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Evaluation of Summer Season Characteristics and Its Changes in Iraq over the Period (1960-2021)

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Abstract:

Anthropogenic climate change has essentially affected the characteristics of the thermal seasons, hence the overall ecosystems, and human health. The characteristics of the thermal seasons in Iraq, and how they change are still unclear. This research has been conducted to: (1) evaluate the spatial characteristics of summer season in Iraq over the period (1960-2021). (2) Estimating changes in the length and timing (onset and end) of summer in Iraq using the Mann-Kendall test (MK) and Sen's slope estimator. The findings indicated that there are significant spatial differences in the average length of the summer season in Iraq. The difference reaching more than 30 days between northern and southern Iraq, It is longer in the south. Results of trend analysis showed that summer season length significantly increases by 3.33 and 6.67 days/decade respectively. Our results reveal that, all over Iraq, the onset of thermal summer season occurs earlier by more than 17 days during (1960-2021). The biggest statistically significant changes in summer advancing were observed in northern and western Iraq. However, the results revealed that the only western Iraq has been recorded advancing at the end of the summer, while the end of the summer at all other parts occurred later.

Keywords: climate change, Iraq, Mann-Kendall test, summer season, trend analysis.

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1. Introduction

Global warming is occurring very quickly, beyond all expectations. According to the 6th Assessment Report (AR6) issued by the Intergovernmental Panel on Climate Change (IPCC), the average global mean temperature during the first two decades of the 21st century (2000 - 2020) has approximately increased to 0.99 °C (0.84 to 1.10 °C) (IPCC, 2021). Furthermore, the same report has pointed out that the last four decades were the warmest in a row of any previous decade since 1850. This increase in temperatures and the accompanying increase in the intensity and frequency of extreme events were attributed to the increase in human activity (Seneviratne et al., 2021). Generally, many studies have confirmed that the Middle East is one of the most vulnerable regions in the world to climate change (e.g., Cramer et al., 2018; Zittis et al., 2022; Price et al., 2021). It has also been projected to be exposed to an increase in heat wave amplitudes of 6–10 °C (Zittis et al., 2016). Additianlly, Zittis et al. (2021) have suggested that, under the high greenhouse gas emission pathway, “severe,” “extreme,” and “very extreme” heat wave events are likely to become very common by 2050-2070. Under these catastrophic scenarios, the effects associated with the extreme rise in temperature will increase even more, especially in the summer. This situation leads to unfortunate impacts on the human being and his health globally and in the Middle East region in particular. Among these effects are also; increased rates of disease and high mortality rates (Ahmadalipour and Moradkhani 2018). The comprehensive list of socio-economic sectors affected by mean temperature rises includes water resource, energy demand, agriculture, labor productivity, ecosystems, tourism, etc. (Hochman et al., 2022; Naqi et al., 2021; Pal and Eltahir, 2016; Muslih, 2022; Casanueva et al., 2020; Siebert and Ewert, 2014). Moreover, the investigated temperature trends in Iraq showed significant upward trends at a rate two to seven times faster than the global mean temperature rise. Furthermore, the strongest warming trends in Iraq were observed in the summer months compared to the winter months (Muslih and Błażejczyk 2017; Salman et al., 2017; Al- Budeiri, 2021). What makes the situation worse is

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that, Iraq is considered one of the most vulnerable counties in Middle East region to climate change and the least able to cope with its effects as a result of limitations in competence and a deficiency of institutions and systems capable of adequately addressing and mitigating the effects of climate change (Berghof Foundation & PPO, 2023). Consequently, the importance and desire of researchers to identify thermal seasons, and verifying its changes under global warming scenarios, and then monitorvarious climate change impacts (Allen and Sheridan, 2016; Wang et al., 2021; Czernecki and Mietus., 2017; Rahman et al., 2020) . The summer season was among the most important of the year, and received many research and investigation worldwide due to its impact (season length and its beginning and end) on human life and activity, agricultural production and the extent of energy consumption, especially in very hot areas such as the Middle East. Numerous studies have found clear trends of change in the length of the summer in different regions of the world (e.g. Park et al., 2018; Park et al., 2022; Lin and Wang, 2022; Peña-Ortiz et al., 2015). However, studies in neighboring countries indicate an increase in temperature related extremes in the region.

Several studies conducted in neighboring countries of Iraq, which concerned dividing the thermal seasons of the year, indicated that the summer season was the longest season compared to other one. These studies also pointed out that there was a noticeable changes in the number of seasons, with a significant increase in the summer’s days (e.g. Almazroui et al., 2020; Ajjur, and Al-Ghamdi, 2021; Aksu, 2022; Doostan and Alijani, 2022; Alghamdi, 2024).

Despite all these importance, risks, and challenges, studies related to the definition and exploration of the changes in the beginning, end and length of seasons have been very limited for Iraq.

Thus far, very little research has been significantly conducted to evaluate the length of the seasons and their variations. AL- Goran (2019) assessed the characteristics of the seasons (thermal and precipitation) at seven climatic stations over Iraq for the period 1956-2016. His analysis is based on the following equation: The winter and summer seasons are determined by taking the average temperature of

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the coldest (warmest) months and dividing it by two. The months in between are known as the transitional seasons. The study reported that the characteristics of the seasons are not stable, as they tend to change. He also pointed out that there was not a consistent pattern for every station; some of them had the greater increase rate in the number of days in the winter season, as is the case in Baghdad, while others, like Sulaimaniya station, had the largest increase in the spring season, and others in which the summer season was the most obvious season for the increase, as in the Rutba station in western Iraq. Abdulkareemet et al (2020) analyzed the Seasonal change in south of Iraq during the period (1981-2017) based on the metrological definition using the average monthly temperatures. They found a clear change in temperature for all seasons, including summer. Kadhim (1998) analyzed the equality of the seasons of the year in Iraq during the period (1963-1993). The study reported that the length of the climatic seasons varies, with summer extending for months in certain stations and seven months in others. The remaining three seasons consist of three months for winter and three months for the two transitional seasons.

Therefore, the aims of this study are; (1) identify the spatial and temporal characteristics of the thermal summer season (i.e., length, onset, and end) through the selected temperature index and average daily temperature. (2) Revealing the long-term changes in the timings and lengths of the thermal summer season in Iraq from 1960 to 2021 using Mann-Kendall test and Sen's slope estimator. It is expected that the outcome of this quantitative study can help researchers study the consequences that summer timing and length changes in Iraq have on human health and comfort, water resources management, and agriculture.

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1. Study Area, Dataset, and Methods

1.1.Study Area

Iraq, located in the south - west of Asia (29˚ 5´ to 37˚ 22´ N and 38˚ 45´ to 48˚ 45´ E), comprises a geographical area of 435 052 km2 (Fig. 1). The total population is around 43,324 million inhabitants (Republic of Iraq). It has an elevation varying from sea level on the coast of the Arabian Gulf to about 3595 m.a.s.l in the northeast part (Zagros Mountains). According to the Köppen-Geiger climate classification a subtropical desert climate (BWh) dominates much of Iraq's territory more than 75.9% of the total Iraqi area, and a semi-arid climate (Bsh) is located in the upland region. The small northern part lies under Mediterranean climate (temperate with a dry summer "Csa") (BWh) (Muslih, 2014). However, the spatial diversity of climate is remarkable, this variety of climate depend on the topographical features, distance from large water bodies, and synoptic patterns affecting the climate during the cold and dry seasons. Annual average temperatures range between 26.4°C (south of Iraq) and less than 20.7 ^{o}C (in north part) (Muslih & Abbas, 2024). Precipitation generally increases in the north and northeast where the annual average rainfall value exceeds 700 mm, while it decreases to less than 100 mm in the far southwest of Iraq. During the study period, 66% of the annual precipitation occurs from December to March.

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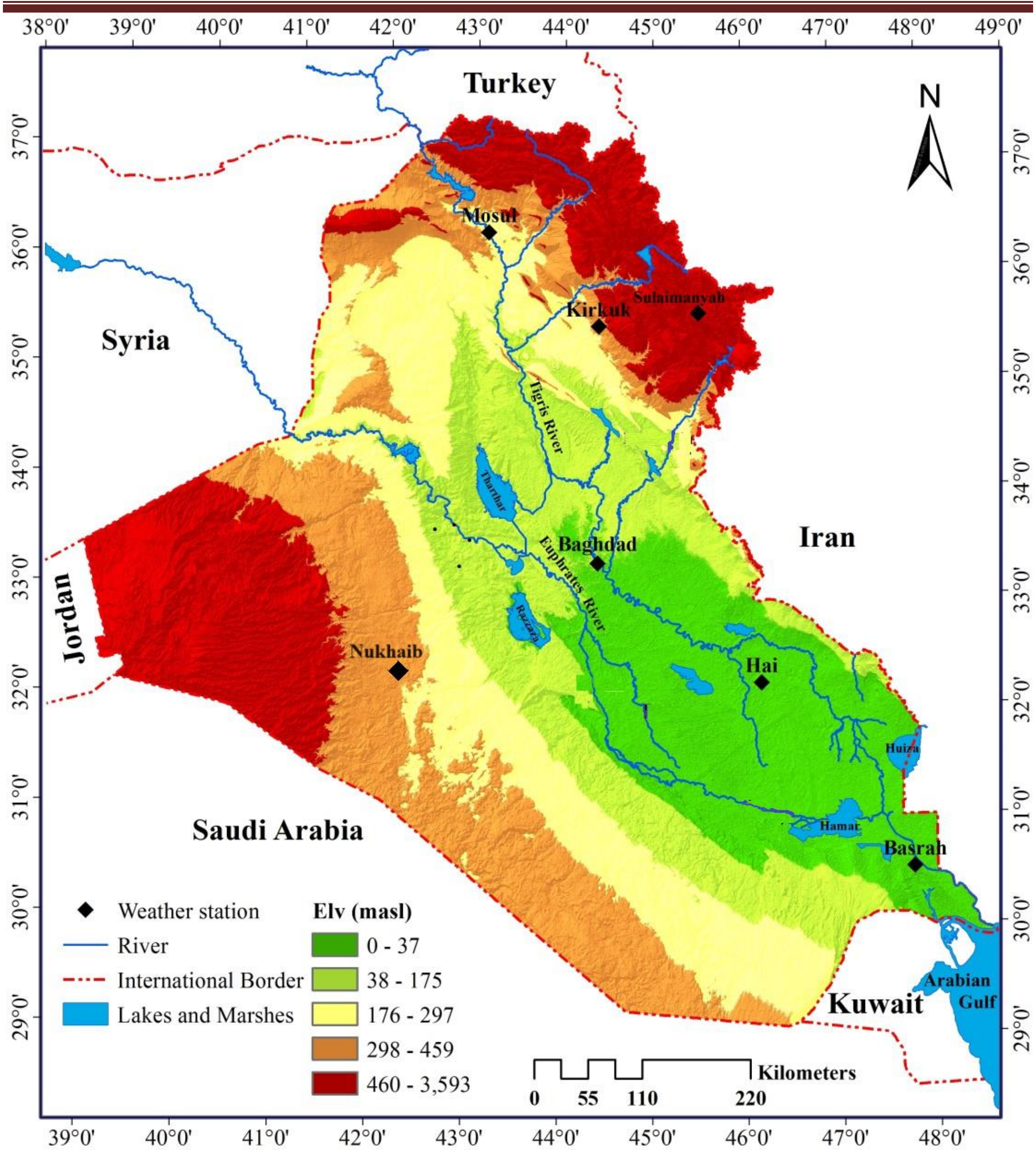

Fig.1 Topographic map of Iraq with spatial distribution of meteorological stations used in the paper.

2.2. Dataset

Daily mean temperature data recorded at seven stations representing different parts of Iraq were obtained from the Iraqi Meteorological Organization and Seismology (IMOS). The location of metrological stations in the study area is shown in fig.1, while details of the selected stations are given in table. 1. For all stations except Sulaimaniya and Nukhaib stations, the data covers a period of 62 years from 1960 to 2021. For two stations (Sulaimaniya and Nukhaib) the period of data collection spans from 1985 to 2021(37 years).

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Following some previous studies (e.g. Aksu, 2022), the missing data were replaced with a mean value of the prior and subsequent 10 days.

Table 1 Details of the selected meteorological stations used in this

Station	Latitude (N)	Longitude (E)	Altitude (m a.s.l)
Mosul	36º19'	43º09'	222.6
Sulaimaniya	35º32'	45º27'	843
Kirkuk	35º28'	44º24'	330.8
Baghdad	33º29'	44º24'	34.1
Hai	32º10'	46º03'	17
Nukhaib	32º02'	42º15'	305
Basrah	30º34'	47º47'	2.4

The spatial distribution of the meteorological stations indicated that the number of stations is irregular to provide a complete description of seasonal variations and changes in Iraq. Taking into account that Iraq has about 40 stations in operation plus 9 stations belonging to the General Department of Meteorology of the Kurdistan region. However, long term daily temperature records with acceptable data quality are available only at seven stations. To ensure data quality, the homogeneity analysis of each time series was performed using the Standard Normal Homogeneity Test (SNHT) that was developed and applied by Alexandersson (1986). Data homogeneity is evaluated using XLSTAT statistical software. These quality control procedures resulted the analysis was performed based on only seven out of 49 stations. Therefore, the selected stations ensured complete, homogeneous, and reliable datasets covering the study period.

2.3. Methods

Definition of the summer

Defining thermal seasons was the subject of many purely theoretical discussions regarding methods of defining the start and end of the seasons. Following the method of some previous studies (e.g. Christidis et al., 2007; Park et al, 2018; Wang et al, 2021), we defined the summer season based on a relative local temperature. Hence, the onset of summer season was defined as the calendar date when the temperature exceeded the 75th percentile of daily temperature averaged over 1960-2021 and the summer ended when the

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temperature was decreases below the 75th percentile "the warmest quarters of the year". The number of days extending from summer onset to summer end is defined summer full length.

The third-degree polynomial fitting was employed to simply smooth the daily mean temperature data and decrease the effect of daily temperature variations. as shown in fig. 2.

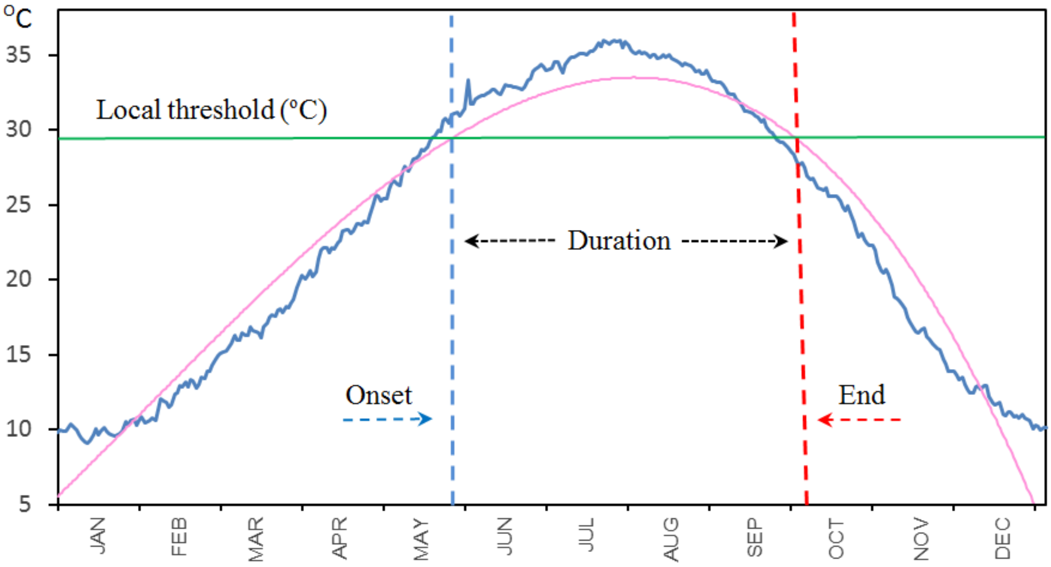

Fig. 2 Schematic illustrating the definitions of the summer season indices (onset, end, and duration) in Baghdad station. The horizontal line coincides to the local temperature threshold (75th percentile).

Trend analysis using the Mann-Kendall test (M-K)

The MK test is a non-parametric test designed to determine a monotonic trend when calculating a set of time series. It was originally developed by Mann (1945) and the distribution of the test statistics was later derived by Kendall (1975). The test is the highest power test that measures non-parametric linear trends (Önöz and Bayazit 2003). This test compared the null hypothesis H0 with the alternative hypothesis HA, where H0 means that the time series values are independent and uniformly and randomly distributed, while HA means that the values are monotonic and tend to increase or decrease.

The Mann-Kendall test statistic (S) is calculated for time series using the following equations (Gilbert 1987; Önöz and Bayazit 2003):

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

where; X = data value; k and j = Counters; n =Number of data; Sgn = An indicator function that takes on the values +1, 0, or -1 according to the sign of xj - x_k:

$$sgn(x_j - x_k) = \begin{cases} +1 \; if \; x_j - x_k > 0 \\ 0 \;\; if \; x_j - x_k = 0 \\ -1 \; if \; x_j - x_k < 0 \end{cases} \quad (2)$$

For n ≥ 10, the statistic S is approximately normally distributed with the variance (S) which computed as:

$$VAR(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)}{18} \quad (3)$$

Where: m is the number of tied groups and ti is the size of the i^{th} tied group:

n = Number of tied, t_p = Number of data in the p^{th} group.

Then, S and VAR (S) are used in order to compute the standard normal variable Z using following equation;

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} \quad if \quad S > 0 \\ 0 \qquad\quad if \quad S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} \quad if \quad S < 0 \end{cases} \quad (4)$$

A positive (negative) value of Z indicates an upward (downward) trend. This test verified the null hypothesis H0 against alternative hypothesis HA, where H0 means time series values are independent and identically distributed randomly while the HA means that there is a monotonous in values and increase or decrease in the trend.

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Sen's median slope estimator

It is a nonparametric estimate used to quantify the magnitude of the trend in time series when H_0 is accepted (Sen, 1968). According the Sen's method, the equations estimator the median (Q_{med}) of N value, which is sorted from smallest to largest, and it is calculated as:

$$Q_{med} = \begin{cases} Q_{[(N+1)/2]}, & if\ N\ is\ odd \\ \frac{1}{2}\ Q_{[N/2]} + Q_{[(N+2)/2]} & if\ N\ is\ even \end{cases}$$

The slope is obtained by the Theil-Sen test when the Mann-Kendall test is used for statistical significance.

3. RESULTS

3.1. Spatial characteristics of the summer season length

The influence of geographical location, elevation, and air mass types over Iraq results in clearly seen variations in the number of thermal summer season days. According to the daily mean averages for the period from 1960 to 2021, the thermal season analysis found the day's number of the summer have gone up with decreasing latitude and altitude. So, they ranged from about 113 days in Sulaimaniya and Mosul stations in north of Iraq at an elevation of 843 m a.s.l and 222.6 m a.s.l, respectively, to about 146 days in the southernmost tip of Iraq at an elevation of 2.4 m a.s.l (Fig.3a). The only exception to the previous rule is Kirkuk station. Despite the fact that it is located in the north of Iraq, near the Mosul station and very close to the Sulaimaniya station, the number of summer season days was similar to those found in the far south. Many previous studies (e.g Muslih and Błażejczyk, 2017) have pointed out such differences in temperature anomalies. They attributed these differences to local factors represented by its topographical location. The above result shows the huge complexity of determining thermal seasons, even within the same region, and indicates the most likely directions of differences (positive and negative) in the number of seasonal days in certain regions, let alone different regions.

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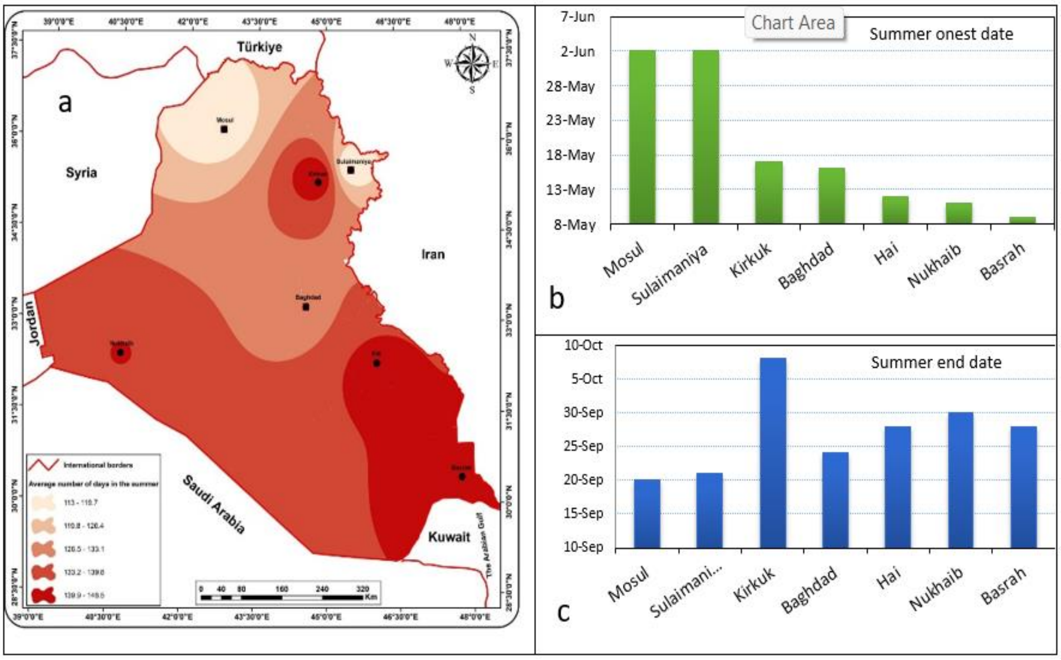

Fig.3 Long-term spatial distribution of; average total days number of the thermal summer season (a), summer onset date (b), and summer end date (c), for the period 1960-2021.

Regarding the summer occurrence date, the early summer starters vary from one part of Iraq to another (Fig.3b). The earliest onset of summer was observed in the south and west of Iraq, where the summer starts in the first half of May. After more than two weeks, the season started in the north of Iraq. The average summer end date is almost similar across the country, and it falls almost between 20 to 30 September, except at Kirkuk station, where the end of the thermal summer season occurred on 8^{th} October (Fig. 3c).

3.2. Observed changes in summer length

To understand the spatial distributions of the trends rate in the thermal summer season in Iraq based on relative threshold, Sen's slope and MK method were applied for each station included in this study; all the results are shown in fig. 4. The notation Z value in the figure represents the amount of the MK, while the magnitude of the slope of the Q_{med} is represented using Sen's slope estimator. As for the number of stars corresponding to Sig. means; two and three stars indicate the significance of change evaluated by MK test, at 99% and 99.99% levels of confidence, respectively.

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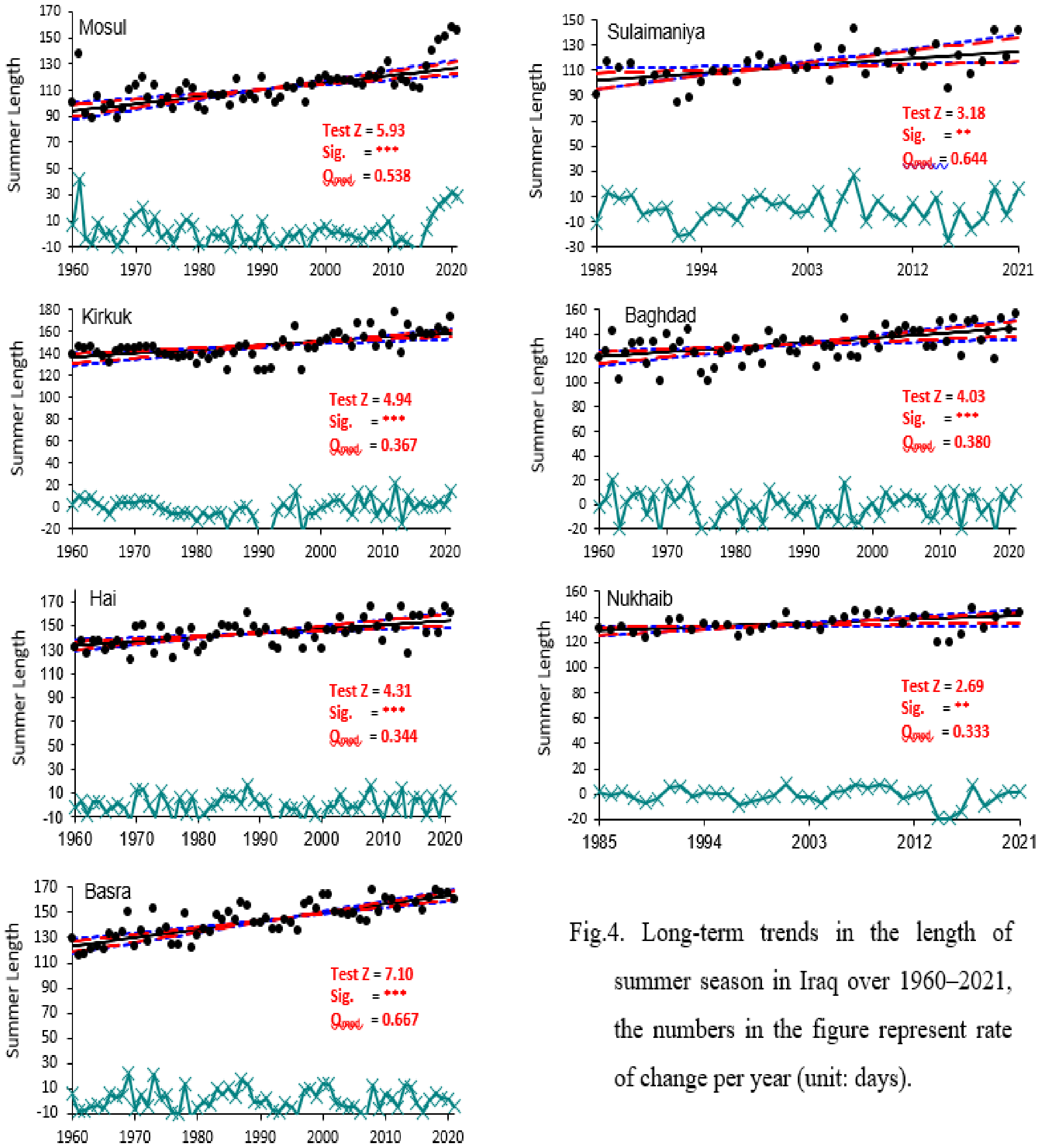

Fig.4. Long-term trends in the length of summer season in Iraq over 1960–2021, the numbers in the figure represent rate of change per year (unit: days).

Fig. 4 shows that there was a significant increase in the summer length over all parts of Iraq during the period (1960–2021) at a ≥ 99% level of confidence. The rate of summer length increase ranged from 0.333 days/year to 0.667 days/year. The maximum increasing rate was observed in Basra station (0.667 days/year), located on the Arabian Gulf in the southernmost point of Iraq. Sulaymaniyah station, located in the far north-east of Iraq, within the mountainous region, registered a high, increasing rate (0.644 days/year). Mosul station, located in northern Iraq within the undulating region, recorded a rate of change of 0.538 days per year. The minimum increasing rate of summer length was observed in Nukhaib station by 0.333 days per year, located within the western desert of Iraq. Followed by Hai and Kirkuk

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stations that are located in the eastern part of Iraq by 0.344 day/year and 0.367 day/year, respectively.

3.3. Observed changes in thermal summer timing

Besides the spatial variation and long-term change of the thermal summer length represented by the number of days, fig. 3b and c display the time series of the summer onset and end for selected stations in Iraq. Fig. 3b shows that there are spatial differences in the summer onset over different parts of Iraq during the period (1960-2021). The differences can last over twenty days between the north and south of Iraq. According to the relative temperature thrashed, thermal summer starts early in southern Iraq (Basra station) in the first ten days of May (at 9-May). On the other hand, the date of the onset of the thermal summer in the high-altitude northern region of Iraq (Sulaymaniyah and Mosul stations) is more than twenty days later than in southern Iraq, which is expected to be at the end of May or the beginning of June.

Fig. 5 shows that the time series of thermal summer onset significantly decreased in all stations including in this study, which means summer has started early in all parts of Iraq with a different amount of changing rate. All over Iraq, the greatest changes in the onset of thermal summer with a value of change greater than four days per decade (-0.45 days/year) belong to Nukhaib station, located in the western desert of Iraq. Moreover, the fig 5 shows that the value of R_2 in Nukhaib station was 0.39, meaning that time explained approximately 39% of the change in summer onset in this station. MK test detected very similar result in northwest of Iraq (Mosul station) with a significant change in time of summer onset at a rate of – 0.42 days/year, and R about 0.60. The aforementioned result means that the thermal summer in northern and western Iraq advanced by approximately 26 days, according to the relative threshold used in this study. It was noted that at the beginning of the time series, thermal summer onset was in most regions in mid-June, while the last years were observed in the first ten days of May. Moreover, changes in onset of thermal summer in other parts of Iraq were statistically significant. In general, the start date of summer came earlier between

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ten and twenty days in central and southern Iraq. The minimum decreasing rate of slope linear trend in onset of summer was detected in in Baghdad station "central Iraq" by a rate -0.17 days/year, than Hai station by a rate – 0.20 days/year.

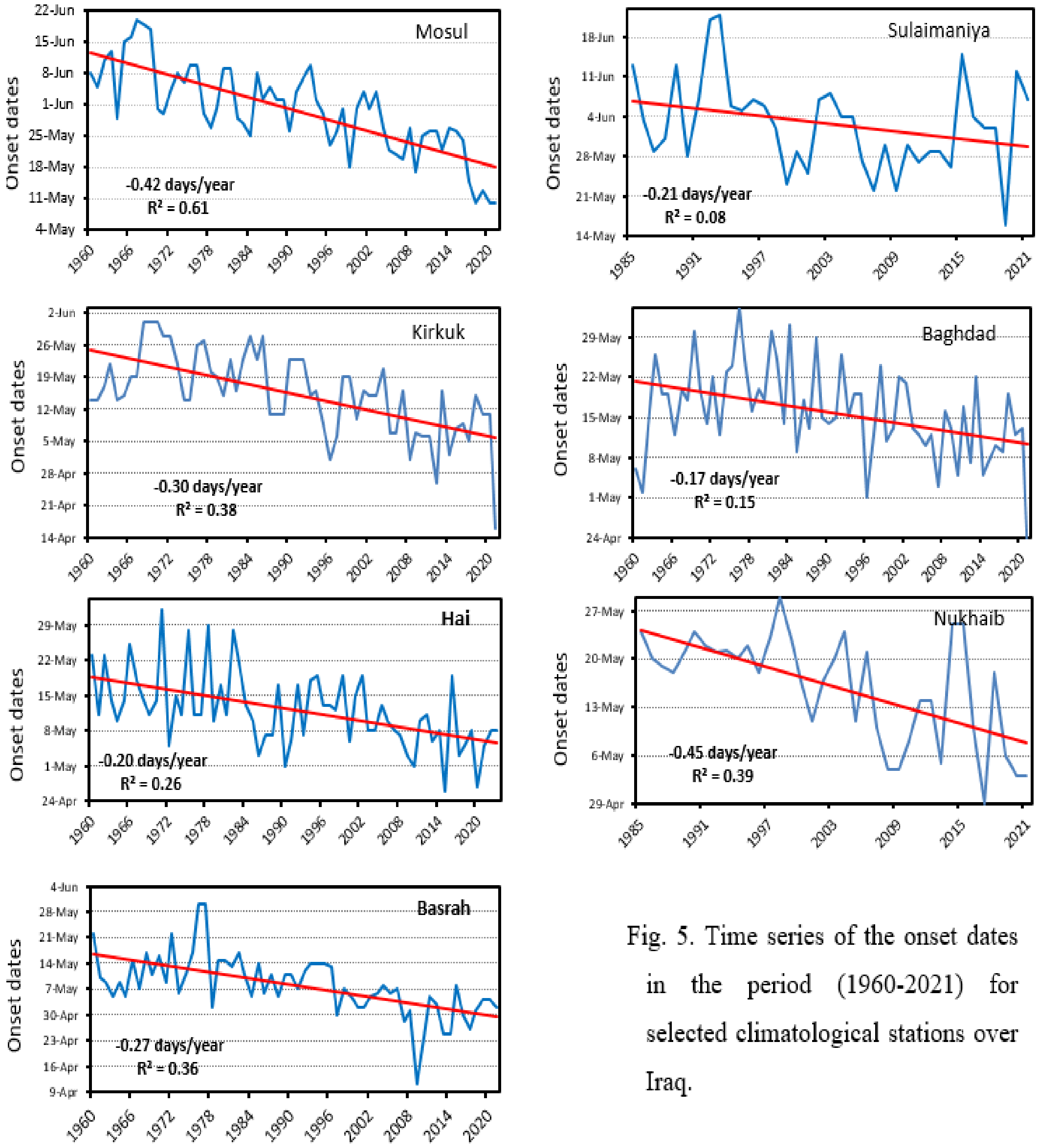

Fig. 5. Time series of the onset dates in the period (1960-2021) for selected climatological stations over Iraq.

Otherwise, the extended thermal summer duration was not only affected by the earlier onset; however, it was also affected by the delayed ending according to the relative temperature threshold that was determined and shown in the methods section. The end dates of summer have exhibited a significant increase (Fig.6). All over Iraq except Nukhaib station experienced a statistical increase in the end of the summer date, which means the thermal summer end was delayed in most part of Iraq.

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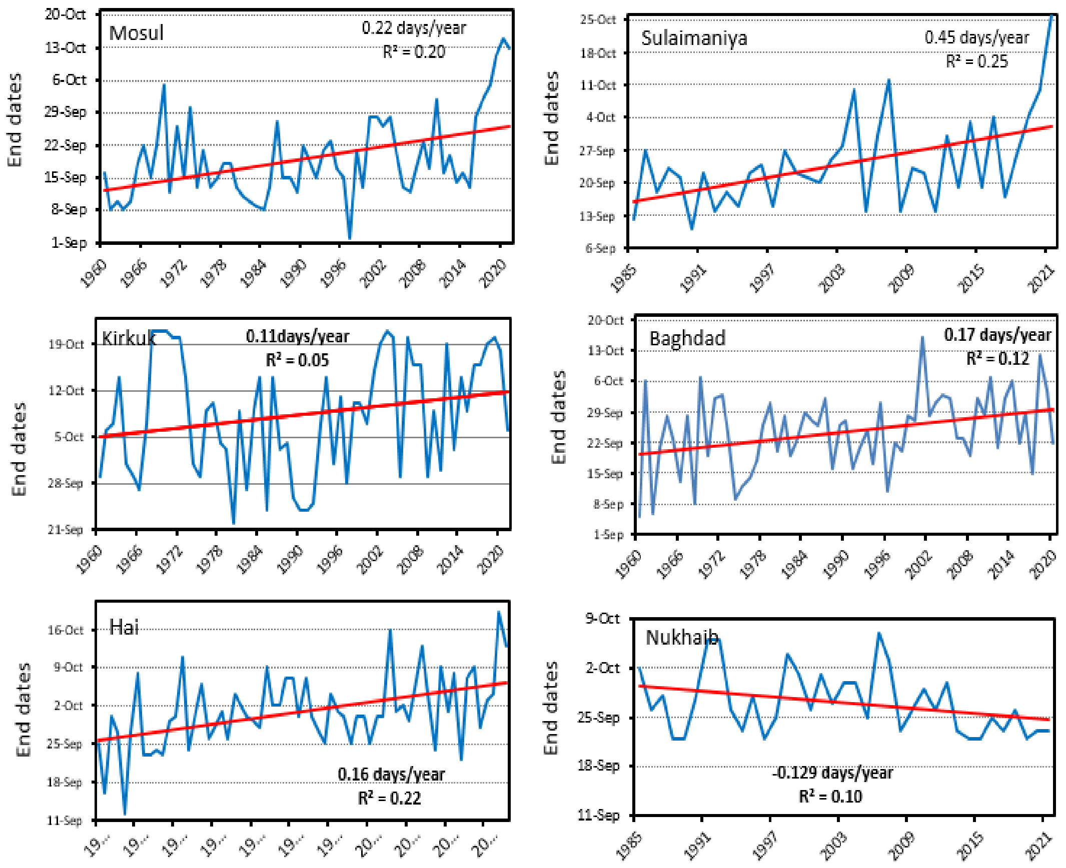

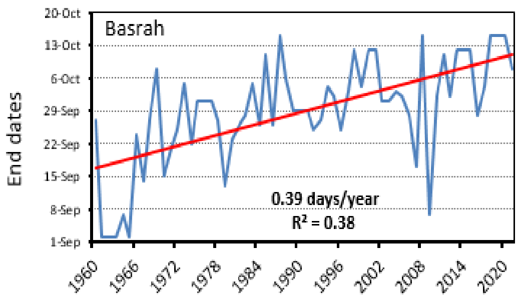

Fig. 6. Time series of the end dates in the period (1960-2021) for selected climatological stations over Iraq.

The biggest changes at the end of summer, with a change of more than 17 days during the period 1985- 2021, by a rate 0.45 days/ year belonged to Sulaymaniyah station, located in the northeast of Iraq. Moreover, changes in Basra station, located on southern coasts of Iraq, were statistically significant at a rate of 0.39 days/year. The thermal summer ended in this station at the beginning of September in the early 1960s, but now it ends at the beginning of October, meaning that the end of the summer season in this station has been delayed by about a full month. Likewise, a statistical significant shift of thermal summer end was also recorded in Mosul, Kirkuk, Baghdad, and Hai stations at rates of (0.22, 0.11, 0.17 and 0.16 days/year) respectively. Nukhaib station, located in the western desert of Iraq, had a negative trend and observed earlier summer end by a rate of -0.10 days/year; however, it was a statistically insignificant change.

4. Discussion

Literature discussing the changes in thermal season characteristics in the Iraq is limited. This makes comparing the results of this study with previous one very difficult, forcing us to resort to comparisons with studies conducted in neighboring countries or in other regions of the Northern Hemisphere. The results show the obvious difference in the number of the thermal summer's days spatially; the differences can be over 33 days between the north and south of Iraq. The number of summer days was found to have increased with decreasing latitude and/or altitude, with a statistically significant correlation as shown in Fig. 7. This result is consistent with findings from previous studies. AL- Goran (2019) also found that the minimum summer days were observed in northern Iraq. Moreover, this result is largely in line with the results of previous studies, which indicated that the rate of increase in temperatures in southern Iraq is greater than in northern part (Muslih and Błażejczyk, 2017; Salman et al 2017; Al- Budeiri 2021). Kadhim (1998) showed that the summer season in Iraq lasts almost half the year (about six months) without analyzing changes in the number of days.

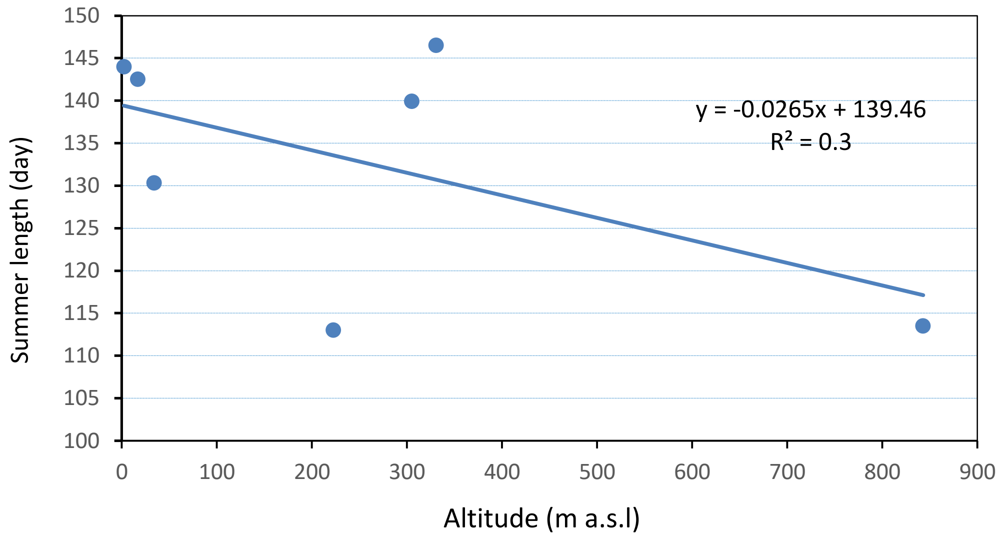

Fig. 7 Relationship between elevation and summer length during the period (1960-2021) over the Iraq.

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The obtained results of analysis of long-term time series trends that extended over the period (1960-2021) using the MK test and Sen's slope estimator suggest that the summer days has increased in all parts of Iraq. The total rates of increase in the number of summer days ranged from 3.33 to 6.67 days/decade, with statistical significant at a probability level of ≥ 99 %. Our results are close to the results of some previous studies. Abdulkareemet et al. (2020) found that the change in the average temperature in the summer season in central and southern Iraq was evident. They also suggested that the summer months average temperatures increased by more than 1°C during the period 2001-2017. Furthermore, other studies clearly indicated that a 1°C increase in global average temperature during 1961–2014 corresponded to a 15-day longer summer in the Northern Hemisphere (Lin and Wang 2022). However, AL- Goran (2019) found different results from this study about the rate of change in summer season duration during the period (1956-2016). He suggested that the increased in the number of summer days includes only central and western parts of Iraq, whereas the number of summer days in southern and northern Iraq decreased statistically significant. This difference is probably due to a number of reasons; AL-Goran adopted the analysis of the seasons days on the basis of the water year, while this study was conducted based on the calendar year. The second is the nature of the criterion originally used by Goran to determine the seasons climatically (presented in the introduction section). Additionally, the indicator used by Al-Goran to identify the climatological seasons in Iraq (presented in detail in the literature review section). Third, he used linear regression method for the valuation of change, while this study used MK and sen's slope methods. Obtained results supported the findings of extra prolongation of summer's duration in neighbouring countries of Iraq, like the Arabian Peninsula for the period 1950-2019 (Ajjur and Al-Ghamdi, 2021); Iran for the period 1959-2018 (Doostan and Alijani, 2022); and Turkey during the period 1965-2020 (Aksu, 2022).

The results of the present study also obviously indicated that the increasing rate of summer duration in Iraq is very closely associated with the estimated rate of increase in the Northern Hemisphere, or even greater. Lin and Wang (2022) estimated that the length of summer in the Northern Hemisphere has increased by 3.9 days/decade over the period 1961-2014. They also reported a significant change in the summer season in line with global warming. The upward trend in the number of summer days was also confirmed in Europe at a rate of 2.4 days/decade during the period 1950-2012 (Peña-Ortiz et al., 2015).

The change in the timings of the thermal summer in Iraq (onset and end) was also obvious. The obtained results suggest that over all of Iraq, thermal summer onset advanced by 2.8 days/decade “as average”, where it ranged from1.7 days/decade to 4.5 days/decade over the period 1960-2021. On the other hand, our outcomes demonstrate that the end date of thermal summer is delayed in all station including in this study, except Nukhaib station in the western desert of Iraq. Overall of Iraq, the rate of summer end delayed by 2.3 days/decade. The changes in the timing of the summer season (onset and end) were confirmed in several studies conducted in neighbouring countries of Iraq. Alghamdi (2024) has found that summer prolong in the Arabian Peninsula during the period 1985-2022, as thermal summer days increased at the expense of advanced at the spring end and delayed autumn onset. Doostan and Alijani (2022) estimated a statistically significant increase in summer days in Iran based on trend analysis of the beginning and end of the four seasons. They reported that the summer timing shift is properly due to Hadley's poleward expansion of 2 to 4 degrees since 1979 during the spring and summer (Doostan and Alijani, 2022; Hu and Fu, 2007).

We believe that the significant increase in temperatures during the months of the transitional seasons (March and April) and (September, and October) played a key role in advancing the onset of summer and delaying its end in Iraq. Many recent studies have documented this temperature increase during the spring and autumn seasons, either in monthly averages (Muslih and Błażejczyk 2017;

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Robaa and Al-Barazanji, 2015; Al- Budeiri 2021), or at the level of daily extremes in temperatures (Salman et al, 2017).

5. Conclusions

The present study used the daily mean temperature of seven climatic stations covering Iraq for 62 years, from 1962 to 2021. In order to; first, define summer, which is defined based on a relative threshold, such as the period when the daily mean temperature is above 75% (1961–2021). Second, estimate the long-term trends in the timings and lengths of the thermal summer season in Iraq using non-parametric MK and Sen's median slope estimator.

The results of this study show a clear variation in summer duration according to decreasing latitude and altitude. The highest number of summer days based on the daily mean temperature for the period from 1960 to 2021 was observed in the far south of Iraq for 146 days. On the other hand, the shortest summer was represented in the mountainous and undulating region of northern Iraq by only 113 days. The analysis presented in this study shows that summer timing also differed greatly between the north and south of Iraq. Our results showed that summer in northern Iraq starts more than two weeks later than in the south. Summer's end at all stations “except the Kirkuk station” occurred in the last ten days of September.

The results showed that the number of summer days trend increased over all parts of Iraq with a statistical significance of ≥ 99%. However, the increasing rates did not the same level over all parts of Iraq, while the maximum yearly rate of increase was found in northern and southern Iraq. Overall, summer length in Iraq is found to increase much faster compared to regional and global average.

The analysis presented in this study shows that the summer in all parts of Iraq tends to start earlier. Additionally, summer had advanced in all parts of Iraq at a rate of 2.8 days/decade. In contrast, the end date of summer was delayed by a rate 2.3 days/decade.

Generally, our results indicate that the length of the summer and its timings (onset and end) are acceptably consistent with the regional and global trends discussed. However, we have found a large variation

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in those trends between the different parts of Iraq; much of this can be attributed to both local and regional differences.

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