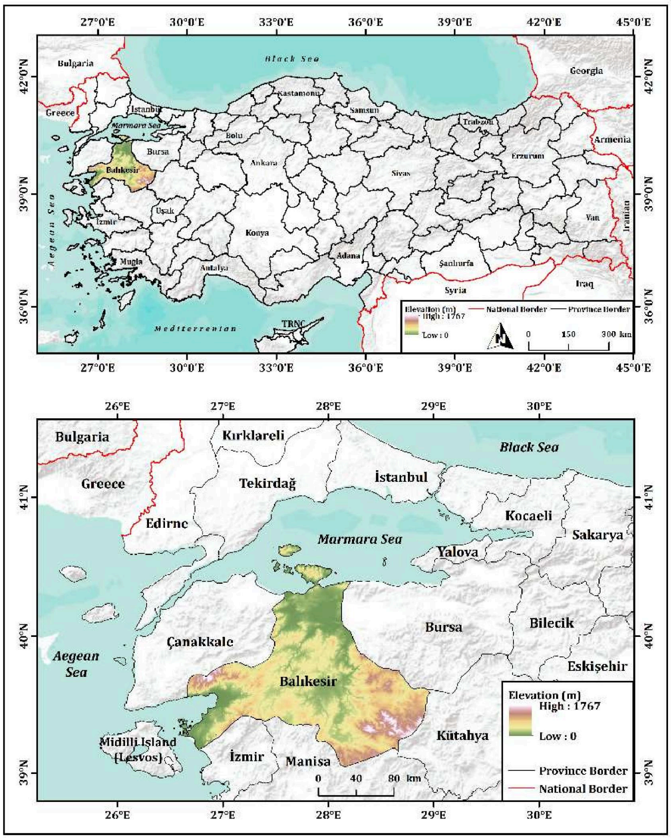


Table 3

Erinç and De Martonne Climate Classification Results of the Stations Used in the Study

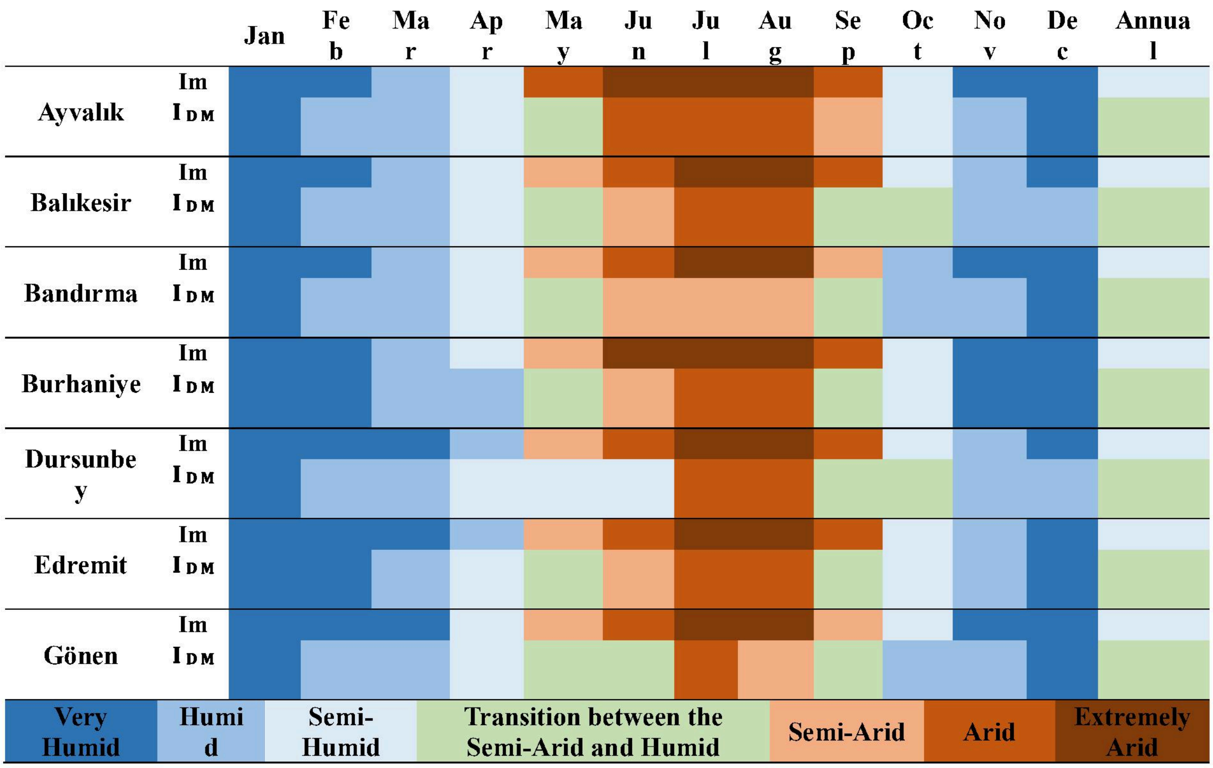


Table 4
Information About the Stations Used

Station Name	Station Number	Latitude (°)	Longitude(°)	Elevation (m)	Measurement Range	Station Type
Ayvalık	17175	39.3113	26.6861	4	1958-2023	Coastal
Balıkesir	17152	39.65	27.8666	102	1938-2004	Non-coastal
Balıkesir (Airport)	17150	39.6326	27.9201	102	1999-2023	Non-coastal
Bandırma	17114	40.3315	27.9965	63	1950-2023	Coastal
Burhaniye	17722	39.4983	26.9755	20	1975-2023	Coastal
Dursunbey	17700	39.5778	28.6322	637	1966-2023	Non-coastal
Edremit	17174	39.5895	27.0192	21	1962-2023	Coastal
Gönen	17674	40.1135	27.6426	37	1695-2023	Coastal

Data and Method

This study utilised 49 years of daily maximum and minimum temperature records from 7 meteorological stations within the boundaries of Balıkesir province, obtained from the General Directorate of Meteorology for the years 1975-2023 (Table 4). The principal criterion for selecting the meteorological stations incorporated in this research was the presence of at least three decades of consistent daily temperature records. Given that the study was executed at the provincial level, meteorological stations located in both the coastal and inland regions of Balıkesir province were deliberately chosen to adequately represent the province's geographical diversity, thereby ensuring a spatially representative and homogeneous distribution throughout the study region. Furthermore, to enhance the accuracy of the climatic assessment of the central district of Balıkesir, data were combined from two distinct stations servicing this locale. As delineated in Table 4, this methodological rationale stems from the fact that the Balıkesir Meteorological Station (ID: 17152) possesses data spanning from 1938 to 2004, while the Balıkesir Airport Station (ID: 17150) has been consistently collecting measurements since 1999. Considering the close spatial proximity and comparable elevation of these two stations, their data were combined into a singular continuous dataset and subsequently analysed accordingly. The stations were additionally categorised into urban and rural classifications. Stations located in urban areas with populations ranging from 300,000 to 500,000 were classified as medium-sized urban stations; those situated in urban areas with populations between 100,000 and 300,000 were designated as small-sized urban stations; and stations in locales with populations under 100,000 were classified as rural stations (Demircan et al., 2017). In accordance with contemporary population statistics, the Balıkesir station was classified as a medium-sized urban station, the Bandırma and Edremit stations were identified as small-sized urban stations, and the Ayvalık, Burhaniye, Dursunbey, and Gönen stations were classified as rural stations.

The observational records obtained from the selected meteorological stations were used to derive 16 temperature-related indices out of the 27 core indices developed by the Expert Team on Climate Change Detection and Indices (ETCCDI) (Rahimi and Hejabi, 2018). The temperature indices were calculated using the RClimdex v1.0 package, developed by the Climate Research Branch of the Meteorological Service of Canada on behalf of ETCCDI, and implemented in the R programming language (Zhang et al., 2011). The calculated indices were categorised into three groups: degree-based indices, day-based indices, and percentage-based indices (Figure 2). RClimdex, an effective tool approved by the World Meteorological Organization (WMO), is widely recognised and used in the analysis of extreme climate events (Almazroui et al., 2014; Sein, Chidthaisong and Oo, 2018; Fall et al., 2021; Kalita, Kalita and Saxena, 2023). In this study, the threshold was defined as four times the mean ± standard deviation (mean - 4 x std, mean + 4 x std) for each day (Zhang et al., 2005; Alexander et al., 2006; Sensoy et al., 2013). The daily maximum temperature (Tmax) and daily minimum temperature (Tmin) records from each station were quality checked before the calculation of the indices. In cases of missing data or when Tmax < Tmin, a value of −99.9 was entered in the corresponding cells in Microsoft Excel (Aykır, 2017).

Figure 2

Extreme Temperature Indices Used in the Study (Adapted from Yin and Sun, 2018 and Climdex: https://www.climdex.org/learn/indices/)

Category	Code	Index Name	Index Definition
Temperature-Based Indices (°C)	TXx	Maximum value of daily maximum temperature	Annual maxima of daily maximum temperature
	TXn	Minimum value of daily maximum temperature	Annual minima value of daily maximum temperature
	TNx	Maximum value of daily minimum temperature	Annual maxima value of daily minimum temperature
	TNn	Minimum value of daily minimum temperature	Annual minima value of daily minimum temperature
	DTR	Daily temperature range	Annual mean difference between daily max and min temperature
Day-Based Indices (Days)	SU25	Summer days	Annual count when daily maximum temperature >25°C
	TR20	Tropical nights	Annual count when daily minimum temperature >20°C
	WSDI	Warm spell duration index	Annual number of days with at least 6 onsecutive days when Tmax >90th percentile
	FD0	Frost day	Annual count when daily minimum temperature <0°C
	ID0	Icing days	Annual count when daily maximum temperature <0°C
	CSDI	Cold spell duration index	Annual number of days with at least 6 consecutive days when Tmin <10th percentile
	GSL	Growing Season Length	Annual number of days between the first occurrence of 6 consecutive days with Tmean >5°C and first occurrence of consecutive 6 days with Tmean <5°C
Percentage-Based Indices (%)	TX90p	Warm days	Percentage of days when daily maximum temperature >90th percentile
	TN90p	Warm nights	Percentage of days when daily minimum temperature >90th percentile
	TX10p	Cold days	Percentage of days when daily maximum temperature <10th percentile
	TN10p	Cold nights	Percentage of days when daily minimum temperature <10th percentile

In this study, statistical methods were applied to address the missing data in the long-term temperature records from the seven meteorological stations. The missing data were estimated using single and multiple linear regression models in R software, based on the temperature data from neighbouring stations (Hasanpour Kashani and Dinpashoh, 2012). The model suitability and reliability of the predicted values were statistically evaluated. The results showed that the estimated values derived from the regression analyses were statistically significant ($p< 0.005$). The low p-values indicate that the regression coefficients are significantly different from zero, which shows that the models have high explanatory power. The quality control and homogeneity of the newly created time series, with the missing data filled in, were assessed using the R-based RHtest software (Ferrelli et al., 2024).

The Mann-Kendall (M-K) test was used to detect significant trends in the time series of the constructed indices. This analysis was performed using the trend package in the R software, in accordance with the equations below. The M-K test (Mann, 1945; Kendall, 1970) is a widely used statistical method, endorsed by the World Meteorological Organization (WMO), to determine the statistical significance of trends in climatological and hydrometeorological time series (Gocic and Trajkovic, 2013; Acar, Gönençgil and Korucu Gümüşoğlu, 2018; Tong et al., 2019; Durmuş, Bulut and Gönençgil, 2021; Gumus, Avsaroglu and Simsek, 2022; Yurtseven, 2023; Bayer-Altın, Türkeş and Altın, 2023; Özdel and Meydan, 2024). The M-K test does not require the data to be normally distributed, and it has the advantage of being less sensitive to outliers and skewed distributions compared to other tests (Dendir and Birhanu, 2022).

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

In this equation, the M-K test statistic S is calculated. n is the number of data, x_i and x_j are the consecutive data values for the time series data of length n, and $\operatorname{sgn}(x_i-x_j)$ is the sign function.

$$\operatorname{sgn}(x_i - x_j) = \begin{cases} +1; (x_j - x_i) > 0 \\ 0; (x_j - x_i) = 0 \\ -1; (x_j - x_i) < 0 \end{cases}$$

The variance of the S value is calculated as follows:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{p} t_i(t_i - 1)(2t_i + 5)}{18}$$

where p is the number of repeated observations in the data set, and t_i value is the number of data values in group p. If the sample size is $n > 10$, the time series is assumed to be normally distributed and the significance of the test whose variance is determined is determined by Z_S;

$$Z_S = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} ; S > 0 \\ 0 \quad ; S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}} ; S < 0 \end{cases}$$

The obtained Z_S value is compared with the Z table to determine whether to accept or reject the null hypothesis. If $|Z_S|>Z_{1-\alpha/2}$, the null hypothesis (H_0), which states that there is no trend in the series, is rejected, indicating a statistically significant trend. In addition, a positive Z_s value suggests an increasing trend, while a negative value indicates a decreasing trend in the time series (Saboohi, Soltani and Khodagholi, 2012; Atta-ur-Rahman and Dawood, 2017; Kliengchuay et al.,

Table 5

M-K Test and Slope Estimate (SE) Results for Degree-Based Indices

		TXx	TXn	TNx	TNn	DTR
Ayvalık	M-K Test	**3.37****	0.87	**4.52****	1.73	−0.35
	SE	0.059	0.018	0.062	0.032	−0.003
Balıkesir	M-K Test	1.50	−0.44	**3.62****	−1.45	**4.11****
	SE	0.029	−0.014	0.069	−0.05	0.048
Bandırma	M-K Test	0.24	0.75	**6.06****	1.19	**-3.14****
	SE	0.013	0.02	0.072	0.032	−0.017
Burhaniye	M-K Test	1.57	1.39	**4.47****	0.64	1.23
	SE	0.025	0.026	0.065	0.009	0.006
Dursunbey	M-K Test	**2.09***	0.45	1.28	0.39	**5.56****
	SE	0.039	0.008	0.011	0.009	0.034
Edremit	M-K Test	**2.12***	0.74	**4.31****	**2.10***	**-2.04***
	SE	0.046	0.019	0.058	0.039	−0.01
Gönen	M-K Test	0.63	0.83	**4.21****	1.09	1.39
	SE	0.025	0.02	0.059	0.031	0.005

2024). The results obtained from the M-K test are statistically analysed at 2 confidence levels.

Z critical value for α 0.05 significance level; $\pm 1.96 \leq |Z| < \pm 2.58$,

Z critical value for α 0.01 significance level; $|Z| \geq \pm 2.58$

Slope Estimate (SE) values produced by the RClimdex software were used to determine the change of trends in unit time. The slope estimate was obtained by the Kendall tau-based calculation, and a p value less than 0.05 indicated that the trend was statistically significant at the 95% confidence level (Sensoy et al., 2013; Marigi, Njogu and Githungo, 2016). p values were also used to evaluate the consistency of the results obtained from the M-K Test. Additionally, changes over the span of 49 years were computed based on the SE values delineated in the tables.

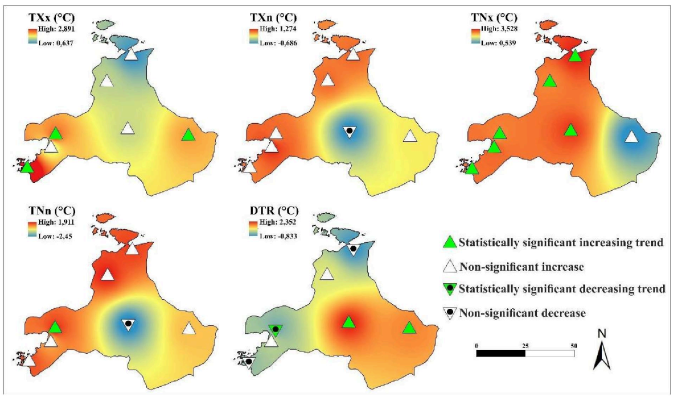
Results

Degree-based Indexes

The **TXx** (maximum temperature maximum) index demonstrated a statistically significant increasing trend at the Ayvalık, Dursunbey, and Edremit stations. Although increasing trends were also observed at the Balıkesir, Bandırma, Burhaniye and Gönen stations, these trends were not statistically significant. Among the stations with significant increases, Ayvalık recorded the highest rise in TXx, with an increase of 2.8°C over the 49-year period, followed by Edremit with 2.2°C and Dursunbey with 1.9°C. For the **TXn** index (minimum of maximum temperatures), the changes observed across all analysed stations were not statistically significant. However, analysis of the **TNx** index (maximum of minimum temperatures) revealed statistically strong and significant increasing trends at all stations except Dursunbey. The magnitude of these increases over the study period (49 years) was calculated as follows: 3.0°C in Ayvalık, 3.3°C in Balıkesir, 3.5°C in Bandırma, 3.1°C in Burhaniye, 2.8°C in Edremit, and 2.8°C in Gönen. Regarding the **TNn** index (minimum of minimum temperatures), a statistically significant increasing trend was identified only at the Edremit station, with a rate of 0.039°C per year. In the **DTR** index (daily temperature range), statistically significant increases were observed at the Balıkesir and Dursunbey stations, with respective increases of 2.3°C and 1.6°C. Conversely, significant decreases were recorded at the Bandırma and Edremit stations, with reductions of −0.8°C and −0.5°C, respectively (Table 5; Figure 3).

Figure 3

Trend Results and Changes in Degree-Based Indices



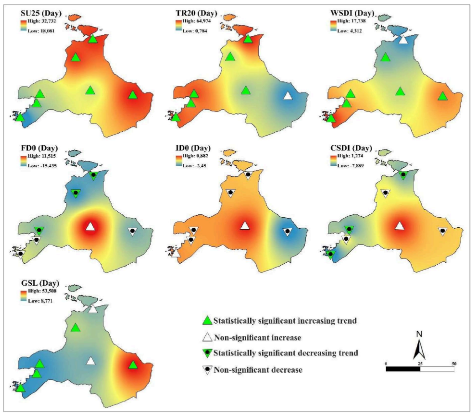
Day-based Indexes

The **SU25** (summer days) index exhibited a statistically strong and significant increasing trend across all stations analysed in the study. Over the 49-year period, the number of summer days increased by 18 days at Ayvalık, 25 days at Balıkesir, 32 days at Bandırma, 22 days at Burhaniye, 33 days at Dursunbey, 25 days at Edremit, and 32 days at Gönen stations. Similarly, for the **TR20** (tropical nights) index, statistically significant increasing trends were observed at all stations except Dursunbey. Among the stations with significant trends, the increase in the number of tropical nights ranged from 18 to 65 days during the same period.

The **WSDI** (warm spell duration index) exhibited a statistically significant increasing trend at all stations except Bandırma. The highest increase was observed at Ayvalık station with 18 days, while the lowest was recorded at Gönen station with 6 days. Although the **FD0** (frost days) index showed a decreasing trend across all stations, statistically significant decreases were only observed at Bandırma, Edremit, and Gönen. The annual decrease in these stations was calculated as −0.288 days in Bandırma, −0.249 days in Edremit, and −0.315 days in Gönen. Regarding the **ID0** (icing days) index, no statistically significant trend was detected in any station analysed. The **CSDI** (cold spell duration index) showed a significant decreasing trend at Ayvalık, Bandırma, and Edremit stations, with decreases of 8, 6, and 7 days over the 49-year period, respectively. Conversely, the **GSL** (growing season length) index demonstrated a statistically significant increasing trend at all stations except Balıkesir and Bandırma, with increases ranging from approximately 9 to 53 days (Table 6; Figure 4).

Figure 4

Trend Results and Changes in Day-Based Indices



Percentage-based Indexes

Statistically strong and significant increasing trends were identified in all stations for both **TX90p** (warm days) and **TN90p** (warm nights). Over the 49-year period, TX90p increased by between 8% and 13%, while TN90p rose by between 5% and 19%. Conversely, the **TX10p** (cold days) index exhibited a statistically significant decreasing trend at all stations. The most pronounced decrease was recorded at the Edremit station with 14%, whereas the lowest decrease was observed at Bandırma and Dursunbey stations, each with 10%. Regarding the **TN10p** (cold nights) index, a statistically significant decreasing trend was observed at all stations except Balıkesir, where a slight increase was detected, although it was not statistically significant. Within the analysed time frame, decreases in TN10p were measured as 14% at Ayvalık and Bandırma stations, 11% at Burhaniye, 6% at Dursunbey, 18% at Edremit, and 13% at Gönen (Table 7; Figure 5).

Figure 5

Trend Results and Changes in Percentage-Based Indices

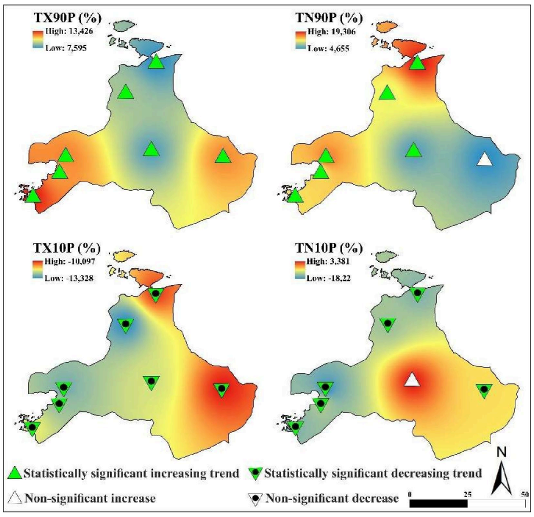


Table 6

M-K Test and Slope Estimate (SE) Results of Day-Based Indices

		SU25	TR20	WSDI	FD0	ID0	CSDI	GSL
Ayvalık	M-K Test	**3.64****	**6.89****	**3.88****	−1.72	0.31	**-3.40****	**2.35***
	SE	0.369	1.194	0.362	−0.112	0.001	−0.161	0.179
Balıkesir	M-K Test	**4.28****	**4.06****	**2.85****	1.26	0.69	0.66	1.04
	SE	0.514	0.362	0.187	0.235	0.018	0.026	0.289
Bandırma	M-K Test	**4.65****	**7.01****	1.56	**-2.49***	−0.26	**-2.57***	1.70
	SE	0.663	1.326	0.088	−0.288	−0.007	−0.123	0.340
Burhaniye	M-K Test	**4.31****	**6.66****	**3.53****	−1.94	−0.81	−0.76	**2.10***
	SE	0.452	1.012	0.306	−0.149	−0.003	−0.046	0.2
Dursunbey	M-K Test	**4.66****	1.24	**4.12****	−1.56	−0.98	−0.87	**3.27****
	SE	0.668	0.016	0.301	−0.241	−0.05	−0.042	1.092
Edremit	M-K Test	**4.92****	**6.94****	**3.02****	**-3.29****	0.06	**-3.50****	**2.48***
	SE	0.515	1.257	0.226	−0.249	0.001	−0.149	0.185
Gönen	M-K Test	**5.51****	**5.60****	**1.96***	**-2.04***	−0.10	−1.63	**2.44***
	SE	0.657	0.524	0.132	−0.315	−0.005	−0.058	0.468

Table 7

M-K Test and Slope Estimate (SE) Results for the Percentage-Based Indices

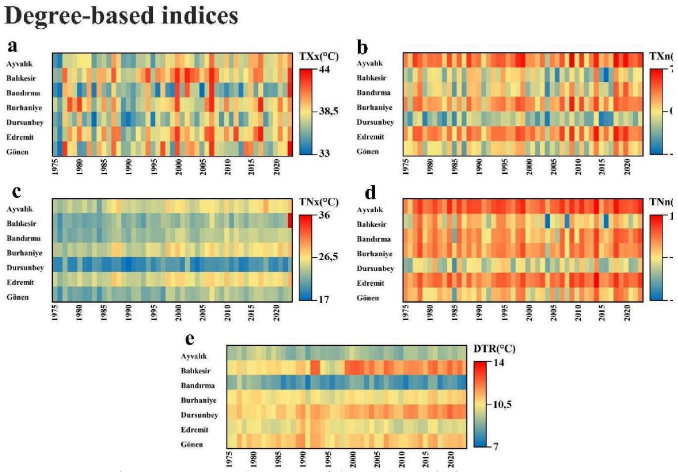
		TX90p	TN90p	TX10p	TN10p
Ayvalık	M-K Test	**5.02****	**5.54****	**-5.69****	**-5.81****
	SE	0.274	0.260	−0.242	−0.293
Balıkesir	M-K Test	**4.15****	**2.51***	**-5.51****	1.85
	SE	0.164	0.117	−0.246	0.069
Bandırma	M-K Test	**4.34****	**6.09****	**-3.98****	**-6.46****
	SE	0.155	0.394	−0.210	−0.295
Burhaniye	M-K Test	**4.16****	**5.23****	**-5.98****	**-5.20****
	SE	0.24	0.256	−0.256	−0.228
Dursunbey	M-K Test	**5.28****	**2.29***	**-5.18****	**-2.66****
	SE	0.245	0.095	−0.206	−0.121
Edremit	M-K Test	**5.23****	**6.20****	**-6.30****	**-6.15****
	SE	0.249	0.334	−0.284	−0.372
Gönen	M-K Test	**4.81****	**4.92****	**-5.53****	**-4.56****
	SE	0.185	0.234	−0.272	−0.265

Temporal Patterns of Extreme Temperature Indexes

According to Figure 6, although interannual fluctuations are observed in the TXx index, a statistically significant increasing trend in maximum temperatures is evident across most stations, particularly since the year 2000. Similarly, the TX90p and TN90p indices, which represent the number of extremely warm days and nights, respectively, have shown a notable upward trend over the past decade (Figures 8a and 8b). The SU25 index also exhibited a consistent increasing trend at all stations, reaching up to 175 days per year in certain locations (Figure 7 a). Furthermore, the TR20 indicator, which represents the number of tropical nights, displays a pronounced increase, especially at coastal stations such as Ayvalık, Burhaniye, and Edremit (Figure 7 b). SU25 has an increasing trend in all stations; in some stations, this value reaches up to 175 days. There is also a remarkable increase in the TR20 indicator, especially in coastal stations such as Ayvalık, Burhaniye and Edremit.

Figure 6

Temporal Patterns of Degree-Based Indexes (1975-2023)



In recent years, the number of tropical nights (TR20) has exceeded 50 days annually in several stations (Figure 7 b). A significant decreasing trend was observed in the TX10p and TN10p indices, which represent cold extreme events (Figures 8a and 8b). Analysis of Figure 8 a indicates that cold days were predominantly concentrated before 2000, while their frequency has markedly declined in the post-2000 period across all stations. Examination of the temporal variation in the GSL index (Figure 7 g) reveals that in coastal stations such as Ayvalık, Burhaniye, and Edremit, the growing season now extends nearly throughout the entire year. Although inland areas such as Dursunbey and Balıkesir initially experienced shorter growing seasons, recent years have shown a significant extension of this period across all stations, indicating a widespread lengthening of the growing season.

Figure 7

Temporal Patterns of Day-Based Indexes (1975-2023)

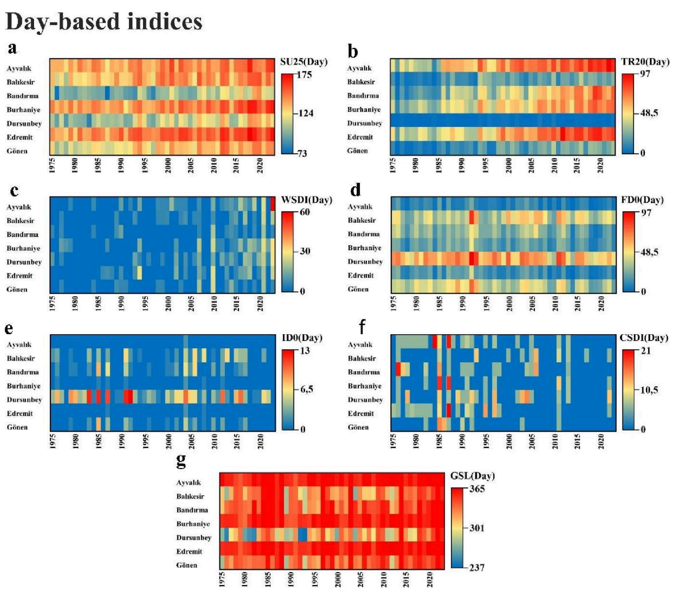
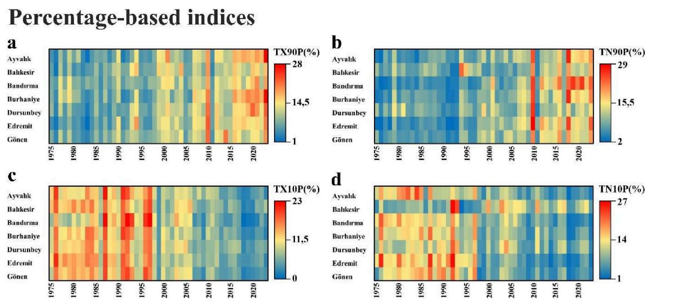


Figure 8

Temporal Patterns of Percentage-Based Indexes (1975-2023)



Discussion and Conclusion

The **TXx** index illustrates an increasing trend across all stations within the research area, denoting a significant escalation in the maximum temperatures recorded during hot days. In the context of ongoing climate change, this trend implies a prospective increase in the frequency and intensity of extreme heat events within Balıkesir province. Concerning the **TXn** index, increasing trends were observed in all stations except Balıkesir, although these changes were not statistically significant. Such increases show that even the cooler days are progressively becoming warmer, indicative of a diminution in the severity of cold spells throughout much of the region. These warming trends, instigated by climate change, may culminate in milder winters and a reduction in cold waves, potentially impacting the phenology of several economically significant crops. This shift may pose challenges for both farmers and agricultural production (Bisbis, Gruda and Blanke, 2018). For instance, the inability to meet chilling requirements may negatively affect both crop yield and quality for certain crops, such as olives, which hold significant economic importance in Balıkesir province (Özdel, Ustaoğlu and Cürebal, 2024). Moreover, milder winters may have harmful effects on ecosystems, including the proliferation of pest populations and an increased risk of diseases (Skendžić et al., 2021). The **TNx** index demonstrates an increasing trend across all stations, which serves as a clear indicator of global warming and highlights the influence of climate change on nighttime temperatures. The warming phenomenon during the night further indicates a comprehensive increase in temperature, extending heat waves beyond the daytime into the night. This increase in nighttime temperatures can limit the opportunity for cooling, intensified by the urban heat island effect, which presents a significant challenge to maintaining optimal comfort levels (Dün and Gönençgil, 2021). An increase in warm nights can lead to sleep disturbances and heat stress, particularly posing risks for the elderly, children, and individuals with chronic diseases (Wolf et al., 2015; Weilnhammer et al., 2021). Additionally, energy consumption may significantly rise due to the increased demand for cooling during hot nights (Li et al., 2019). The TNn index is increasing across all stations except Balıkesir. These increases indicate that even the coldest nights are becoming warmer in most parts of the study area, which could result in yield losses for agricultural products that require cooling (Atkinson, Brennan and Jones, 2013). On the other hand, the reduction in cold nights may lead to a decrease in the energy consumption for heating, especially in residential areas (Li et al., 2019). It was found that the DTR increased at some stations while decreasing at others. A decrease in the DTR indicates that nighttime temperatures are rising faster than daytime temperatures, thereby narrowing the day–night temperature difference. In contrast, an increase in DTR signifies that the temperature variation between day and night is widening (Sun et al., 2019). A statistically significant increase in the DTR was identified at the Balıkesir and Dursunbey stations, which may be attributed to their inland geographical positions where the maritime influence is minimal. In such regions, lower humidity levels and diminished cloud cover frequently result in accelerated heat dissipation during nighttime, thereby contributing to a broader temperature disparity between day and night. Additionally, the relatively elevated altitudes of these stations may further facilitate nighttime cooling. Factors such as proximity to the sea, humidity levels, cloud cover, elevation, and land use diversity may significantly influence the temperature variability.

The significant upward trend in the SU25 index across all stations indicates that the number of days with maximum temperatures exceeding 25°C is generally increasing in Balıkesir province, indicating more frequent and prolonged heatwaves.The ascending SU25 values recorded across the various stations indicate an overall rise in temperature and an augmentation in the frequency of hot days, particularly prominent during the summer months. Furthermore, the TR20 index evidences an increase in the number of nocturnal periods characterised by temperatures exceeding 20°C within the province. In a similar vein, the WSDI has increased at all stations, signifying that prolonged hot periods are becoming more frequent and last longer. These increases could have substantial impacts on public health, energy consumption, ecosystems, agriculture, and water resources. The FD0 index shows a decreasing trend at most stations, indicating that the number of days with temperatures below 0°C is decreasing. This trend is consistent with the general reduction in frost events in temperate climates due to climate change (IPCC, 2021). Similarly, the CSDI shows a decrease at all stations except for Balıkesir, indicating that cold waves are becoming less frequent in the study region, a phenomenon that is associated with the milder winter conditions induced by climate change. The GSL index increased at all stations, with statistically significant increases in most areas, indicating that the growing season has generally lengthened. A longer growing season implies milder climates, with spring arriving earlier and fall extending later. From an agricultural perspective, this extended growing season offers opportunities for farmers to grow more crops and potentially harvest more than once per year. However, it could place additional pressure on water resources and terrestrial ecosystems (Christiansen, Markstrom and Hay, 2011; Sensoy et al., 2013).

The TX90p and TN90p indexes have increased across all stations, which could pose significant challenges for vulnerable populations, such as children and the elderly, particularly those with chronic respiratory or cardiovascular diseases (Franchini and Mannucci, 2015; Paz et al., 2016). From an agricultural perspective, these increases may place additional stress on the crops. The decreasing trends observed in the TX10p index indicate that extreme cold days are becoming less frequent.Similarly, the TN10p index shows a decrease in most stations, indicating fewer cold nights, meaning that night-time minimum temperatures are generally rising and the overall climate is becoming warmer. These findings are consistent with similar studies in the literature (Erlat and Türkeş, 2013; Sensoy et al., 2013; Acar Deniz and Gönençgil, 2017; Erlat and Güler, 2018; Dün and Gönençgil, 2021) and support the results obtained in the present study. Concurrent with our findings, previous research has also reported significant upward trends in warm temperature extremes and downward trends in cold extremes across various regions of Türkiye. For example, Erlat and Yavaşlı (2011) identified significant increases in the annual number of hot days, hot nights, tropical days, and summer days in the Aegean region. Similarly, Acar (2018) detected statistically significant increases in temperature extremes in the Central Anatolia Region. Abbasnia and Toros (2020), in their nationwide study, highlighted a general increase in extreme heat events alongside a decrease in cold extremes. Durmuş, Bulut, and Gönençgil (2021) found declining trends in frost and ice days as well as in cold spell duration period indices in the Antalya Section, while summer days, tropical nights, and warm spell duration period indices showed significant increases. Aksoy and Yeşilırmak (2022) reported decreasing trends in cold indices and increasing trends in warming-related indices across 36 meteorological stations in Western Anatolia. Aydın and Karabulut (2022) also observed decreasing trends in frost and ice days in Konya, along with increases in warm nights, warm days, summer days, and the warm spell duration period. Likewise, Yurtseven (2023), using data from the Kandilli Observatory, found significant increasing trends in the number of warm days, warm nights, summer days, and tropical nights, while the number of frost days significantly declined.

The observational stations of Ayvalık, Balıkesir, Bandırma, Burhaniye, Dursunbey, Edremit, and Gönen, as analysed in this study, are situated within the Marmara and Aegean regions, encompassing both coastal and inland territories. This study, which examines alterations in indices pertinent to extreme temperature phenomena over a 49-year period (1975-2023), uncovers significant increasing trends in indices representing maximum temperatures (TXx, TNx, SU25, TR20, WSDI, TX90p, and TN90p), alongside decreasing trends in indices representing minimum temperatures (FD0, CSDI, TN10p, and TX10p). These trends exhibit a general relationship with one another.

For instance, the SU25 index exhibited an increase at rates fluctuating between 0.37 and 0.67 days annually, which is commensurate with an augmentation of 3.7 to 6.7 summer days per decade. The TR20 index demonstrated an escalation of 1.01 to 1.33 nights per year (equating to 10.1 to 13.3 nights per decade), thereby indicating a significant prolongation of the warm nocturnal conditions. In a similar vein, the WSDI exhibited an annual increase ranging from 0.09 to 0.36 days (0.9 to 3.6 days per decade), thereby indicating a rise in the frequency of persistent heat events. Furthermore, pronounced increases in the SU25 and TR20 indices within densely populated urban locales such as Balıkesir, Edremit, and Bandırma underscore the escalating thermal stress experienced in these regions. Significantly, in Ayvalık and Edremit, the TR20 index has risen by more than one additional night per annum, which may have precipitated a decline in nighttime thermal comfort. While these warming patterns may temporarily yield advantages for summer tourism by potentially prolonging the season, sustained long-term elevations in extreme heat may adversely affect tourist satisfaction and truncate average durations of stay, particularly within the marine tourism sector. Likewise, forecasts for the Mediterranean coastlines of Spain imply that ascending temperature trends could extend the coastal tourism duration, engendering favourable conditions especially during the months of April-May and September-October (de la Vara et al., 2024). Additionally, the northern coastal territories of Spain are anticipated to experience positive ramifications from these climatic changes, both temporally and spatially (Barrutiabengoa et al., 2025). Nonetheless, such warming trends may lead to heightened energy consumption for cooling purposes and an increased demand for water resources.

On the other hand, even less populated inland stations such as Dursunbey are not exempt from this trend, with TX90p increasing by approximately 0.24 days per year and heatwave duration (WSDI) increasing by 0.30 days per year. In contrast, cold extremes exhibited a declining trend. FD0 decreased by up to 0.32 days per year (approximately 3.2 fewer frost days per decade), while CSDI declined by up to 0.15 days per year (1.5 days per decade). TX10p decreased by up to 0.28 days per year (2.8 days per decade), and TN10p declined by up to 0.37 nights per year (3.7 nights per decade).

Between 1975 and 2023, notable demographic transformations were documented in the locales encompassing the seven stations under scrutiny. For instance, the populace of Balıkesir city centre experienced an escalation from 85,004 in 1970 to 374,304 in 2023, signifying an increase of approximately 340% (≈4.4 times). Likewise, the population surged by approximately 322% in Ayvalık (≈4.2 times), 322% in Bandırma (≈4.2 times), 452% in Burhaniye (≈5.5 times), 612% in Edremit (≈7.1 times), and 447% in Gönen (≈5.4 times). Although Dursunbey's population has augmented by around 340% (≈4.4 times) relative to 1970, a recent decline in demographic numbers has been noted within the district. These population increases correspond with the observed ascendant trends in the temperature indices. Population growth in urbanised regions frequently results in alterations in land cover and land utilisation, augmented energy consumption, a higher ratio of artificial surfaces, and an increased density of heat-retaining structures—all of which contribute to shifts in urban dynamics. The observation that stations classified as rural also demonstrate warming trends—some displaying statistically significant Z-scores at the 0.001 level—while trends of cooling have receded, implies that urbanisation, in conjunction with global climate change, is exerting indirect environmental impacts even on rural territories. For instance, Edremit, which has witnessed a nearly sevenfold population increase since 1970, manifests statistically significant trends in extreme temperature indices. Among these indices, TN90p (Z = 6.20), TR20 (Z = 6.94), and SU25 (Z = 4.92) distinctly illustrate this phenomenon. Similarly, although Ayvalık is categorised as a rural station, it has recorded significant augmentations in indicators such as TX90p (Z = 5.02), TR20 (Z = 6.89), and WSDI (Z = 3.88).

The analysis results of stations in Balıkesir province highlight a dynamic that has been observed at some stations in particular and requires careful interpretation. The fact that statistically significant trends (high Z-scores) are accompanied by relatively low annual slope values indicates that climate change is slow but steady. For example, at the Edremit station, SU25 shows a statistically significant upward trend (Z = 4.92), with an annual rate of increase calculated at 0.51 days. Similarly, FD0 at Edremit shows a decrease with a significant score of Z = −3.29, and the annual rate of change is around −0.25 days. These seemingly small annual rates, when projected over ten-year periods, result in a cumulative effect of approximately 5 additional summer days and 2.5 fewer frost days. Therefore, although these changes may have limited effects in the short term, they have the potential to produce significant results in the long term for important sectors such as agricultural production patterns, water resources, energy consumption, public health, and tourism in the work area. Therefore, analysing not only the direction of trends but also their speed and cumulative effects is of great importance in understanding climate vulnerability specific to the field of work and developing adaptation strategies.

The observed temperature increases and the rising trends in extreme temperature events at the stations in the study area clearly highlight the impacts of climate change in the region. For the agricultural sector, increasing temperatures and prolonged heatwaves, especially during the summer months, could make agricultural processes more vulnerable. Balıkesir province, an important centre for olive and cereal production, also holds significant potential for vegetable and fruit cultivation, dairy production, and livestock breeding. However, changing temperature conditions pose a considerable threat to this potential. Additionally, the continuous rise in temperatures is likely to increase irrigation demand and create challenges in managing water resources in the coming years. Beyond agriculture, rising temperatures and extreme climate events may also significantly affect the spread of infectious diseases and pests. As temperatures rise, agricultural pests can spread over larger areas and increase their populations. Climate change may also accelerate the spread of infectious diseases, particularly those caused by vectors—organisms that transmit disease agents. The frequency of extreme heat events may lead to more weather-related deaths and illnesses, posing serious risks, particularly for vulnerable populations such as the elderly, children, and individuals with chronic diseases, whose bodies are less able to regulate temperature (Ebi et al., 2021). Rising temperatures may also directly impact the infrastructure and energy sectors, with increased demand for cooling systems and a heightened risk of infrastructure damage due to extreme heat. In terms of tourism, while higher temperatures may provide some short-term benefits, the long-term effects of extreme heat could negatively affect tourism activities. Furthermore, persistent temperature increases may also drive migration mobility, as people seek more livable environments.

The results obtained in this study indicate that both coastal and inland settlements have experienced changes in temperature indices at varying rates. While this may not pose an immediate issue, if these trends continue, they could significantly impact the economic activities, population density, and settlement potential of the study area in the future. In this context, it is crucial to develop and implement adaptation strategies. Local governments and relevant stakeholders should adopt multifaceted measures, including optimising water management in agriculture, improving energy efficiency, expanding green spaces to mitigate the urban heat island effect, and raising public awareness about heat-related risks. These measures are vital for reducing the negative effects of climate change and ensuring the region's long-term sustainability.

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Author Details

Muhammed Mustafa Özdel (Dr.)
[1] Non-affiliated, Kayseri, Türkiye
0000-0003-0715-4566 m.mustafaozdel@gmail.com

Melike Durak (Res. Asst.)
[2] Balıkesir University, Faculty of Science and Letters, Department of Geography, Balıkesir, Türkiye
0000-0003-3102-9132

Dilek Aykır (Assoc. Prof.)
[3] Izmir Kâtip Çelebi University, Faculty of Social and Human Sciences, Department of Geography İzmir, Türkiye
0000-0002-2748-4055

Alaattin Kızılçaoğlu (Prof. Dr.)
[2] Balıkesir University, Faculty of Science and Letters, Department of Geography, Balıkesir, Türkiye
0000-0002-2050-4244

REFERENCES

Abbasnia, M. and Toros, H. (2018). Analysis of long-term changes in extreme climatic indices: a case study of the Mediterranean climate, Marmara Region, Turkey. *Pure* *and Applied Geophysics*, *175*(11), 3861-3873. https://doi.org/10.1007/s00024-018-1888-8

Abbasnia, M. and Toros, H. (2020). Trend analysis of weather extremes across the coastal and non-coastal areas (case study: Turkey). *Journal of Earth System Science*, *129*, 1-13. https://doi.org/10.1007/s12040-020-1359-3

Acar, Z. (2018). İç Anadolu Bölgesi'nin ekstrem sıcaklık özellikleri. *Türk Coğrafya Dergisi*, (71), 93-99. https://doi.org/10.17211/tcd.436198

Acar, Z., Gönençgil, B., & Korucu Gümüşoğlu, N. (2018). Long-term changes in hot and cold extremes in Turkey. *Journal of Geography*, *0*(37), 57-67. https://doi.org/10.26650/JGEOG2018-0002

Acar Deniz, Z. ve Gönençgil, B. (2017). Türkiye sıcaklık ekstremlerindeki değişkenlikler. *İstanbul Üniversitesi Coğrafya Dergisi*, (35), 41-54.

Acar Deniz, Z. and Gönençgil, B. (2015). Trends of summer daily maximum temperature extremes in Turkey. *Physical Geography*. *36*(4), 268-281. https://doi.org/10.1080/02723646.2015.1045285

Aksoy, S. and Yeşilırmak, E. (2022). Batı Anadolu'da ekstrem sıcaklıklardaki zamansal değişimler. *Adnan Menderes Üniversitesi Ziraat Fakültesi Dergisi*, *19*(1), 93-101. https://doi.org/10.25308/aduziraat.1035921

Alavinia, S. H. and Zarei, M. (2021). Analysis of spatial changes of extreme precipitation and temperature in Iran over a 50-year period. *International Journal of Climatology*, *41*(S1), E2269-E2289. https://doi.org/10.1002/joc.6845

Alexander, L. V., Zhang, X., Peterson, T. C., Caesar, J., Gleason, B., Tank, K. ... Vazquez-Aguirre, J. L. (2006). Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical Research: Atmospheres*, *111*(D5), 1-22. https://doi.org/10.1029/2005JD006290

Almazroui, M., Islam, M. N., Dambul, R., & Jones, P. D. (2014). Trends of temperature extremes in Saudi Arabia. *International Journal of Climatology*, *34*(3), 808-826. https://doi.org/10.1002/joc.3722

Atkinson, C. J., Brennan, R. M., & Jones, H. G. (2013). Declining chilling and its impact on temperate perennial crops. *Environmental and Experimental Botany*, 91, 48-62. https://doi.org/10.1016/j.envexpbot.2013.02.004

Atta-ur-Rahman, and Dawood, M. (2017). Spatio-statistical analysis of temperature fluctuation using Mann–Kendall and Sen's slope approach. *Climate Dynamics*, *48*(3-4), 783-797. https://doi.org/10.1007/s00382-016-3110-y

Aydın, K. ve Karabulut, M. (2022). Konya'da ekstrem sıcaklık indislerinde gözlemlenen eğilim ve değişimlerin incelenmesi. *International Journal of Advances in Engineering and Pure Sciences*, *33*(4), 533-549.

Aykır, D. (2017). Türkiye'de ekstrem sıcaklık indislerinin eğilimlerinde şehirleşmenin etkisi. *Türk Coğrafya Dergisi*, 69, 47-57. https://doi.org/10.17211/tcd.306742

Barrutiabengoa, J. M., Carta, G., González, N., Pérez, D., & Yücel, G. (2025). Climate change scenarios and the evolution of Spanish tourism. *Climatic Change*, *178*, 129. https://doi.org/10.1007/s10584-025-03967-8

Bayer-Altın, T., Türkeş, M., & Altın, B. N. (2023). Evolution of drought climatology and variability in the Central Anatolia Region, Turkey, for the period 1970–2020. *Pure and Applied Geophysics*, *180*(8), 3105-3129. https://doi.org/10.1007/s00024-023-03321-y

Bisbis, M. B., Gruda, N., & Blanke, M. (2018). Potential impacts of climate change on vegetable production and product quality – A review. *Journal of Cleaner Production*, *170*, 1602-1620. https://doi.org/10.1016/j.jclepro.2017.09.224

Carbon Brief, (2022, April, 21). Carbon Brief. Retrieved from https://www.carbonbrief.org/mapped-how-climate-change-affects-extreme-weather-around-the-world/

Choi, G., Collins, D., Ren, G., Trewin, B., Baldi, M., Fukuda, Y., & Zhou, Y. (2009). Changes in means and extreme events of temperature and precipitation in the Asia-Pacific Network region, 1955–2007. *International Journal of Climatology*, *29*(13), 1906-1925. https://doi.org/10.1002/joc.1979

Christiansen, D. E., Markstrom, S. L., & Hay, L. E. (2011). Impacts of climate change on the growing season in the United States *Earth Interactions*, *15*(33), 1-17. https://doi.org/10.1175/2011EI376.1

Croitoru, A. E. and Piticar, A. (2012). Changes in daily extreme temperatures in the extra-Carpathians regions of Romania. *International Journal of Climatology*. *(33)*8, 1987–2001. https://doi.org/10.1002/joc.3567

de Martonne, E. (1926). Une nouvelle fonction climatologique: L'indice d'aridité. *Meteorologie*, 2, 449-459.

de la Vara, A., Cabos, W., Gutierrez, C., Olcina, J., Matamoros, A., Pastor, F., Khodayar, S., & Ferrando, M. (2024). Climate change impacts on the tourism sector of the Spanish Mediterranean coast: Medium-term projections for a climate services tool *Climate Services*, *34*, 1-17. https://doi.org/10.1016/j.cliser.2024.100466

Demir, Ö., Atay, H., Eskioğlu, O., Tüvan, A., Demircan, M., & Akçakaya, A. (2013). Rcp4.5 senaryosuna göre Türkiye'de sıcaklık ve yağış projeksiyonları. *III. Türkiye Climate Change Congress*, İstanbul, Türkiye. http://www.mgm.gov.tr/FILES/iklim/rcp-45.pdf

Demircan, M., Arabacı, H., Akçakaya, A., Şensoy, S., Bölük, E., & Coşkun, M. (2017, July). İklim ve şehirleşme: Minimum sıcaklık trendleri. *IV. Türkiye İklim Değişikliği Kongresi*, İstanbul, Türkiye. 2017.

Dendir, Z. and Birhanu, B. S. (2022). Analysis of observed trends in daily temperature and precipitation extremes in different agroecology of Gurage Zone, Southern Ethiopia. *Advances in Meteorology*, *2022*, 1-13. https://doi.org/10.1155/2022/4745123

Durmuş, B., Bulut, İ., & Gönençgil, B. (2021). Antalya Bölümünde sıcaklık ve yağış indislerinin değişim analizleri. *Türk Coğrafya Dergisi*, 78, 91-108. https://doi.org/10.17211/tcd.1009270

Dün, S. ve Gönençgil, B. (2021). Ege Bölgesi kıyılarında sıcaklık indislerinin analizi. *Türk Coğrafya Dergisi*, 77, 77-86. https://doi.org/10.17211/tcd.897028

Ebi, K. L., Capon, A., Berry, P., Broderick, C., de Dear, R., Havenith, G., ... Jay, O. (2021). Hot weather and heat extremes: health risks. *The lancet*, *398*(10301), 698-708. https://doi.org/10.1016/S0140-6736(21)01208-3

Erel, T. L. (1992). Balıkesir'de 1935-1990 yılları arasında şehir ve kır nüfusları. *Uludağ Üniversitesi Eğitim Fakülteleri Dergisi*, *7*(2), 57-70.

Erinç, S. (1965). *Yağış müessiriyeti üzerine bir deneme ve yeni bir indis*. İstanbul: İstanbul Üniversitesi Coğrafya Enstitüsü Yayınları, No:41.

Erlat, E. ve Güler, H. (2018). Türkiye'de sıcaklık ekstremlerinin sürelerinde gözlenen değişim ve eğilimler (1950-2017). *Ege Coğrafya Dergisi*, 27(2), 135-148.

Erlat, E. ve Türkeş, M. (2017). Türkiye'de tropikal gece sayılarında gözlenen değişmeler ve eğilimler. *Ege Coğrafya Dergisi*, *26*(2), 95-106.

Erlat, E. and Türkeş, M. (2013). Observed changes and trends in numbers of summer and tropical days, and the 2010 hot summer in Turkey. *International Journal of Climatology*, *33*(8), 1898-1908. https://doi.org/10.1002/joc.3556

Erlat, E. ve Yavaşlı, D. (2011). Ege Bölgesi'nde sıcaklık ekstremlerinde gözlenen değişim ve eğilimlerin değerlendirilmesi. *Ankara Üniversitesi Çevrebilimleri Dergisi*, *3*(1), 25-37. https://doi.org/10.1501/Csaum_0000000042

Erlat, E. ve Yavaşlı, D. (2009). Ege Bölgesi tropikal yaz günü sayılarındaki değişim ve eğilimler. *Ege Coğrafya Dergisi*, *18*(1-2), 1-15.

Fall, S., Coulibaly, K. M., Quansah, J. E., El Afandi, G., & Ankumah, R. (2021). Observed daily temperature variability and extremes over Southeastern USA (1978–2017). *Climate*, *9*(7), 1-20. https://doi.org/10.3390/cli9070110

Ferrelli, F., Pontrelli Albisetti, M., Brendel, A. S., Casoni, A. I., & Hesp, P. A. (2024). Appraisal of daily temperature and rainfall events in the context of global warming in South Australia. *Water*, *16*(2), 1-18. https://doi.org/10.3390/w16020351

Filonchyk, M., Peterson, M. P., Zhang, L., Hurynovich, V., & He, Y. (2024). Greenhouse gases emissions and global climate change: Examining the influence of CO2, CH4, and N2O. *Science of the Total Environment*, 935, 173359. https://doi.org/10.1016/j.scitotenv.2024.173359

Franchini, M. and Mannucci, P. M. (2015). Impact on human health of climate changes. *European Journal of Internal Medicine*, *26*(1), 1-5. https://doi.org/10.1016/j.ejim.2014.12.008

Frimpong, B. F., Koranteng, A., & Molkenthin, F. (2022). Analysis of temperature variability utilising Mann–Kendall and Sen's slope estimator tests in the Accra and Kumasi Metropolises in Ghana. *Environmental Systems Research*, *11*(1), 24. https://doi.org/10.1186/s40068-022-00269-1

Giorgi, F. (2006). Climate change hot spots. *Geophysical Research Letters*. *33*(8), L08707. https://doi.org/10.1029/2006GL025734

Gocic, M. and Trajkovic, S. (2013). Analysis of changes in meteorological variables using Mann-Kendall and Sen's slope estimator statistical tests in Serbia. *Global and Planetary Change*, *100*, 172-182. https://doi.org/10.1016/j.gloplacha.2012.10.014

Gumus, V., Avsaroglu, Y., & Simsek, O. (2022). Streamflow trends in the Tigris River basin using Mann–Kendall and innovative trend analysis methods. *Journal of Earth System Science*, *131*, 34. https://doi.org/10.1007/s12040-021-01770-4

Hasanpour Kashani, M. and Dinpashoh, Y. (2012). Evaluation of efficiency of different estimation methods for missing climatological data. *Stochastic Environmental Research and Risk Assessment*, *26*(1), 59-71. https://doi.org/10.1007/s00477-011-0536-y

IPCC, (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

IPCC, (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp. https://doi.org/10.1017/9781009157896.

Jahn, M. (2015). Economics of extreme weather events: Terminology and regional impact models *Weather and Climate Extremes*, *10*, 29-39. https://doi.org/10.1016/j.wace.2015.08.005

Kalita, R., Kalita, D., & Saxena, A. (2023). Trends in extreme climate indices in Cherrapunji for the period 1979 to 2020. *Journal of Earth System Science*, *132*, 74. https://doi.org/10.1007/s12040-023-02087-0

Kendall, M. G. (1970). *Rank correlation methods* (4th ed.). London: Charles Griffin.

Keskin M. E. ve Saplıoğlu, K. (2023). Türkiye'nin Doğu Anadolu bölgesindeki sıcaklık eğilimlerinin Yenilikçi Trend Analizi ve Mann-Kendall ile belirlenmesi. *Journal of Innovations in Civil Engineering and Technology*, *5*(1), 1-16.

Kliengchuay W., Mingkhwan R., Kiangkoo N., Suwanmanee S., Sahanavin, N., Kongpran, J. ... Tantrakarnapa, K. (2024). Analyzing temperature, humidity, and precipitation trends in six regions of Thailand using innovative trend analysis. *Scientific Reports*, *14*(1), 7800. https://doi.org/10.1038/s41598-024-57980-5

Li, X., Zhou, Y., Yu, S., Jia, G., Li, H., &Li, W. (2019). Urban heat island impacts on building energy consumption: A review of approaches and findings. *Energy*, *174*, 407-419. https://doi.org/10.1016/j.energy.2019.02.183

Likinaw, A., Alemayehu, A., & Bewket, W. (2023). Trends in extreme precipitation indices in Northwest Ethiopia: Comparative analysis using the Mann–Kendall and innovative trend analysis methods. *Climate*, *11*(8), 164. https://doi.org/10.3390/cli11080164

Manalo, J. A., Matsumoto, J., Takahashi, H. G., Villafuerte II, M. Q., Olaguera, L. M. P., Ren, G., & Cinco, T. A. (2021). The effect of urbanization on temperature indices in the Philippines. *International Journal of Climatology*, *42*(2), 850-867. https://doi.org/10.1002/joc.7276

Mann, H. B. (1945). Nonparametric tests against trend. *Econometrica*, *13*(3), 245-259. https://doi.org/10.2307/1907187

Marigi, S. N., Njogu, A. K., & Githungo, W. N. (2016). Trends of extreme temperature and rainfall indices for arid and semi-arid lands of South Eastern Kenya. *Journal of Geoscience and Environment Protection*, 4(12), 158-171. https://doi.org/10.4236/gep.2016.412012

Mtewa, T. K., Ngongondo, C., Dulanya, Z., Boyce, C., & Mtilatila, L. (2025). Temporal trends in extreme temperature indices over Malawi during 1961–2015. *Discover Atmosphere*, *3*(1), 1. https://doi.org/10.1007/s44292-025-00025-x

Nastos, P. T. and Matzarakis, A. P. (2008). Variability of tropical days over Greece within the second half of the twentieth century. *Theoretical and Applied Climatology*, *93*: 75-89. https://doi.org/10.1007/s00704-007-0325-1

Özdel, M. M., Ustaoğlu, B., & Cürebal, İ. (2024). Modeling of the potential distribution areas suitable for olive (*Olea europaea* L.) in Türkiye from a climate change perspective. *Agriculture*, *14*(9), 1629. https://doi.org/10.3390/agriculture14091629

Özdel, M. M. and Meydan, A. (2024). Diyarbakır Havzası yöresinde 1964-2023 dönemi sıcaklıklarında gözlenen değişim ve eğilimler. *Menba Kastamonu Üniversitesi Su Ürünleri Fakültesi Dergisi*, *10*(2), 29-42. https://doi.org/10.58626/menba.1496870

Paz, S., Negev, M., Clermont, A. & Green, M. (2016). Health aspects of climate change in cities with Mediterranean climate, and local adaptation plans. *International Journal of Environmental Research and Public Health*, *13*(4), 438. https://doi.org/10.3390/ijerph13040438

Rahimi, M. and Hejabi, S. (2018). Spatial and temporal analysis of trends in extreme temperature indices in Iran over the period 1960–2014. *International Journal of Climatology*, *38*(1), 272-282. https://doi.org/10.1002/joc.5175

Saboohi, R., Soltani, S., &Khodagholi, M. (2012). Trend analysis of temperature parameters in Iran. *Theoretical and Applied Climatology*, *109*(3-4), 529-547. https://doi.org/10.1007/s00704-012-0590-5

Scorzini, A. R., Bacco, M., & Leopardi, M. (2018). Recent trends in daily temperature extremes over the central Adriatic region of Italy in a Mediterranean climatic context. *International Journal of Climatology*, 38(S1), e741-e757. https://doi.org/10.1002/joc.5403

Stott, P. A., Christidis, N., Otto, F. E., Sun, Y., Vanderlinden, J. P., Van Oldenborgh, G. J., ... Zwiers, F. W. (2016). Attribution of extreme weather and climate-related events. *WIREs Climate Change*, *7*(1), 23-41. https://doi.org/10.1002/wcc.380

Sein, K. K., Chidthaisong, A., & Oo, K. L. (2018). Observed trends and changes in temperature and precipitation extreme indices over Myanmar. *Atmosphere*, *9*(12), 477. https://doi.org/10.3390/atmos9120477

Sensoy, S., Demircan, M. & Alan, I. (2008, May). Trends in Turkey climate extreme indices from 1971 to 2004. *Third International Conference BALWOIS*. Ohrid, Republic of Macedonia.

Sensoy, S., Türkoğlu, N., Akçakaya, A., Ekici, M., Demircan, M., Ulupınar, Y., Atay, H., Tüvan, A. & Demirbaş, H. (2013, June). Trends in Turkey climate indices from 1960 to 2010. *6th Atmospheric Science Symposium*, İstanbul, Türkiye.

Skendžić, S., Zovko, M., Živković, I. P., Lešić, V., & Lemić, D. (2021). The impact of climate change on agricultural insect pests. *Insects*, *12*(5), 440. https://doi.org/10.3390/insects12050440

Sun, X., Ren, G., You, Q., Ren, Y., Xu, W., Xue, X., ... Zhang, P. (2019). Global diurnal temperature range (DTR) changes since 1901. *Climate Dynamics*, *52*, 3343-3356. https://doi.org/10.1007/s00382-018-4329-6

Sun, Y., Hu, T., Zhang, X., Li, C., Lu, C., Ren, G., & Jiang, Z. (2019). Contribution of global warming andurbanization to changes in temperatureextremes in Eastern China. *Geophysical Research Letters*, *46*(20), 11426-11434. https://doi.org/10.1029/2019GL084281

Taşoğlu, E., Öztürk, M. Z., & Yazıcı, Ö. (2024). High resolution Köppen-Geiger climate zones of Türkiye. *International Journal of Climatology*, *44*(14), 5248-5265. https://doi.org/ 10.1002/joc.8635

Tong, S., Li, X., Zhang, J., Bao, Y., Bao, Y., Na, L., & Si, A. (2019). Spatial and temporal variability in extreme temperature and precipitation events in Inner Mongolia (China) during 1960–2017. *Science of the Total Environment*, *649*, 75-89. https://doi.org/10.1016/j.scitotenv.2018.08.262

TurkStat, (2023). Address-based population registration system statistics. Retrieved from https://biruni.tuik.gov.tr/medas/?kn=92&locale=tr

UNDRR (2020, April, 21). Human cost of disasters 2000-2019. Retrieved from https://www.undrr.org/publication/human-cost-disasters-overview-last-20-years-2000-2019

Wang, X., Wu, L., & Liu, H. (2024). Extreme temperature index in China from a statistical perspective: Change characteristics and trend analysis from 1961 to 2021. *Atmosphere*, *15*(11), 1398. https://doi.org/10.3390/atmos15111398

Weilnhammer V., Schmid, J., Mittermeier, I., Schreiber, F., Jiang, L., Pastuhovic, V. ... Heinze, S. (2021). Extreme weather events in Europe and their health consequences – A systematic review. *International Journal of Hygiene and Environmental Health*, *233*, 113688. https://doi.org/10.1016/j.ijheh.2021.113688

WMO, (2016). World Meteorological Organization Statement on the status of the global climate in 2015. WMO-No. 1167.

Wolf, T., Lyne, K., Martinez, G., & Kendrovski, V. (2015). The health effects of climate change in the WHO European Region. *Climate*, *3*(4), 901-936. https://doi.org/10.3390/cli3040901

Xoplaki, E., Gonzalez-Rouco, J. F., Gyalistras, D., Luterbacher, J., Rickli, R., & Wanner, H. (2003). Interannual summer air temperature variability over Greece and its connection to the large-scale atmospheric circulation and Mediterranean SSTS. 1950–1999. *Climate Dynamics*, *20*, 537–554. https://doi.org/10.1007/s00382-002-0291-3

Yılmaz, E. ve Özcanlı, M. (2021). Van şehir gelişimi ile şehir ısı adası arasındaki ilişkiler ve sıcaklık değişimleri. *Van İnsani ve Sosyal Bilimler Dergisi*, *1*(1), 40-60.

Yin, H. and Sun, Y. (2018). Characteristics of extreme temperature and precipitation in China in 2017 based on ETCCDI indices. *Advances in Climate Change Research*, *9(*4), 218-226. https://doi.org/10.1016/j.accre.2019.01.001

Yurtseven, N. (2023). Türkiye'nin en uzun meteoroloji/klimatoloji gözlemlerine sahip olan Kandilli Rasathanesi'nin sıcaklık ekstremlerinde gözlenen değişim ve eğilimler (1912 – 2021). *Ege Coğrafya Dergisi*, *32*(1), 33-49. https://doi.org/10.51800/ecd.1279622

Zhao, N., Jiao, Y., Ma, T., Zahao, M., Fan, Z., Yin, X., Liu, Y., & Yue, T. (2019). Estimating the effect of urbanization on extreme climate events in the Beijing-Tianjin-Hebei region, China. *Science of the Total Environment*, *688*, 1005-1015. https://doi.org/10.1016/j.scitotenv.2019.06.374

Zhang, X., Aguilar, E., Sensoy, S., Melkonyan, H., Tagiyeva, U., Ahmed, N. … Wallis, T. (2005). Trends in Middle East climate extreme indices from 1950 to 2003. *Journal of Geophysical Research: Atmospheres*, *110*(D22), D22104. https://doi.org/10.1029/2005JD006181

Zhang, X., Alexander, L., Hegerl, G. C., Jones, P., Tank, A. K., Peterson, T. C. … Zwiers, F. W. (2011). Indices for monitoring changes in extremes based on daily temperature and precipitation data. *WIREs Climate Change*, *2(*6), 851-870. https://doi.org/10.1002/wcc.147