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Identification of the extreme daily maximum temperatures and their frequencies and intensities in Iraq

Shiemaa A. Hashim[1], Muna H. Ahmed[2], Monim H. Al-Jiboori[1*], Ebtesam F. Khanjer[2], Yasmin Q. Tawfeek[1]

[1]*Atmospheric Sciences Department, College of Sciences, Mustansiriyah University, Baghdad, Iraq.*
[2]*Department of Remote Sensing and GIS, College of Science, University of Baghdad, Baghdad, Iraq.*

Corresponding author: Monim H. Al-Jiboori (*Email: mhaljiboori@gmail.com*)

Abstract

Extreme maximum air temperature (ETmax) has significant impacts on ecosystems, human health, and socio-economic systems, especially in climate-vulnerable regions such as Iraq. The purpose of this study is to identify ETmax exceedances and analyze their frequency in six provinces of Iraq: Basra, Shanafiya, Baghdad, Rutba, Kirkuk, and Shakhan, using daily Tmax data obtained from NASA/POWER for 10 years (2014 to 2023). Using the 95th percentile method, thresholds of Tmax, their extreme temporal frequency, intensity, and annual trends were evaluated in four seasons: winter, spring, summer, and fall. Summer and spring show the highest thresholds (5.2%), with 50°C in Basra and Baghdad. The fall peak in Basra is 47°C (4.6%), while Rutba records the lowest thresholds in all seasons. Short-term exceedances (1-3 days) are common throughout Iraq, especially in winter, spring, and summer, while longer durations (>4 days) are rare but occur occasionally, with Rutba and Baghdad showing notable extended events. All regions except Shanafiya show an increasing trend in extreme Tmax exceedances, with Rutba and Kirkuk showing the largest increase (~1 day/year). Overall, Iraq shows an increasing trend in extreme Tmax events, driven by urbanization and climate dynamics. The national average shows an increase of ~0.66 day/year. The results underscore the increasing climate instability in Iraq and highlight regional disparities in exposure to extreme heat. Identifying ETmax in Iraq has critical practical implications in several sectors such as public health, agriculture, water resources, energy demand, urban heat, wildfires, economy, ecosystems, and disaster preparedness. This knowledge enables policymakers to develop effective mitigation and adaptation strategies.

Keywords: Extreme Tmax occurrences, persistence, Iraq threshold value, trend.

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1. Introduction

The daily maximum temperature (Tmax) plays an important role in people's and agriculture's lives [1] and is essential for providing insights into climate patterns such as heatwaves, drought, and hydrological forecasting [2-4]. The study of Tmax is crucial for several reasons, as it has substantial adverse effects on environmental, economic, health-related issues, and habitats. It indicates the highest temperature recorded at a specific location within a given period, typically measured at a height of 2 m above the surface over the course of a day, month, season, or year [5, 6]. However, the above effects are exacerbated when extreme weather events occur due to natural climate variability or human-induced global climate change. Therefore, extreme maximum temperature (ETmax) can be defined as the highest temperature recorded in a given location over a given period of time that significantly exceeds the normal maximum temperature range for that area. Studying ETmax is vital for understanding the broader impacts of ongoing climate change, protecting public health, preserving ecosystems, and maintaining infrastructure, such as power grid overloads due to increased energy demand for cooling. Roads, railways, and buildings are also more prone to damage during extreme heat, especially in the summer months. Increased evaporation rates can reduce water availability, impacting drinking water supplies and drought conditions, particularly in arid and semi-arid regions [7-9]. Understanding ETmax supports governments and organizations in developing strategies to mitigate the effects of climate change, such as heat action plans, cooling centers, and changes in building design [10].

For places like Iraq, studying ETmax can reveal shifts in weather patterns that are becoming increasingly important as the climate changes. Iraqi cities top the list of the world's hottest cities today. Iraq, particularly its southern regions, has experienced more frequent and intense heat waves in recent years. The hottest temperature recorded from 1949 to July 2024 was reported by the Basra airport weather station. The countrywide record for the highest temperature ever recorded is 53.8°C, set in Basra on July 22, 2016 [11]. Iraq's climate is changing faster than people can adapt. Between May and October, the heat scorches everything that is dead and sears everything that is alive. During the day, the sun forces people indoors; at night, the heat lingers in cities that feel like the inside of a hair dryer. In spring and early fall, however, temperatures rise above the seasonal average.

In arid and semi-arid regions such as Iraq [12], ETmax is a major concern, especially in summer when temperatures can exceed 50°C. The frequency and intensity of these temperature extremes have increased in recent decades due to several factors, including climate change, urbanization, and limited vegetation cover [13]. A growing trend is the frequency and intensity of heat waves, defined as extended periods of excessively high temperatures that can last from several days to weeks. To quantify these trends in Iraq, studies often use climate indices such as annual Tmax and the frequency of days with temperatures above a certain threshold [14, 15]. The study of ETmax in Iraq is an important topic, especially considering the region's exposure to high temperatures and climate variability, and it involves analyzing the occurrence of extremely high temperature events over time, where maximum temperatures are often extreme.

Many studies have been conducted on ETmax using long-term historical records in most developed countries such as Canada [16], Europe [17], India [18], Bangladesh [19], Saudi Arabia [20], and even Iraq [15]. Colombo, Colombo, et al. [21] examined the frequencies of summer (June, July, and August) extreme events using Tmax for 9 cities in Canada. Using mean and variance, they found an increase in the frequency of both single and consecutive days with Tmax above a threshold value; for example, a 3 °C increase in Tmax occurred in Toronto with a frequency of 7.5% for a 5-day consecutive run. In Europe, Sulikowska and Wypych [17] evaluated the effects of different percentile-based methods of defining hot days on their frequency, trends, and geographical patterns in summer. Their results showed that the use of this method led to differences in the geographical patterns of frequencies and trends of hot days. The changes in the frequency of occurrence of extreme temperatures and their intensities in 7 homogeneous regions of India during the period 1969-2005 were studied [18]. They found a significant increasing trend in hot days in summer, which was observed only in the inner peninsula. Recently, Rahman, et al. [19] analyzed Tmax datasets during 1991-2021 in Bangladesh and found that the frequency of days with a threshold of Tmax > 36 °C was persistent for many days in 2014, especially in the western part. These findings were also observed in Saudi Arabia when analyzing seasonal time scales [20]. In Iraq, some attempts were made to investigate extreme temperature and extreme heat waves [14, 15]. The former used the reanalysis dataset of Tmax obtained from ECMWF for the period 2006-2017 at four provinces (Basra, Baghdad, Rutba, and Khanagean) during summer months and considered 50 °C in Basra based on the anomaly method [14]. The latter studied the heat waves by analyzing observed Tmax obtained from the Baghdad meteorological station for the period 2004-2018 for summer months (June-August). Using the 95th threshold percentile, which is ≥ 47.6 °C, most cases for 2-3 consecutive days were concentrated in July and August [15].

In the presented study, Tmax data from NASA POWER (Prediction of Worldwide Energy Resources) for the period (2013-2023) were used to identify extreme maximum temperatures and variations in extreme temperature events over this period in six provinces (Basra, Shanafiya, Baghdad, Rutba, Kirkuk, and Mosul (Shakhan)). The use of source data is thus a robust method for studying and understanding extreme temperature events, especially given its reliability, accessibility, and consistency over a multi-year period, and is particularly helpful for regions such as Iraq, with sparse in-situ measurements. The main objectives of the current study are to 1) determine the thresholds using the 95th percentile method for each season, 2) find the daily number of ETmax with frequencies, 3) frequencies for the highest ETmax intervals, and 4) calculate the trends of the number of exceedances.

2. Materials and Methodology

2.1 Study Area

The Republic of Iraq is located in the Middle East and is bordered by six countries: Kuwait, Iran, Turkey, Syria, Jordan, and Saudi Arabia, and has significant geographic and climatic characteristics. It lies between approximately 29° and 38° N latitude and 39° to 49° E longitude. The country slopes from mountains over 3,000 m above sea level along the borders with

Iran and Turkey to the remnants of sea-level reedy marshes in the southeast. Figure 1 shows a map of Iraq with the six provinces highlighted: Basra, Shanafiya, Baghdad, Rutba, Kirkuk, and Shakhan, located at elevations of 5.2, 19.1, 38.7, 341.4, 624.6, and 747 m above mean sea level (msl), respectively.

For a study of extreme temperatures, it is essential to focus on a specific study area within the country. Iraq has different climatic zones, ranging from arid to semi-arid, and experiences extreme temperatures, especially during the summer months. Iraq is one of the hottest countries in the world during the summer, especially in the southern regions, with temperatures often exceeding 50°C in areas such as Basra. Iraq's climate is mostly arid to semi-arid, with extreme temperatures particularly common in the summer months. The extreme temperatures and arid climate make Iraq highly susceptible to drought, which affects agriculture and water resources [22]. The mountainous region of northern Iraq receives significantly more precipitation than the central or southern desert region. Iraq receives very little rainfall, with most precipitation occurring in winter [23].

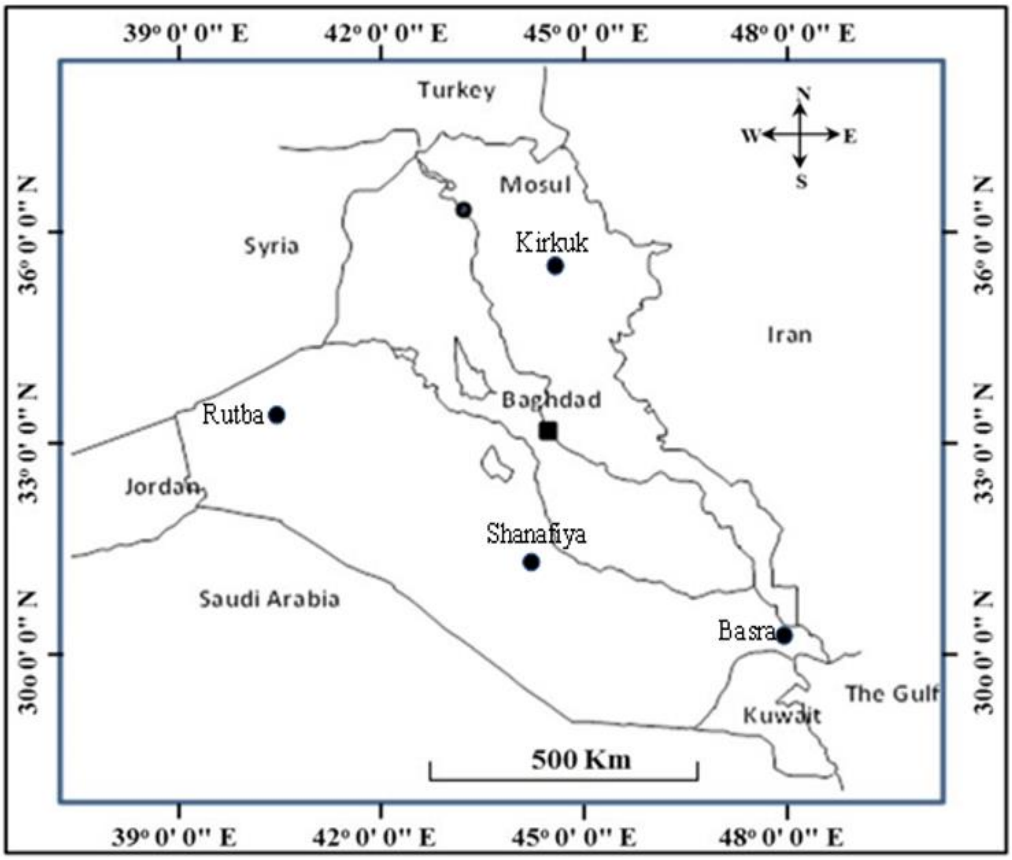

Figure 1.
Map of the study area with studied cities denoted by solid circles.

Basra is known for extremely high temperatures and harsh arid conditions, especially in summer. This area frequently experiences extreme heat events, making it suitable for studying maximum temperature events. While Shanafiya and Baghdad also experience high temperatures, they may have slightly more moderate conditions compared to the south. As the capital, Baghdad's data is useful for understanding how extreme temperatures affect highly populated and urbanized areas. The northern regions represented by Shakhan, especially in mountainous areas, experience more varied climates, with potential cooling effects from elevation. Northern Iraq allows for a comparison of extreme temperatures in lower and higher elevation areas, highlighting temperature variability within the country. The western desert region, represented by Rutba, is generally arid and experiences extreme temperature swings. Studying this area provides insight into how extreme temperatures manifest in Iraq's desert zones. Together, these regions cover the major climatic zones of Iraq, providing a well-rounded approach to analyzing extreme temperature events in different environments.

2.2. Data Source

The NASA POWER platform is a data service that provides meteorological and solar energy data from NASA satellite observations, models, and reanalyses. This dataset provides high-quality, satellite-derived data covering the globe with a focus on providing reliable, accessible, and accurate information for the energy sector. POWER data is widely used in a variety of sectors, including renewable energy (solar and wind), agriculture, and climate studies, due to its multi-year consistency and accessible format, which allows users to easily access long-term historical climate and environmental data. Daily maximum temperature data from 2013 to 2023 have been downloaded in ASCII format from the website (https://power.lars.nasa.gov) for the six Iraqi cities whose locations are shown in Figure 1.

2.3. Methodology

2.3.1. Definition of an Extreme Event and its Threshold Value

A warm spell of Tmax can be considered extreme if its value exceeds a threshold, which can be determined using almost three methods: choosing a constant absolute value [14], empirical examination of Tmax data at each studied location [17], and choosing baseline periods depending on historical long-term records, such as since 1961 [24]. In this paper, the second method was used to calculate threshold values of days across six different geographical areas in Iraq. Using the percentile method to set a threshold involves selecting a specific percentile in the Tmax data set as the cutoff for extreme values. This method is commonly used in climatology and environmental studies to identify extreme weather events, such as high temperatures, by setting a threshold that reflects the most extreme conditions [25]. Temperatures above this 95th percentile threshold, which represents a 95% confidence level, would be considered extreme maximum temperatures. The 95th percentile, a standard statistical measure used in interpreting performance data, is a number that is greater than 95% of the numbers in a given data set. The use of percentiles is generally preferred for consistency across years and locations, especially when analyzing long-term data. The reason this statistic is so useful for measuring data throughput is that it gives a very accurate picture of the maximum traffic generated on an interface. In addition, the approach provides insight into the frequency of extreme temperature events and whether they are becoming more frequent or severe over the years in the six provinces studied. The 95th percentile, however, is the highest value that remains after discarding the top 5% of a numerically sorted set of collected data. In other words, it marks the threshold where only 5% of the data points are higher. This is often used to identify a threshold to classify any data points above it as "extreme" events, as it provides a way to focus on the top 5% of observations, so this approach is preferred by the IPCC [26]. Sorting the collected data in ascending order is the first necessary step because it relies on the order of the data. Second, a percentile formula (Equation 1) is applied to identify the 95th percentile of the number of records (N) [25].

$$\text{Percentile ranking} = \frac{\mathrm{p}}{100} \times \mathrm{N} \tag{1}$$

Also, it was used in different time scales within the calendar of years divided by the standard four seasons: winter (December-February with 902 days), spring (March-May with 920 days), summer (June-August with 920 days), and fall (September-November with 912 days). This approach is useful, especially for comparing its results in geographical areas with different climates and seasons, but it has a limitation in that it does not directly address the intensity or frequency of extreme events. Events above the threshold are considered extreme regardless of their actual magnitude. The obtained daily frequencies of exceedances above the thresholds for each season were also calculated by dividing them by the total number of Tmax data in the period (2014-2023).

2.3.2. Intensity of Tmax

Intensity refers to how extreme or severe high temperature events compare to typical conditions in a given region or time period. It quantifies how much a temperature event exceeds a threshold or baseline and indicates the "extremity" of heat events. The common method for calculating the daily Extreme Tmax Intensity (ETmaxI) for Tmax events based on the threshold value is expressed by the following equation:

$$\mathrm{ETmaxI} = \mathrm{Tmax} - \mathrm{T}_{95\mathrm{th}} \tag{2}$$

This measures how much the temperature exceeds the extreme threshold, giving a relative intensity of the event.

2.3.3. Statistical Analysis

Extreme event analysis requires an assessment of the homogeneity of daily Tmax data, even when obtained from NASA/POWER sources. It can help validate the reliability of extreme event analyses by ensuring that the results accurately represent actual climate variations and are not affected by model adjustments or data processing changes. Calculating the mean, standard deviation (SD), that is a measure of the dispersion or spread of Tmax values around the mean, and coefficient of variation (CV) over a period of time, have been identified to indicate inhomogeneities that may be associated with heat waves or other extreme climate events. However, CV is often expressed as a percentage and is determined as Brown [27]

$$\mathrm{CV}(\%) = \frac{\mathrm{SD}}{\mathrm{mean}} \times 100 \tag{3}$$

This metric provides a normalized measure of variability that allows comparison of variability across regions or time periods. For extreme Tmax, a high CV would indicate that temperatures are highly variable, while a low CV would indicate greater stability in extreme values. By analyzing SD and CV, it's possible to quantify the consistency and volatility of extreme temperature patterns in Iraq, which is critical for managing climate-related risks. A linear regression model, Equation 4, is used to calculate the trend [28], which represents how quickly the number of extreme hot days per year has changed over the years [29, 30].

$$\mathrm{Y} = \gamma * \mathrm{X} + \beta \tag{4}$$

Where Y is a number of extreme hot days, X the years, and γ the slope of the line (rate of change per year), and β is the intercept (value of Y when X=0). The steps of the methodology described above is summarized in Figure 2.

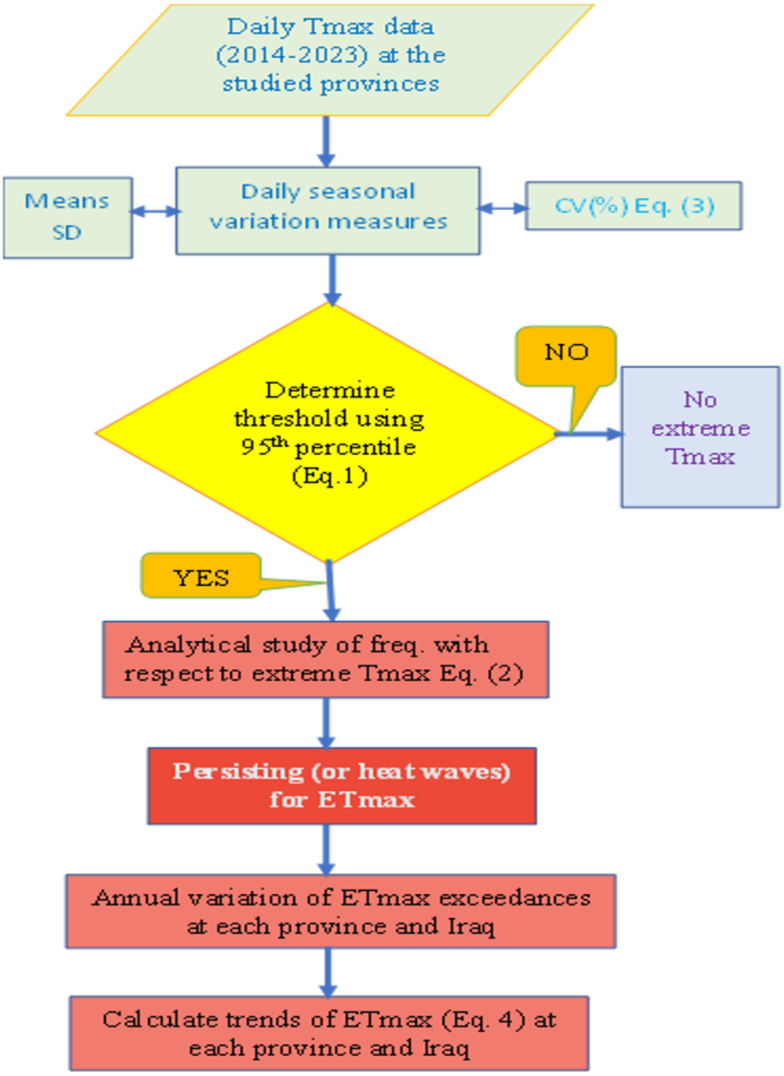

Figure 2.
Flowchart of the methodology in this study.

3. Results and Discussion

3.1. Daily Seasonal Variations of Tmax

To understand the daily and seasonal Tmax variation with a focus on hot extreme Tmax across the entire period (2014-2023), reaching a peak as Iraq experiences the highest extreme heat in recent decades, we separately plotted the daily seasonal cycles as shown in Figures 3-8. In each figure, the x-axis represents days within the season, while the y-axis represents daily Tmax. This visually shows the seasonal rise and fall in Tmax along with days that break the expected pattern. Additionally, each figure is divided into four panels, each representing winter, spring, summer, and autumn, respectively. Although the high Tmax in the south and middle of Iraq, represented by Basra, Shanafiya, and Baghdad, was clear, they exhibit less fluctuation in each season. In contrast, Rutba, Kirkuk, and Shakhan show considerable fluctuation, recording a slight decrease in Tmax values. During the spring and fall seasons, there are continuous rises and falls in all of Iraq's provinces: Basra, Shanafiya, Baghdad, Rutba, Kirkuk, and Shakhan, as shown in Figures 3b and d, 3b and d, 4b and d, 5b and d, 6b and d, 7b and d, and 8b and d, respectively.

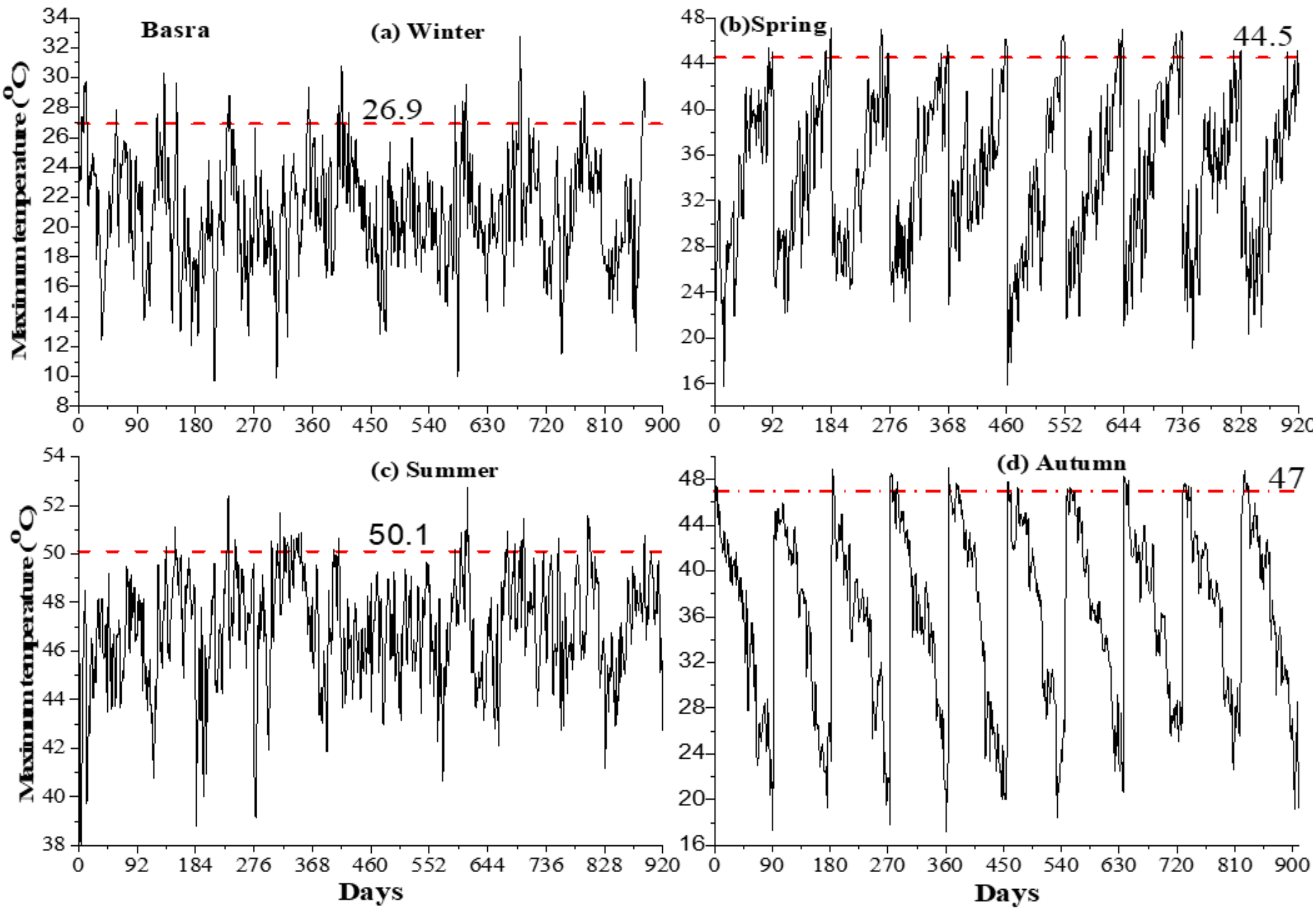

Figure 3.
Daily seasonal Tmax variations in Basra in (a) winter, (b) spring, (c) summer, and (d) autumn for the period (2014-2023).

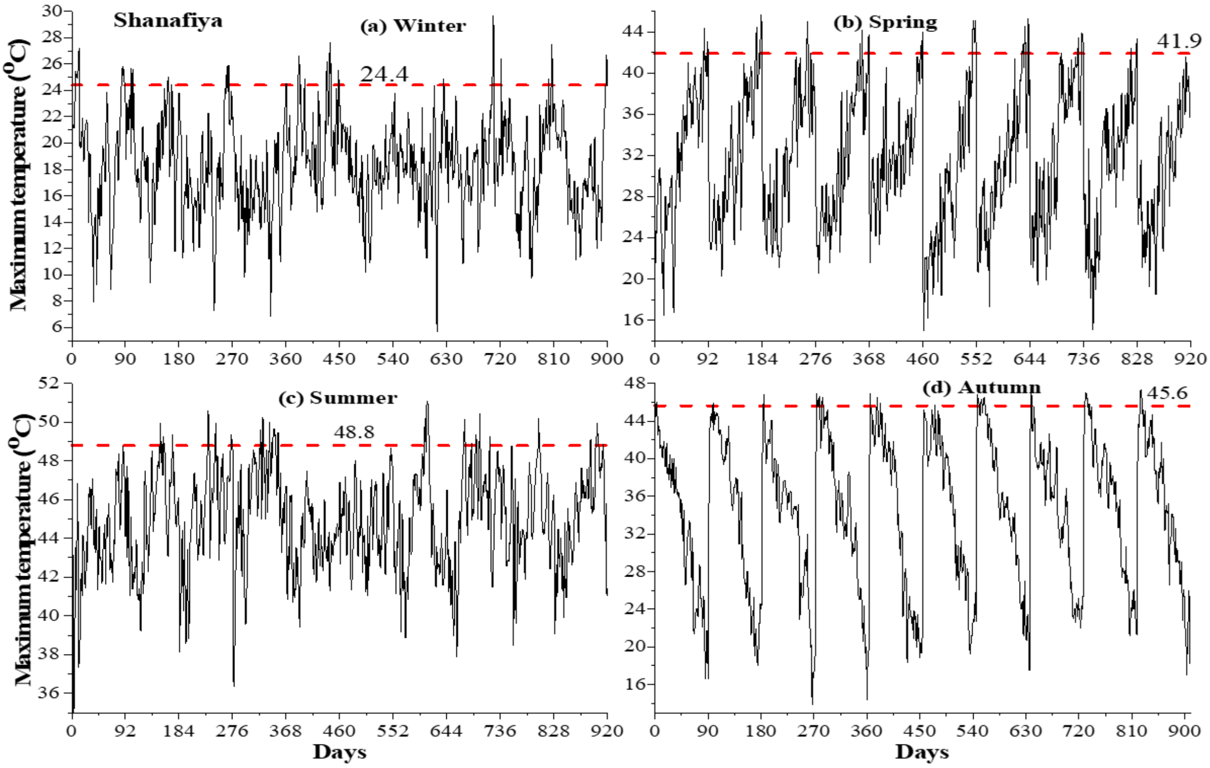

Figure 4.
Same as Figure 3, but for Shanafiya.

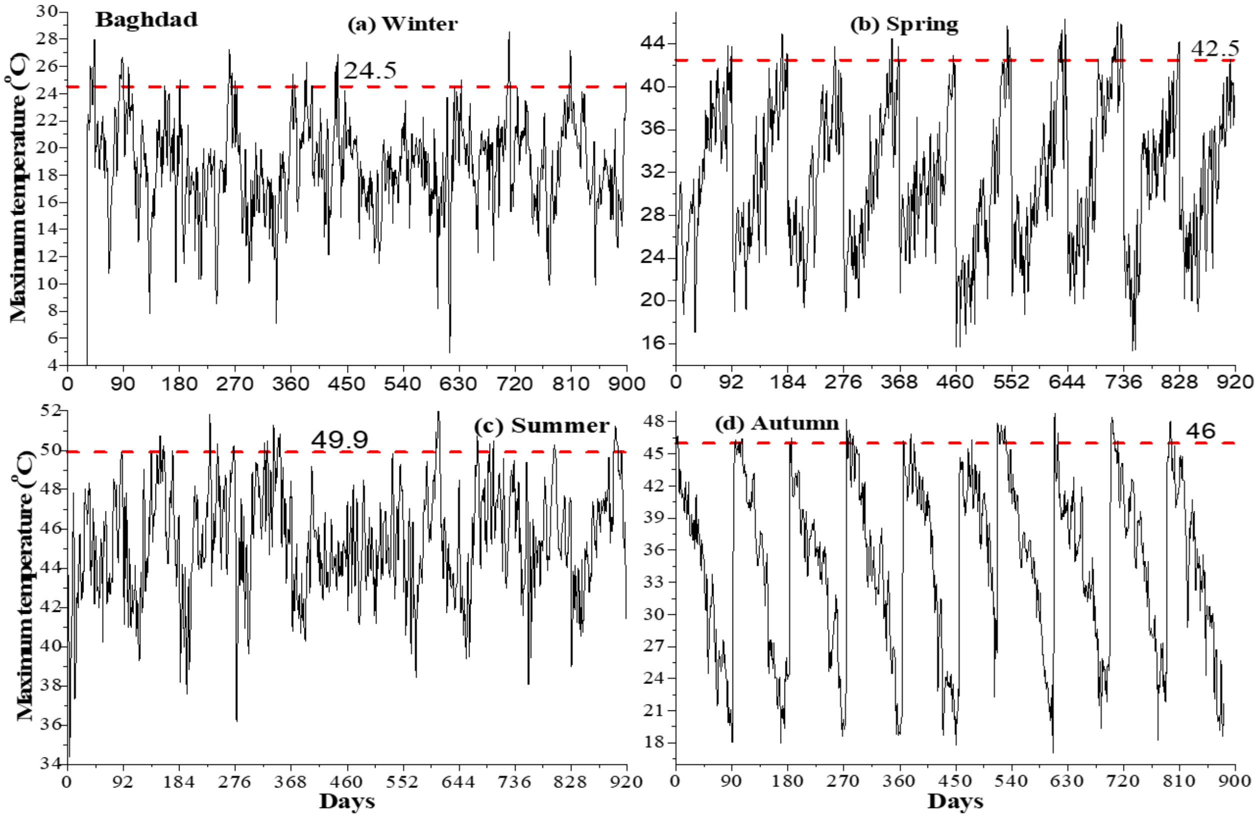

Figure 5.
Same as Figure 3, but for Baghdad.

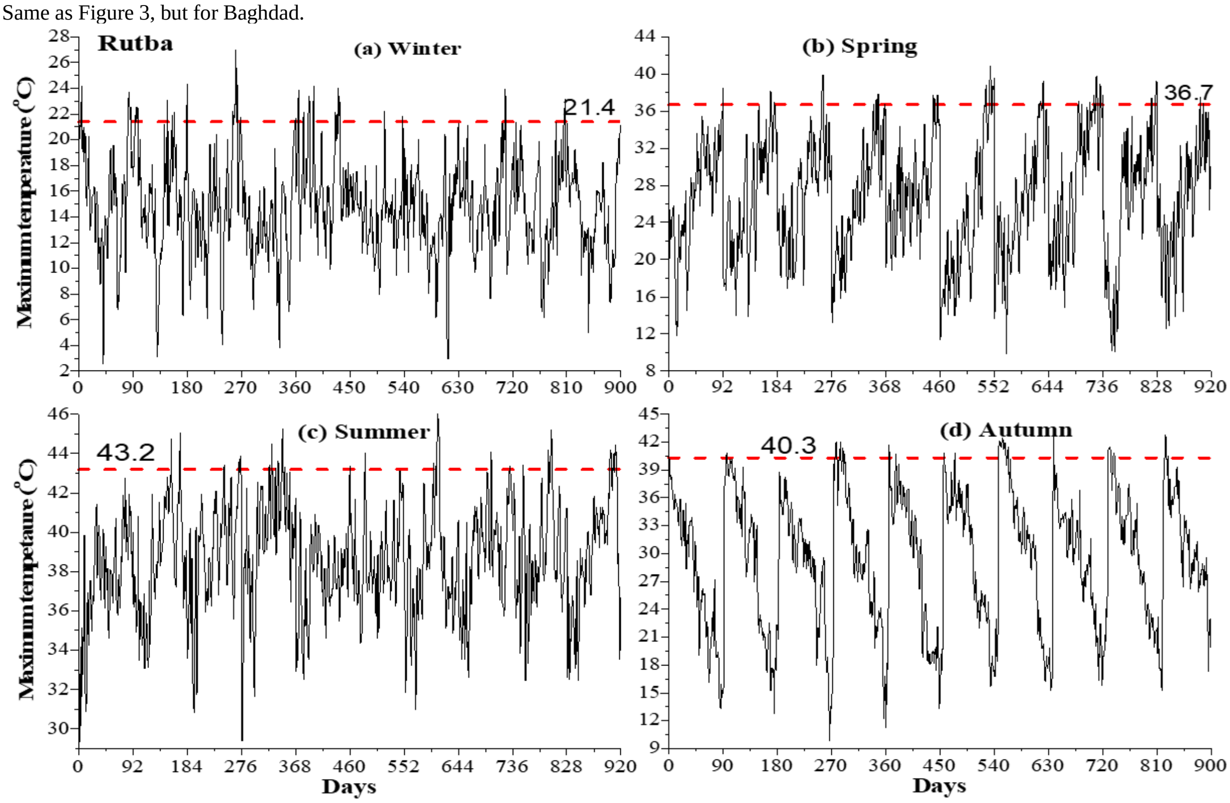

Figure 6.
Same as Figure 3, but for Rutba.

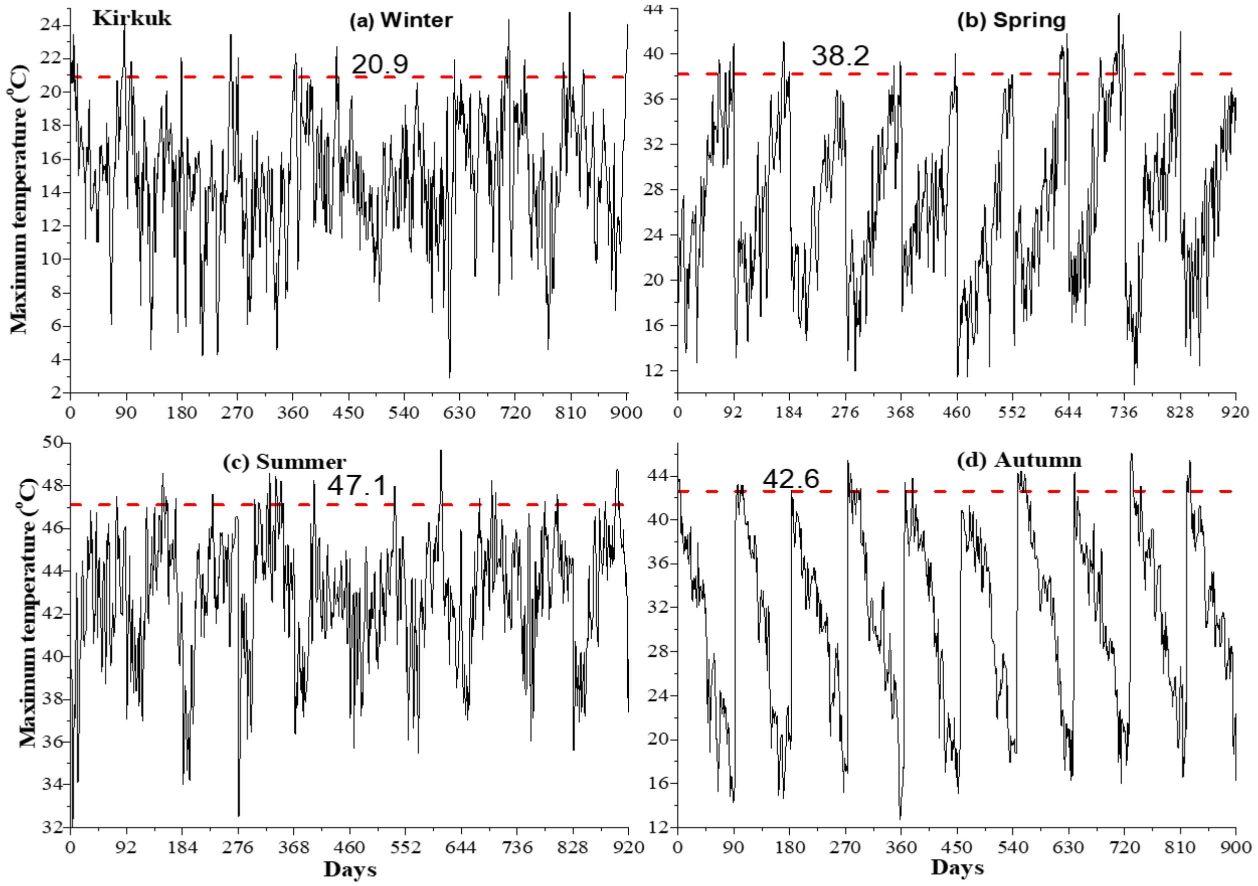

Figure 7.
Same as Figure 3, but for Kirkuk.

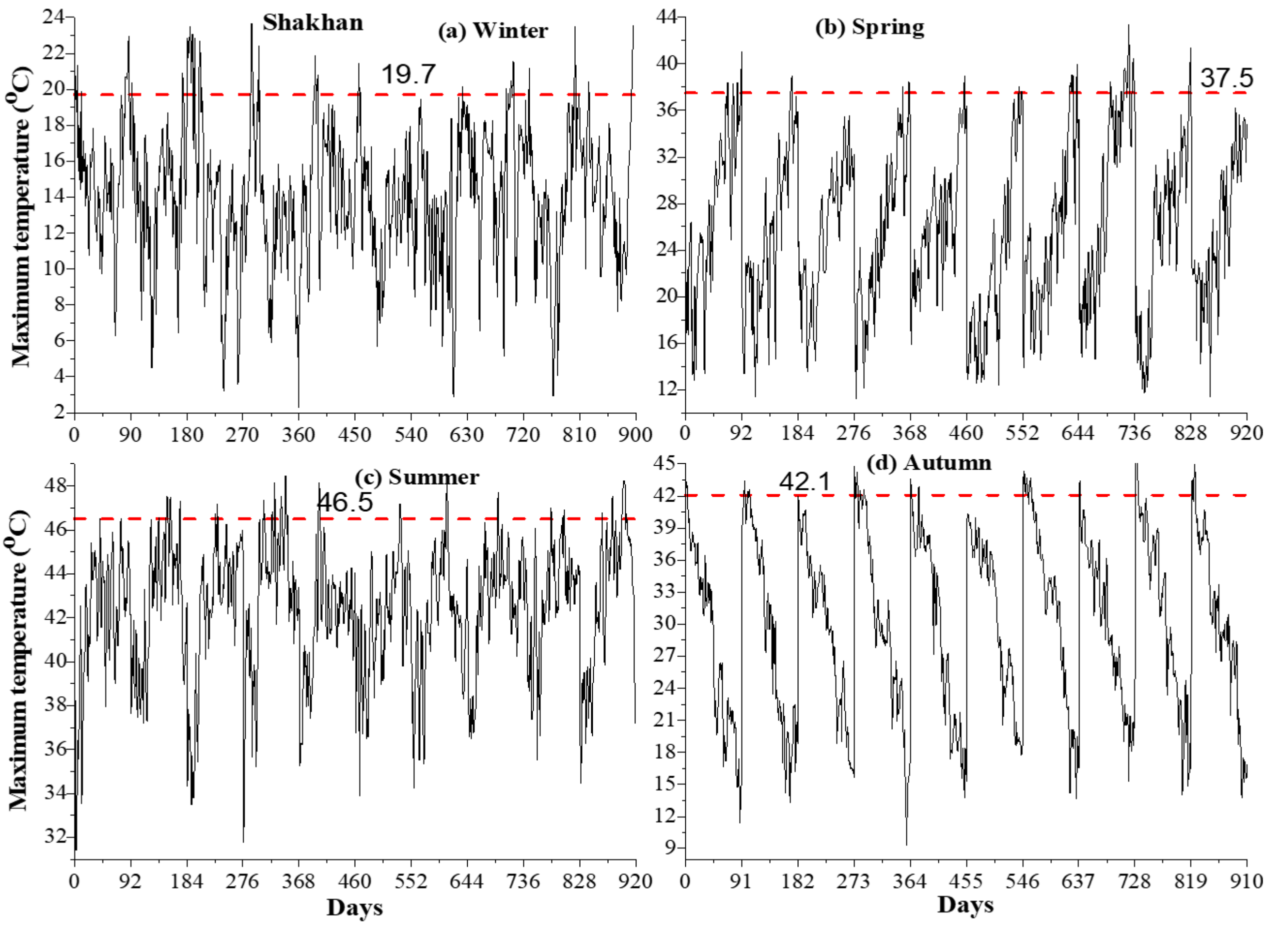

Figure 8.
Same as Figure 3, but for Shakhan.

Statistical characteristics such as ordinary means, SD, CV, highest Tmax, and Tmax range were calculated through the entire period (2014-2023) across all provinces and reported in Table 1. Seasonal means for Tmax in Basra were highest values of 20.7, 34.1, 46.9, and 36 °C through 10 years studied in this paper. Also, summer highest Tmax was passed 51 °C in the central and south parts of Iraq: Basra~ 52.7, Baghdad ~52.6, and Shanafiya ~51.1 °C. The SD of seasonal means showed the small values in winter and summer reflecting the low scattering in daily Tmax around their means, while this pattern is different in the shoulder seasons (spring and autumn). The percentage of CV has low value ranging from 4.8 in summer to 21.7% in autumn with temperature range of 26.2 °C and it should be moted that the SD and percentages were the less values among the other provinces. This means that Basra's hot climate characterized with a relatively slight stable, especially in summer because of its nearby Gulf Sea and low elevation. However, the areal means for Tmax with SD and CV was also calculated, which presented in last row of Table 1. The percent of CV was small in summer reflecting the stable climate owing to no passing synoptic pressure systems in this season. The annual means of daily Tmax have were 16.7, 29.1, 43.1 and 32.4 °C in winter, spring, summer, and autumn, respectively, with an annual heat range of 26.4 °C. These values agree with those reported by the World Bank for the period (1991-2022) for the same seasons, which are 16.8, 29.4, 42.4, and 31.7 °C, respectively with an annual Tmax range of 25.6 °C [31]. This comparison might support the reliability and validation of the data analyzed in this work, especially in the crucial of extreme Tmax analyses described in the following subsections.

The heat distribution in Iraq was approximately regular, where high mean Tmax was clear in the south and gradually declined in the northern and western areas. In the northern part of Iraq, represented by Shakhan, experiences the lowest daily Tmax in winter (14±3.7 °C) and spring (25.9±6.9 °C), which transitions to Rutba in summer and autumn with values of 38.6±2.8 and 29.1±7.4 °C, respectively. It is an interesting result in this paper that Shakhan is also characterized with a significant heat range (28.4 °C) that can fairly reveal extreme weather. In the west of Iraq (Rutba) the highest Tmax values were found to be the lowest in three warm seasons (spring ~24.3, summer~46, and autumn ~43.3 °C), therefore, it would be better to setup the solar energy farms.

Table 1.
Seasonal mean Tmax with SD, CV(%), highest Tmax, and annual Tmax range in all provinces and the country.

Seasons Province	Winter				Spring				Summer				Autumn				Ann. range (C)
	Mean (°C)	SD (°C)	CV (%)	Max (°C)	Mean (°C)	SD (°C)	CV (%)	Max (°C)	Mean (°C)	SD (°C)	CV (%)	Max (°C)	Mean (°C)	SD (°C)	CV (%)	Max (°C)	
Basra	20.7	3.7	17.8	32.8	34.1	6.7	19.9	47.1	46.9	2.2	4.8	52.7	36	7.8	21.7	49	26.2
Shanafiya	18.3	3.6	19.7	29.7	30	7.8	25.9	45.7	42.2	6.8	16.2	51.1	34.2	8.1	23.6	47.4	23.9
Baghdad	17.7	3.5	18.8	28.6	31.4	6.7	21.4	46.3	45.4	2.8	6.1	52.6	34.4	8	23.3	48.8	27.7
Rutha	14.8	3.8	25.6	27	26.6	6.4	24.3	40.9	38.6	2.8	7.3	46	29.1	7.4	25.4	43.3	23.8
Kirkuk	14.9	3.7	24.9	24.8	26.8	7	26.1	43.6	42.8	2.9	6.9	49.7	30.8	8.1	26.2	46.1	27.9
Shakhan	14	3.7	26.7	23.7	25.9	6.9	26.7	43.4	42.4	3	7.1	48.5	29.9	8.2	27.5	45.8	28.4
Iraq	16.7	3.7	22.3	27.8	29.1	6.9	24.1	44.5	43.1	3.4	8.1	50.1	32.4	7.9	24.6	46.7	26.4

Table 2.
Seasonal threshold values and number of days whose Tmax greater than threshold values in all provinces.

Seasons Province	Winter			Spring			Summer			Autumn		
	T_{th} (°C)	Days no.>T_{th} (°C)	Rel freq. (%)	T_{th} (°C)	Days no.>T_{th} (°C)	Rel freq. (%)	T_{th} (°C)	Days no.>T_{th} (°C)	Rel freq. (%)	T_{th} (°C)	Days no.>T_{th} (°C)	Rel freq. (%)
Basrah	26.9	39	4.3	44.5	47	5.2	50.1	48	5.2	47	42	4.6
Shanafiya	24.4	30	3.3	41.9	37	4	48.8	45	4.9	45.6	45	5
Baghdad	24.5	34	3.8	42.5	44	4.8	49.9	38	4.1	46	45	5
Rutha	21.4	28	3.1	36.7	43	4.7	43.2	43	4.7	40.3	48	5.3
Kirkuk	20.9	41	4.6	38.2	39	4.2	47.1	48	5.2	42.6	47	5.2
Shakhan	19.7	38	4.2	37.7	44	4.8	46.5	48	5.2	42.1	44	4.8

3.2. Seasonal Extreme Tmax

Extreme values of Tmax in all seasons and areas derived by the 95^{th} percentile using Equation 1 displayed in Table 2. These values were added in Figures 3-8 as red horizontal lines to recognize them from the other Tmax. This analysis interprets both seasonal patterns, trends and highlighting unusual high-Tmax occurrence or events. This breakdown gives a climatological daily cycle showing how extreme Tmax deviate from seasonal norms through each year, which could have implications for heat-related stress or changes in extreme weather patterns. Any daily Tmax that exceeds the threshold is considered a warm outlier or spell according to the threshold's values presented in Table 2 across the seasons and years for all studied provinces. Also, this table contains number of days greater than threshold values and their frequencies, which are not constant, but changing according to the seasons and locations of the cities.

In winter, number of the threshold values across all cities are less than those in the remaining seasons especially in Shakhan with 19.7 °C (4.2%), while they have roughly large number in Basra with 4.3%. The 95^{th} threshold value found in summer and spring with 5.2% are largest among other seasons whereas 50 °C values are domain in Basra and Baghdad in summer. This is expected because Basra located in the further place of the south part and nearest to large water bodies, while Baghdad is the capital of Iraq and characterized with high-density population [32, 33]. In autumn the highest threshold value with 47 °C was recorded in Basra with less frequency 4.6% among other provinces. Rutba city recorded less threshold values in spring, summer, and autumn (36.7, 43.2, and 40.3 °C).

3.3. Frequencies and Persistence of Extreme Tmax

Understanding the dynamics of ETmax frequencies and persistence in Iraq is crucial for formulating policies and building resilience against future climate challenges. Therefore, the extreme hot occurrences expressed as ETmaxI were determined for all different geographic regions studied in this paper. These were departures from the threshold values based on Equation 2, and hence were divided into several intervals with a constant range of 1 °C, hence number of hot days was calculated in each interval. Table 1 presents these intervals with their extreme numbers in all seasons: winter, spring, summer, and autumn. The number of ETmax intervals across Iraq's provinces in winter and autumn were found to be larger than those in summer and autumn. This means that cold seasons are more influenced by the current climate changes.

The number of ETmax days were distributed over 5 intervals in winter and 3 intervals in summer, except in Rutba. The ETmax intervals following directly the threshold values were contained the greater frequencies of ETmax days. In Shakhan, number of ETmax days has relative increases at the last interval. The most important result is the behaviour of the ETmax in Basra, which passed the 50 °C with 35 days of 48 focused in the nearest interval to a threshold value. While 10 hottest Tmax recorded in the period (2014-2023) with values of 51-52 °C and 3 values of ETmax greater than 52 °C. After Basra, through Baghdad located in the middle of Iraq, it has also serious problem with the values of ETmax reaching out more than 50 °C and passing 51 °C with extreme 6 days and only one day at 52 °C. in the west of Iraq, Rutba region showed the lowest ETmax with 25 of 43 days in the interval of 42.2-43.9 °C even though their numbers, and the remaining days (17) have more than 44 °C. In general, the autumn season has a temperature interval less than those in spring and most of them occurred at the beginning of September.

Table 3.
Seasonal intervals of Highest Tmax exceedance over threshold (2014-2023) in all provinces.

Season	Basra		Shanyfiya		Baghdad		Rutba		Kirkuk		Shankhan	
	ETmax int. (°C)	**#**	**ETmax int. (°C)**	**#**	**ETmax int. (°C)**	**#**	**ETmax int. (°C)**	**#**	**ETmax int. (°C)**	**#**	**ETmax int. (°C)**	**#**
Winter	26.9-27.9	17	24.4-24.9	10	24-24.9	7	21.4-21.9	12	20.9-21.9	23	19.2-19.9	7
	28-28.9	10	25-25.9	13	25-25.9	12	22-22.9	28	22-22.9	11	20-20.9	18
	29-29.9	8	26-26.9	4	26-26.9	10	23-23.9	4	23-23.9	4	21-21.9	7
	30-30.9	3	27-27.9	2	27-27.9	4	24-24.9	3	24-24.9	3	22-22.9	4
	>31	1	>28	1	28-28.9	1	>25	1	-	-	23-23.9	2
Spring	44.5-44.9	10	41.9-42.9	17	42.5-42.9	13	36.7-37.9	24	38.2-38.9	8	37.5-37.9	8
	45-45.9	20	43-43.9	12	43-43.9	17	38-38.9	8	39-39.9	13	38-38.9	18
	46-46.9	15	44-44.9	4	44-44.9	8	39-39.9	8	40-40.9	11	39-39.9	12
	47-47.9	2	45-45.9	4	45-45.9	4	40-40.9	3	41-41.9	5	40-40.9	3
	-	-	-	-	46-46.9	2	-	-	>42	2	>41	3
Summer	50.1-50.9	35	48.8-49.9	32	49.9-50.9	31	43.2-43.9	25	47.2-47.9	35	46.5-46.9	19
	51-51.9	10	50-50.9	12	51-51.9	6	44-44.9	12	48-48.9	12	47-47.9	22
	52-52.9	3	51-51.9	1	52-52.9	1	45-45.9	5	49-49.9	1	48-48.9	7
	-	-	-	-	-	-	46-46.9	1	-	-	-	-
	47-47.9	32	45.6-45.9	16	46-46.9	27	40.3-40.9	20	42.6-42.9	10	42.1-42.9	21
Autumn	48-48.9	9	46-46.9	24	47-47.9	13	41-41.9	19	43-43.9	20	43-43.9	15
	49-49.9	1	47-47.9	5	48-48.9	5	42-42.9	8	44-44.9	12	44-44.9	5
	-	-	-	-	-	-	43-43.9	1	45-45.9	4	45-45.9	3
	-	-	-	-	-	-	-	-	46-46.9	1	-	-

For calculating the intensity of ETmax with their duration, referred to as persisting or heatwaves, which are characterized by extreme hot weather continuing for at least two consecutive days [34]. In general, 1-day duration exceedances are the most prevalent across all Iraqi cities and for three seasons: winter, spring, and summer. In autumn, 1-day and 2-day durations are approximately the same across all provinces. The 2-day duration was more frequent in summer for Basra. This result was also found in the cities of Saudi Arabia, but with lower intensity [20]. The 3-day durations are found to dominate in the whole of Iraq, occurring roughly four times during the period (2014-2023), especially in winter and spring, but less so in summer and autumn. The 4-day durations dominate in Iraq, but with fewer chances in other seasons. As Baghdad is the capital characterized by a high-density population, it experiences more serious heatwaves for 2- and 3-day durations, especially in warm seasons (i.e., spring, summer, and autumn). Kirkuk city shows high frequencies of 2-day durations, particularly in summer. Finally, ETmax events for durations greater than 5 °C (i.e., 6, 7, 8, 9, and sometimes 12-day durations) occurred in autumn in Rutba, described as warm spells that sometimes occurred in all provinces at once, except for Baghdad, where the 7-day duration repeated 3 times.

Table 4.
Seasonal daily frequencies of ETmax consecutive events across all studied provinces and Iraq.

Season	**Winter**						**Spring**						**Summer**						**Autumn**					
Province	1	2	3	4	5	>5	1	2	3	4	5	>5	1	2	3	4	5	>5	1	2	3	4	5	>5
Basra	7	5	5	1	1	1	9	1	3	3	1	1	13	8	3	-	2	-	7	3	2	3	1	1
Shanafiya	13	2	3	1	1	1	7	5	5	2	-	1	10	7	2	2	1	1	5	4	5	3	-	1
Baghdad	10	2	3	2	1	1	7	3	8	-	1	-	8	8	1	-	-	3	4	8	3	-	-	2
Rutba	16	3	2	2	-	1	14	6	4	2	-	-	14	4	3	1	2	-	5	5	2	2	1	1
Kirkuk	8	6	5	1	-	1	5	4	1	2	1	2	11	8	2	2	-	1	6	7	3	-	-	2
Shakhan	9	5	5	2	-	-	8	3	2	2	2	-	13	3	6	1	-	-	4	5	2	1	2	1
Iraq	11	4	4	2	1	1	8	4	4	2	1	1	12	6	3	1	1	1	5	5	3	2	1	1

3.4. Annual Variations of ETmax Occurrences

Using the seasonal ETmax exceedances, their annual numbers at each year were computed at specific provinces, and then areal mean across Iraq for all extreme days of ETmax were also computed by summing these number and dividing over 6. Annual time series for all regions as well as areal means for the 10-year period running from 2014 to 2023, were plotted together in Figure 8 to study their variations through estimating the trend (or slope) using the linear regression model explained in Equation 4. This analysis highlights the spatial variability in Iraq's vulnerability to extreme heat events, emphasizing the need for localized mitigation and adaptation strategies. However, although there is a high scatter in variations of frequencies of exceedances shown in Figure 9, the general increase was approximately clear during this period, especially in 2020 and 2021, which were characterized by extreme climate where very little rain experienced lower rainfall than average compared to other years, with significant variation across the country, high temperature and severe drought [12, 22, 23]. In contrast, the less frequencies of ETmax days were found in 2019 across the whole Iraq, ranging from 2 days in Kirkuk to 14 in Rutba. It is an interesting result that in 2017, the number of extreme Tmax days are almost the same in all provinces. For comparison purposes, unfortunately up to our knowledge, the analysis used in this study was not found in the previous articles carried out in Iraq or countries around it. Therefore, in Poland [35] illustrated that the number of extreme days of summer Tmax were increased during the decade (2005-2015) of the total period (1951-2015), especially in mountainous areas greater than 500 m above msl.

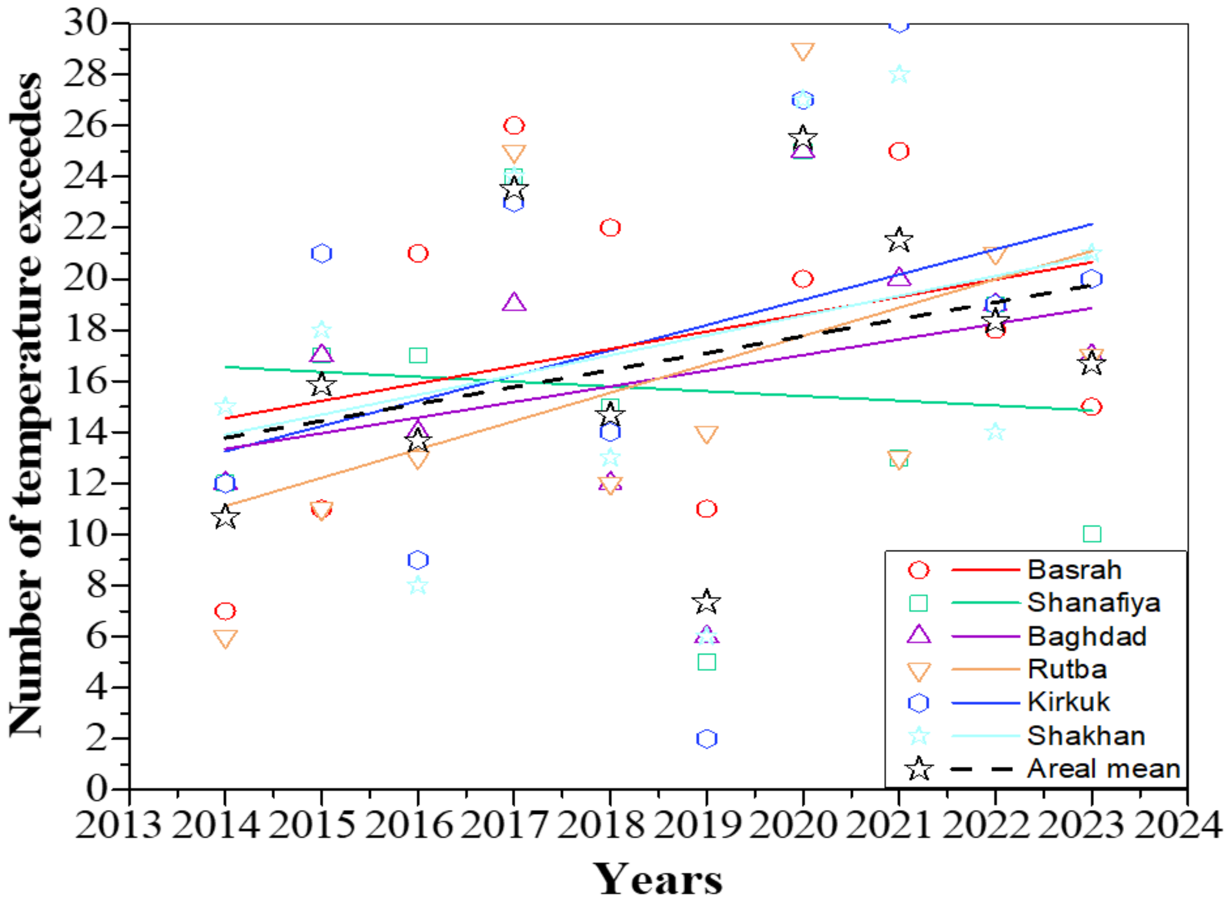

Figure 9.
Annual variation of extreme Tmax occurrences at six Iraqi provinces and its areal mean for the period (2014-2023).

Six best fitting lines were passed separately through the annual ETmax values for each region and even whole Iraq drawn from Equation 4. Based on the number of hot extreme Tmax, the constants of γ and β with correction coefficient were reported in Table 5. All annual trends have positive upward behaviour in five regions: Basra, Baghdad, Rutba, Kirkuk, and Shakhan, while only Shanafiya showed a weak decrease downward trend with a R=-0.09, suggesting a slight decline in extreme Tmax exceedances. Rutba and Kirkuk exhibit a noticeable increase in extreme Tmax occurrences with a steeper trend of about 1 day/year compared to other provinces. Shakhan also displays the least significant trend with a 0.78 day/year, but no substantial increase over the years. While Basra and Baghdad experienced a slightly upward trend with about 0.65 day/year, aligning with the overall pattern observed in the country. In general speaking, the northern part of Iraq has more influenced with ETmax occurrences from the other part.

The increasing trends, particularly in Basra, Baghdad, Rutba, Kirkuk, and Shakhan, suggest these cities are experiencing a sharper rise in extreme temperature occurrences, possibly due to urbanization, lower vegetation cover, or regional climate dynamics. The areal mean, represented by a black dashed line, indicates an increasing trend (~0.66 day/year with R=0.35) in the number of extreme temperature events across Iraq over the studied period. This suggests a consistent rise in extreme Tmax occurrences during the analyzed period due to potential climate change impacts, whereas small changes in the mean global temperature can lead to disproportionate increases in the number of extreme events [36].

Table 5.
Values of the intercept and trend derived from Equation 4 for all studied provinces and Iraq.

Province	Intercept	Slope (or trend)	R
Basra	-1352.5	0.68	0.32
Shanafiya	394.9	-0.19	-0.09
Baghdad	-1219.5	0.61	0.35
Rutba	-2222.6	1.1	0.48
Kirkuk	-1976.3	0.99	0.35
Shakhan	-1548.5	0.78	0.31
Iraq	-1320.7	0.66	0.35

4. Conclusions

Based on the daily POWER/NASA data for maximum temperature for the last decade (2014-2023), this study has demonstrated the variations and their breakdown related to extreme values in six provinces spread across Iraq, covering various geographic and climatic features. It has experienced a significant increase in the frequency and intensity of extreme Tmax, particularly during the summer seasons. The main findings can be summarized as follows:

1. Basra experienced the highest seasonal mean Tmax with values of 20.7, 34.1, 46.3, and 36 °C across all seasons, compared with the other provinces.
2. In summer, Basra and Baghdad recorded the highest values of Tmax, exceeding 52 °C during this period.
3. High fluctuations in seasonal mean Tmax in Iraq were clear in the spring and autumn seasons, with an annual mean percentage of 24.6.
4. Using 95^{th} percentile, the relative frequencies of ETmax were high in Basra in spring and summer with a ratio of 5.2%. The same percentage was also found in Kirkuk and Shakhan. The most ETmax frequencies were occurred in September of autumn season.
5. The intensity of ETmax expressed by persisting of 1-day duration has a large number across all provinces, while more than successive 2 days of ETmax (warm spell) were also dominated in these provinces, but with less frequencies.
6. The upward trends in the number of ETmax exceedances in each province, and even Iraq, were noticeable, especially in Rutba and Kirkuk, while in Shanafiya the trend has slightly declined.

Through the analysis used in this paper, it reveals a noticeable increase in the frequency and intensity of extreme heat events. Basra and Baghdad exhibit the highest extreme Tmax threshold and more frequent extreme events compared to other provinces, reflecting their greater vulnerability due to their arid climate and low climate stability. Basra consistently records the highest Tmax values, influenced by its arid climate and proximity to desert regions. These events pose serious challenges to public health, agriculture, water resources, and energy demands, underscoring the urgent need for climate adaptation strategies and sustainable resource management. The findings in this paper highlight significant regional disparities in Iraq's exposure to extreme heat, with southern provinces facing heightened risks to public health, agriculture, and water resources. The increasing trend of extreme Tmax underscores the need for targeted adaptation measures, including heat action plans and sustainable resource management, to mitigate the impacts of rising temperatures across Iraq.

References

[1] J. Blunden and D. S. Arndt, "State of the climate in 2019," *Bulletin of the American Meteorological Society*, vol. 101, no. 8, pp. Si–S429, 2020. https://doi.org/10.1175/2020BAMSStateoftheClimate.1

[2] S. I. Seneviratne *et al.*, *Weather and climate extreme events in a changing climate. In V. Masson-Delmotte, 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, & B. Zhou (Eds.), Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. https://doi.org/10.1017/9781009157896.013, 2021.

[3] G. Ma, A. A. Hoffmann, and C. S. Ma, "Daily temperature extremes play an important role in predicting thermal effects," *Journal of Experimental Biology*, vol. 218, no. 14, pp. 2289–2296, 2015. https://doi.org/10.1242/jeb.122127

[4] Z. M. Hassan, M. H. Al-Jiboori, and H. M. Al-Abassi, "Heat waves and health impact on human in Baghdad," *Scientific Review Engineering and Environmental Sciences*, vol. 29, no. 2, pp. 212–222, 2020. https://doi.org/10.22630/PNIKS.2020.29.2.18

[5] R. Akhtar, *Extreme weather events and human health: International case studies*. Springer Nature. https://doi.org/10.1007/978-3-030-23773-8, 2020.

[6] M. H. Al-Jiboori, M. J. Abu-Shaeer, and A. S. Hassan, "Statistical forecast of daily maximum air temperature in arid areas at summertime," *Journal of Mathematical and Fundamental Sciences*, vol. 52, no. 3, pp. 353–365, 2020. https://doi.org/10.5614/j.math.fund.sci.2020.52.3.8

[7] Z. S. Mahdi, M. J. Abu-Al Shaeer, and M. H. Al-Jiboori, "Quantitative relationships among potential evapotranspiration, surface water, and vegetation in an urban area (Baghdad)," *Italian Journal of Agrometeorology*, vol. 29, no. 2, pp. 81–88, 2024. https://doi.org/10.13128/ijam-2024-029

[8] Z. S. Mahdi, Y. Q. Tawfeek, and M. H. Al-Jiboori, "Relationship between monthly surface water derived from Sentinel-2 imagery and meteorological data (precipitation and evaporation) at Baghdad, Iraq," *Water Practice & Technology*, vol. 19, no. 5, pp. 1794–1809, 2024. https://doi.org/10.2166/wpt.2024.098

[9] M. H. Ahmed, Z. S. Mahdi, M. H. Al-Jiboori, and D. A. Mahmood, "Interannual variations of normalized difference vegetation index and potential evapotranspiration and their relationship in the Baghdad area," *Open Agriculture*, vol. 9, pp. 1–12, 2024. https://doi.org/10.1515/opag-2022-0386

[10] X. Li, F. Hu, Y. Pu, M. H. Al-Jiboori, Z. Hu, and Z. Hong, "Identification of coherent structures of turbulence at the atmospheric surface layer," *Advances in Atmospheric Sciences*, vol. 19, no. 4, pp. 687–698, 2002. https://doi.org/10.1007/s00376-002-0008-x

[11] M. Kelly, "Accuweather. WUSA9," Retrieved: https://www.wusa9.com/article/weather/accuweather, 2020.

[12] J. S. A. Abd Al Rukabie, S. S. Naif, and M. H. Al-Jiboori, "Quantitative impact of monthly precipitation on urban vegetation, surface water, and potential evapotranspiration in Baghdad under wet and dry conditions," *Nature Environment and Pollution Technology*, vol. 23, no. 4, pp. 2383–2389, 2024. https://doi.org/10.46488/NEPT.2024.v23i04.041

[13] T. A. Dhamin, E. F. Khanjer, and F. K. Mashee, "The effect of temporal resolution of climatic factors on agricultural degradation in Southern Baghdad by applying remote sensing data," *Iraqi Journal of Science*, vol. 64, no. 2, pp. 994–1006, 2023.

[14] E. A. Ahmed and A. S. Hassan, "The impact of extreme air temperature on the characteristics of Iraq's weather," *Iraqi Journal of Science*, vol. 59, no. 2C, pp. 1139–1145, 2018. https://doi.org/10.24996/ijs.2018.59.2C.19

[15] Z. M. Hassan, M. H. Al-Jiboori, and H. M. Al-Abassi, "The effect of extreme heat waves on mortality rates in Baghdad during the period (2004–2018)," *Al-Mustansiriyah Journal of Science*, vol. 31, no. 2, pp. 15–23, 2020. https://doi.org/10.23851/mjs.v31i2.753

[16] A. F. Colombo, D. Etkin, and B. W. Karney, "Climate variability and the frequency of extreme temperature events for nine sites across Canada: Implications for power usage," *Journal of Climate*, vol. 12, no. 8, pp. 2490–2499, 1999. https://doi.org/10.1175/1520-0442(1999)012<2490:CVATFO>2.0.CO;2

[17] A. Sulikowska and A. Wypych, "Summer temperature extremes in Europe: How does the definition affect the results?," *Theoretical and Applied Climatology,* vol. 141, no. 1–2, pp. 19–30, 2020. https://doi.org/10.1007/s00704-020-03166-8
[18] S. K. Dash and A. Mamgain, "Changes in the frequency of different categories of temperature extremes in India," *Journal of Applied Meteorology and Climatology,* vol. 50, no. 9, pp. 1842–1858, 2011. https://doi.org/10.1175/2011JAMC2687.1
[19] M. M. Rahman *et al.*, "Are hotspots and frequencies of heat waves changing over time? Exploring causes of heat waves in a tropical country," *Plos One,* vol. 15, no. 9, p. e0300070, 2024. https://doi.org/10.1371/journal.pone.0300070
[20] M. Almazroui, "Changes in temperature trends and extremes over Saudi Arabia for the period 1978–2019," *Advances in Meteorology,* p. 8828421, 2020. https://doi.org/10.1155/2020/8828421
[21] A. F. Colombo, D. Etkin, and B. W. Karney, "Climate variability and the frequency of extreme temperature events for nine sites across Canada: Implications for power usage," *Journal of Climate,* vol. 12, no. 8, pp. 2490-2502, 1999.
[22] S. A. Muter, Y. K. Al-Timimi, and M. H. Al-Jiboori, "Analysis of temporal and spatial drought characteristics in Iraq using the standard precipitation index (SPI)," in *Proceedings of the 5th International Conference of Modern Technologies in Agricultural Sciences (5th-ICMTAS), 17–18 April 2024, Najaf, Iraq*, 2024.
[23] S. A. Muter, M. H. Al-Jiboori, and Y. K. Al-Timimi, "Assessment of spatial and temporal monthly rainfall trend over Iraq," *Baghdad Science Journal,* vol. 22, no. 3, pp. 910–922, 2025. https://doi.org/10.21123/bsj.2024.10367
[24] N. P. Thomas, A. B. Marquardt Collow, M. G. Bosilovich, and A. Dezfuli, "Effect of baseline period on quantification of climate extremes over the United States," *Geophysical Research Letters,* vol. 50, no. 17, p. e2023GL105204, 2023. https://doi.org/10.1029/2023GL105204
[25] D. S. Wilks, *Statistical methods in the atmospheric sciences*, 4th ed. Elsevier. https://doi.org/10.1016/B978-0-12-815823-4.00001-8, 2020.
[26] IPCC, *Managing the risks of extreme events and disasters to advance climate change adaptation: A special report of working groups I and II of the intergovernmental panel on climate change*. Cambridge University Press. https://doi.org/10.1017/CBO9781139177245, 2012.
[27] C. E. Brown, *Coefficient of variation. In Applied Multivariate Statistics in Geohydrology and Related Sciences* (Berlin, Heidelberg). Springer. https://doi.org/10.1007/978-3-642-72189-6_8, 1998.
[28] N. T. Ibraheem, M. H. Al-Jiboori, H. H. Hussain, T. O. Roomi, and A. Al-Salihi, *Study of intra-annual and annual air temperatures over Iraq for period (1970–2021). In IOP Conference Series: Earth and Environmental Science*. IOP Publishing. https://doi.org/10.1088/1755-1315/1223/1/012018, 2023.
[29] H. M. Al-Samarrai and M. H. Al-Jiboori, "Prediction of daily maximum air temperature for transitional seasons by statistical methods in Baghdad," *Iraqi Journal of Science,* vol. 64, no. 4, pp. 2085–2094, 2023.
[30] H. M. Al-Samarrai and M. H. Al-Jiboori, "Forecasting of daily maximum air temperature for winter and summer seasons for meteorological Baghdad station. In S. A. Albermany, A. J. Obaid, & O. A. Al-Owaedi (Eds.)," in *Proceedings of the 4th International Scientific Conference of Engineering Sciences and Advances Technologies. AIP Publishing. https://doi.org/10.1063/5.0095873*, 2022, vol. 2830, pp. 1–10.
[31] The World Bank Group, "Country summary. Climate Change Knowledge Portal," Retrieved: https://climateknowledgeportal.worldbank.org/country/iraq, 2021.
[32] B. I. Wahab, S. S. Naif, and M. H. Al-Jiboori, "Development of annual urban heat Island in Baghdad under climate change," *Journal of Environmental Engineering and Landscape Management,* vol. 30, no. 1, pp. 179–187, 2022. https://doi.org/10.3846/jeelm.2022.16374
[33] S. A. Haraj and M. H. Al-Jiboori, "Study of aerodynamic surface roughness for Baghdad City using signal-level measurements," *Baghdad Science Journal,* vol. 16, no. 1 Suppl, pp. 215–220, 2019. https://doi.org/10.21123/bsj.2019.16.1(Suppl.).0215
[34] World Meteorological Organization (WMO), *Guidelines on the definition and characterization of extreme weather and climate events (No. 1310)*. Geneva, Switzerland: World Meteorological Organization, 2023.
[35] A. Wypych, A. Sulikowska, Z. Ustrnul, and D. Czekierda, "Temporal variability of summer temperature extremes in Poland," *Atmosphere,* vol. 8, no. 12, p. 258, 2017. https://doi.org/10.3390/atmos8120258
[36] Intergovernmental Panel on Climate Change (IPCC), *Global warming of 1.5 °C: IPCC special report on impacts of global warming of 1.5°C above pre-industrial levels in the context of strengthening the global response to climate change, sustainable development, and efforts to eradicate poverty*. Cambridge: Cambridge University Press, 2022.