تغير المناخ وتحليل اتجاهات درجة الحرارة: دراسة حالة منطقة السليمانية، العراق

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Climate Change and Trend Analysis of Temperature: The Case of Sulaymaniah Region, Iraq

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Keywords : Climate Change, Temperature Anomaly Index (TAI), Köppen - Trewartha climate classification Index (K-T CCI), As Sulaymaniyah.

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الملخص:

تهدف الدراسة إلى توضيح تغير المناخ وتحليل اتجاهات درجات الحرارة: حالة منطقة السليمانية، العراق. ولهذا الغرض استخدمت الدراسة المنهج الوصفي التحليلي باستخدام بيانات درجات الحرارة من (1973–2021). بالإضافة إلى ذلك استفاد الباحث من عدة اختبارات إحصائية منها (المتوسط المتحرك لمدة (3، 5، 7 سنوات)، متوسط الانحراف، مؤشر الشذوذ الحراري (التغيرات الإيجابية والسلبية)، ومؤشر تصنيف كوبن – تريوارثا للمناخ باستخدام برنامج SPSS. وجدت النتائج أنه على مدى الخمسين عامًا الماضية، ارتفع متوسط درجة الحرارة السنوية بشكل مطرد، وحدثت السنوات الأكثر دفئًا على التوالي في السنوات الأخيرة (2020، 2021، و2022)، كما يشير تصنيف كوبن–تريفارثا واختبار STI إلى المتوسط السنوي ترتفع درجات الحرارة موسمياً، حيث احتلت المراكز من الأول إلى الرابع، حيث وجدت هذه الدراسة أن الاتجاهات الخطية لمتوسط درجات الحرارة في الشتاء (0.4)، والصيف (0.31)، والربيع

(0.3)، والخريف (0.14) قد ارتفعت بشكل طفيف ، على مدى عقود، انخفضت الأيام الأكثر برودة (0 وما دون) في فقدان البرد وتحولت من شديدة البرودة إلى معتدلة إلى منخفضة البرودة، خاصة بعد عام 2009.

كما ارتفعت درجات الحرارة التي وصلت إلى (44 درجة مئوية أو أكثر) بين عامي 1992 و2023. كما ارتفع متوسط درجة الحرارة القصوى السنوية من حار إلى حار جداً. وارتفعت أدنى متوسط لدرجة الحرارة بشكل مطرد وتحولت من البرودة إلى الحرارة الشديدة. وكان التغير المناخي عند مستوى مرتفع وخطير في منطقة الدراسة بشكل يصعب التنبؤ به. ومن ثم، تقترح هذه الدراسة إجراء المزيد من البحوث حول تغير المناخ وآثاره السلبية لتسريع نهج التكيف والتخفيف.

ABSTRACT:

The study aims to illustrate Climate change and trend analysis of temperature: the case of Sulaymaniah, Iraq. For this purpose, the study used a descriptive-analytic method using Temperature data from (1973-2021). In addition, the researcher benefited from several statistical tests, including (moving mean for (3, 5, and 7 years), mean deviation, temperature Anomaly index (positive and negative variabilities), and Köppen - Trewartha climate classification Index using the SPSS. Results found that Over the past 50 years, the annual average temperature has steadily increased, and the warmest years occurred in succession in the last years (2020, 2021, and 2022). Also, The Köppen-Trewartha classification and STI test indicate annual average temperature increases. Seasonally, with the first to fourth places, this study found that the linear trends of the average temperature in winter (0.4), summer (0.31), spring (0.3), and autumn (0.14) have slightly risen. In addition, Over decades, the coldest days (0 and below) have decreased in cold loss and shifted from very cold to moderate-to-low-cold, especially after 2009.

Furthermore, Temperatures reaching (44°C or higher) increased between 1992 and 2023. Moreover, the average annual maximum temperature rose from hot to very hot. The lowest average temperature increased steadily and transformed from cold to extremely hot., Climate change has been at a high and dangerous level in the study area in a way that is hard to predict. Hence, this study suggests more research on climate change and its adverse impacts for accelerating adaptation and mitigation approaches.

1.Introduction:

Climate change is a dangerous phenomenon that affects countries worldwide, and the Middle East areas are highly and mainly affected by

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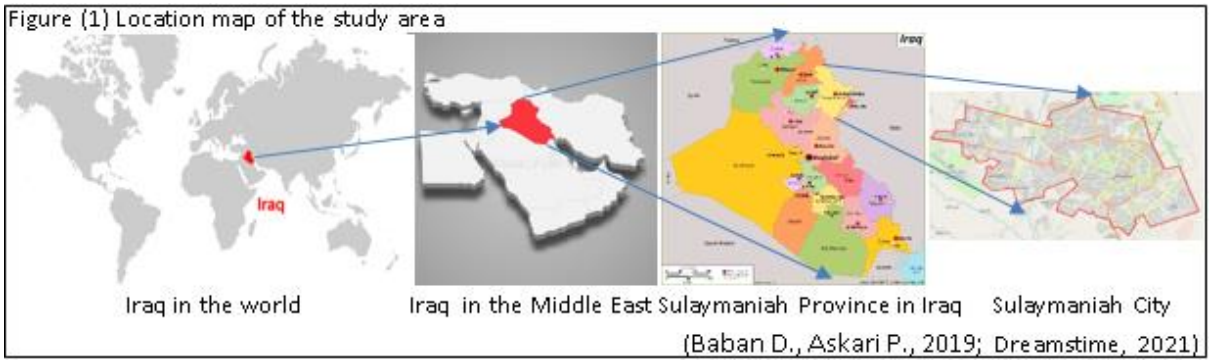
it. Annually, hundreds of species of animals, plants, and food crops are destroyed or endangered due to this phenomenon. Although this phenomenon is global, each region is affected in different ways and levels. Of course, this is due to the differences in natural and human characteristics of each area compared to its surroundings. According to the results of local, regional, and international studies (Mohammadamin, 2013; Hassan, Khalid and Taeb, 2022), the study area within Iraq has reached a dangerous level of climate change. Accordingly, the effects of climate change in the region can be seen as decreasing the average annual rainfall, changes in the amount of precipitation in the seasons, increasing dust storms and rising seasonal and annual temperatures, and the expansion of desertification. It is worth mentioning that the impacts of climate change on the residents of the study area and its surroundings increase yearly, such as increased diseases, mortality and mobility, and dozens of species of animals, plants and food crops are destroyed or threatened.

Temperature is one of the leading climate variable types that directly and indirectly impact other climatic variabilities and all human activities. Therefore, it is crucial to ascertain the extent of climate change associated with temperature trends and its effects in the research, and also, understanding the degree of seasonal and annual temperature changes can help choose a specific and suitable approach to adaptation and mitigation strategies. For this reason, this study is being conducted to determine the level of changes in temperature trends.

2-BACKGROUND OF THE STUDY

2.1STUDY AREA AND SIGNS

This study was carried out in Sulaymaniyah province, northeast of Iraq. It has a region of around (1,733 km2) in the center of its province. The city of Sulaymaniyah is located in the northeastern of Iraq. It is naturally featured by an overall of its surface. It is mountainous and surrounded by valleys and several small plains. It is also surrounded by northwest and southeast mountain ranges, paying a 3.5% dividend on sloppy land. The northern of the city is higher nearly (800 meters) above sea level compared with its southern (800 meters) (Abdulrahman et al., 2021: 113). According to astronomical coordinates, it is situated between latitudes (35° 32' 01") and (35° 35' 40") in the north and longitudes (45° 22' 37") and (45° 28' 33") in the east (Fathullah, 2000: P. 43) {See Fig (1)}. Based on the estimations of World Population Review (2023), the population is (800,793) people, with an average yearly growth rate of (2.76%).



2.2A summary of the meteorological and seismology station in Sulaimaniyah:

The station was established in 1968, is situated in the Sulaimaniyah plain, and rises to a height of approximately 884.8 meters above sea level. The desert area was deserted at the beginning of the station's establishment. Then, due to population growth and the expansion of the master plan of the city, its current location became the city's center. Astronomically, it is located at latitudes (35° 33' 36") in the north and (45° 27' 04") in the west. The geographical location of the station is situated among five seas: the Caspian Sea with (422 km) in the northeast; the Black Sea with (678 km) in the northwest; the Mediterranean Sea with (846 km) in the west; the Red Sea in the south-west with (1210 km); in the southeast of the Arabian Gulf with (580 km) in the southeast. Of these, due to factors like (a lack of or weak natural limitations between the station, location concerning wind directions, and water area wideness) both the Mediterranean Sea and Arabian Gulf rank first and second in terms of how they affect the weather at the station. In terms of soil ،the station's location is based on the type of soil and the color of the dark brown. The upper layer of the plant (1-4%) of organic matter and at the same time (9%) of the structure of the church (Ahmed, 2011).

2.3. Weather Characteristics of the Sulaymaniyah station:

Temperature: The average annual and seasonal temperature varies so that some years are recorded at a few degrees higher or lower than the previous years. The average annual temperature in the study area reaches (19 °C), and the average seasonal temperature is always different. The highest temperatures recorded in the summer reach about (31.6 °C). Otherwise, the lowest temperature is recorded in the winter, about (7.5 °C). This difference is basically due to several reasons, such as (the hours of sunlight exposure, flow time and direction of winds, amount of precipitation and moisture, and falling angle of the sunlight) (See Fig 2).

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Evaporation: The average amount of vapor in summer is much higher (1100 mm) than in winter (160 mm). Generally, the average annual amount of steam is about (2, 231 mm). The main reasons for the difference in the amount of seasonal and yearly evaporation are related to the temperature, the characteristics of the winds blowing over the area, the air fall due to the location of the aeronomic region, which is the location of the orbit of the crab circle, and prevents many evaporation operations (Fig 2) (Ahmed, 2011; Mhamadamin, 2013; SDMS, 2022).

Rain: According to the data analyzed between (1936 and 2021), the average annual rainfall in the study area is about (670.5 mm). Seasonally, the highest average rainfall in the study area is in winter, which is the wettest season and the average rain reaches (328.7 mm). It is due to several reasons, such as impacts of atmospheres directed from the Mediterranean Sea, Arabian Gulf and the Red Sea, the tilt of the sun's angle ،the abundance of accumulated clouds in the sky reaching (4.5 Oktas). On the contrary ،the driest season is summer, and the average rainfall gets about (0.6 mm) due to high temperatures ،excessive humidity ،and continental climate dominance (SDMS, 2022).

Relative humidity: The annual average relative humidity is about (45%), and since the area does not have precipitation constantly, the temperature is high on most days and the area has continental weather. The average relative humidity varies between hot and cold seasons. For example, in summer, it reaches about 22.8% which is the lowest, in contrast to the highest in winter (65.7%) (See Fig 2) (SDMS, 2022).

Wind speed: The survey area generally includes many types of wind throughout the year due to the geographical location of the area and the type of complex topography known for its area. The average wind speed in the study area reaches 1.6 m/s. The highest wind speed is in summer (1.8 m/s) due to rising temperatures and the arrival of hot and dry air mass (CT). On the contrary ،the lowest average is December at 1.1 m/s due to lower temperatures and the appearance of polar air mass.

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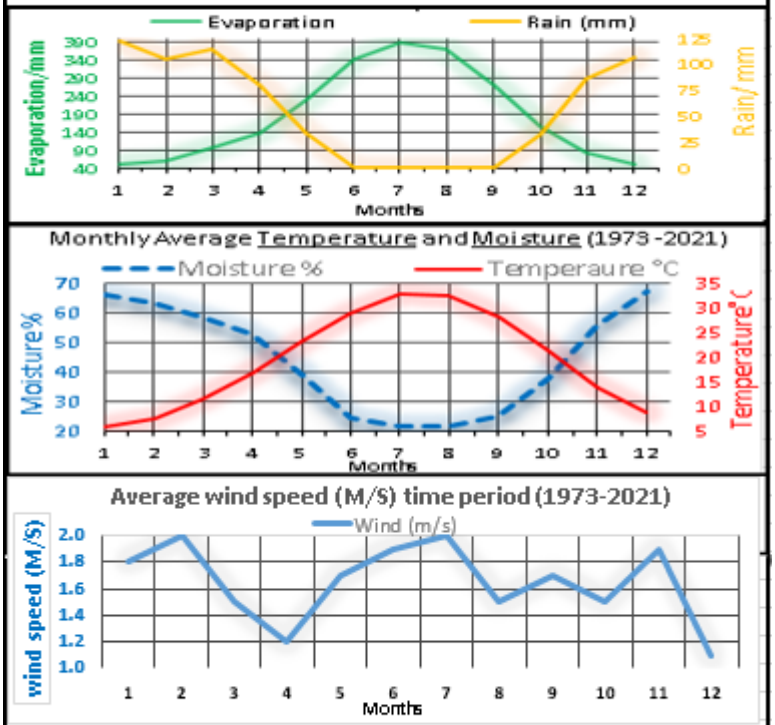
Figure (2): shows the average seasnal (1-12 months) of Precipitation (1936-2021), Evaporation, Temperature and Reative Humidity time Period (1973-2021).



The researcher's work depending on the recorded data of the Kurdistan Regional Government's Ministry of Transport and Communication/Seismic Meteorology Directorate of Sulaymaniyah 2021

3. RESEARCH METHOD

Based on quantitative data analysis, the description, analysis, and comparison methodologies were employed in this study. For this purpose, the research also relies on temperature data records for Sulaymaniyah from 1973 to 2022 that were retrieved from the archives of the Iraqi Meteorological Agency and the Sulaimaniyah Meteorological and Seismology Station archives. To be more realistic and accurate, the data recorded incorrectly were ignored in the analysis, including data from the year (1991). Additionally, the data analyzed annually, monthly, and seasonally are set according to meteorological calculations {See Table (1)}.

Table (1) shows meteorological statistics for seasons

Winter			Spring			Summer			Autumn		
December	January	February	March	April	May	June	July	August	September	October	November
12	1	2	3	4	5	6	7	8	9	10	11

(National Oceanic National Oceanic and Atmospheric Administration, 12/ 08/ 2021)

In addition, to accurately determine the results, this study benefited from several statistical tests using SPSS, including a simple regression

equation to determine the degree of the slope and direction of the analyzed data over time, temperature anomaly indices (TAI) (positive and negative) to determine annual and seasonal average temperature comparing with total annual and seasonal temperature, Köppen-Trewartha climate classification Index to classify average annual and seasonal temperature which ranked into (10) groups as shown in Table (2). The standardized Temperature Index was another test to identify anomalously cold and hot periods by indicating temperatures below and above the median. The researcher benefited from some other statistical tests such as moving mean for (3, 5 years), and mean deviation.

Table (2): distribution temperature classes according Köppen - Trewartha climate classification.

Temperature Range/ °C	Type of Temperature	Code	color
≥35	severely hot	I	
28 to 34.9	very hot	H	
22.2 to 27.9	hot	A	
18 to 22.1	warm	B	
10 to 17.9	mild	L	
0.1 to 9.9	cool	K	
−9.9 to 0	cold	O	
−24.9 to −10	very cold	C	
−39.9 to	severely cold	D	
≤−40	excessively cold	E	

(Belda et al., 2014; Baker et al., 2010; Yadav, Waikhom and Singh, 2019)

Table (3) shows the distribution values of Standarized temperature index		
Extremely hot	≥ 2	
Very hot	1.5 to 2	
Moderately hot	1 to 1.5	
Near normal	1 to -1	
Moderately cold	-1 to -1.5	
Very cold	-1.5 to -2	
Extremely cold	-2 ≤	
		(Fasel , 2015:2)

4.RESULTS AND DISCUSSIONS:

4.1. The Average Annual Temperature Change:

The data analyzed in (Fig 3) explains that significant changes in the average annual temperature occurred between (1973 and 2021). In terms of temperature change between 1973 and 2022, it is clear that the average

temperature has steadily increased over the past 50 years in a way that it raised to (21.8 °C) in 2021. It means that long-term temperature change has been recorded. The linear trend shows that temperature has increased by (0.40 °C) each year. In addition, according to the nature of temperature changes, the study period is divided into two stages: the first is between (1973 and 1994); the second is between (1995 and 2022). Each stage is different and opposite in terms of temperature changes. Accordingly, in the first stage, the average annual temperature was (18.62 ℃), but in the second stage, due to the high-temperature rise ،it increased to (20.13 ℃). It means the average annual temperature rise in the last 28 years has increased by about (1.51 ℃) (See Fig 3-A).

In terms of extreme weather, Using the Köppen- Trewartha classification resulted in the average temperature being higher as time passed. It is also clear that the highest and lowest average temperatures are continuously rising. For example ،the lowest averages have been recorded after 1992 to rise step by step, including (1992 (15.6 ℃), 1997 (18.4 ℃, 2011 (18.9 ℃), 2019 (20 ℃), 2020 (20.71 ℃)). As well as the highest averages steadily increased after 1977 by (18.8 ℃) and followed by (1978 (19.5 ℃), 1979 (19.7 ℃), 1987 (19.7 ℃). 1995 (20.5 ℃), 1998 (20.5 ℃) 1999 (20.7 ℃), 2010 (21.5 ℃), and 2021 (21.8 ℃)}. This result proves that the average annual temperature has significantly changed in the long term and will set new records decade after decade. It also means that the observed temperature trends in the study area have changed from climate fluctuations to long-term climate change (See Fig 3 A and C).

The Standardized Temperature Index (STI) found significant temperature changes in the study area. Based on the results, the average temperature dropped significantly from 1973 until 1992, when the average temperature dropped to (-3.44 °C), the coldest year in the study period. On the contrary, the average temperature trends have risen gradually in a way that it, for the first time, raised about (1.04 °C- moderately hot- in 1999) compared to the total annual average, and in 2010 it rose to (1.81 °C - very hot), then in 2021 was recorded at the highest record of increase of approximately (2.05 °C - extremely hot) the hottest year in the history of the region's meteorological data. Another result is that the record period of temperature increases from year to year continues to be shorter, and due to this, the warmest years came in succession in the last years (2020, 2021, and 2022) (See Fig 3-D). Moreover, in the implementation of the movement average test, it was found that the average annual temperatures from the beginning of 1973 to 1992 were at a moderate range level, but since 1992 until nowadays, the deviations have been in

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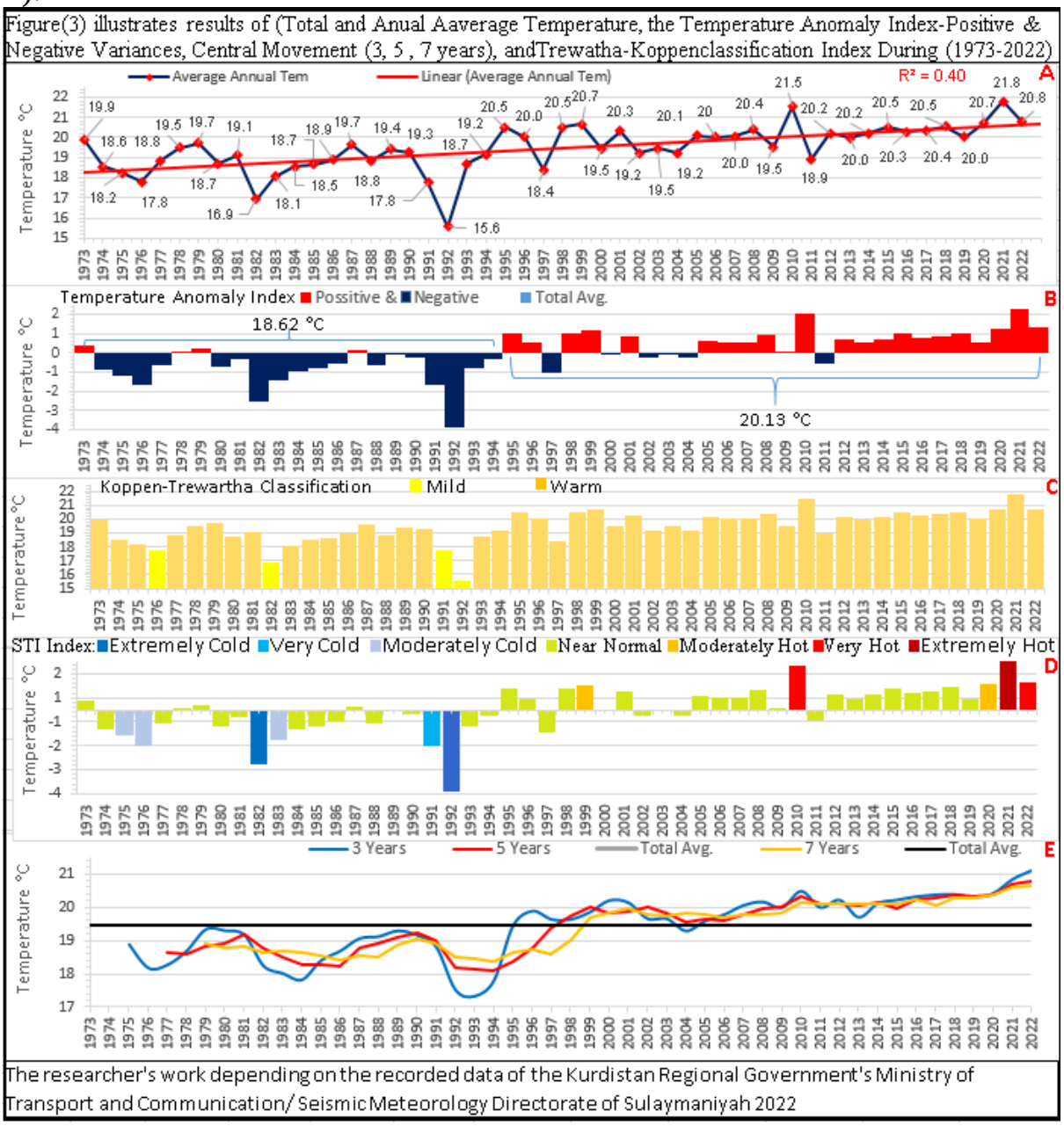
the short and light range ،but they still have continued to rise (See Fig 3-E).



Figure(3) illustrates results of (Total and Anual Aaverage Temperature, the Temperature Anomaly Index-Positive & Negative Variances, Central Movement (3, 5 , 7 years), andTrewatha-Koppenclassification Index During (1973-2022)

The researcher's work depending on the recorded data of the Kurdistan Regional Government's Ministry of Transport and Communication/ Seismic Meteorology Directorate of Sulaymaniyah 2022

4.2. The Average Seasonal Temperature Change:

Figs (4, 5, 6, and 7) point out the analysis of seasonal average temperatures during (1973-2021) in which the study period is divided into two stages; the first is the short-term climate fluctuation changes in average temperatures in the direction of declining and cooling; the second is the long-term climate change in the order of average temperatures. The duration of each of the two stages varies depending on the seasons.

First: Temperature Change in Winter:

Fig (4-A & B) shows the Average spring temperature for the period (1973-2022), and it was divided into two stages. During the first stage (1973-1994), the average temperature trendier decreased in the form of short-term fluctuations in which the average temperature was recorded at a low level in some years, and others experienced many declines. Otherwise, the average temperature has been registered as a continuous rise in degrees during the second stage (1995-2022). Due to this, in terms of climate type, the study area has been changed from short-term climate fluctuations to long-term climate change.

The use of a linear trend showed a deviation of (0.4°) from the average seasonal temperature per year, but at the stage's level, especially at the second stage (1995-2022), a 27-year continuous increase has been recorded. As a result, it seems that the average seasonal temperature of winter is in the first place of temperature rise compared to other seasons. Another consequence is that (See Fig 4-B) the overall average of winter temperatures in the first stage was (5.99 °C), but in the second stage it rose to (8.13 °C). It means the average temperature has increased about (2.14 °C) in the last 27 years, which is a high level compared to its period. This is because the average temperature is above the average in most second-stage years.

The Köppen- Trewartha classification shows a gradual rise in the average winter temperature, particularly after 1992. The average temperature in all years has increased, and in some years, climatic characteristics changed from cool to mild temperatures, such as 2010 (10.77 °C) and 2021 (10.10 °C). It also means that the observed temperature trends in winter have changed from climate fluctuations to long-term climate change (See Fig 4-A and C).

In addition, the Standardized Temperature Index (STI) found that significant changes in the winter's average temperature had occurred, especially after 1992. Based on the results, the average temperature trends in most years have risen gradually compared to the total seasonal average of winter. For instance, the average temperature recorded in cold temperature in (7) years from 1973 to 1992 including 1974 (-1.96 °C- Very Cold), 1975 (-1.31 °C - Moderately Cold), 1982 (-2.16 °C - Extremely Cold), 1983 (-1.59 °C – Very Cold, 1989 (-1.19 °C – Moderately Cold), 1991 (-1.66 °C- Very Cold), 1992 (-2.95 °C- Extremely Cold), however, there were (7) years that average temperature have gotten raised higher compared with the usual seasonal temperature including 1996 (1.05 °C- Moderately hot), 1999 (1.43 °C - Moderately hot), 2001 (1.31 °C - Moderately hot), 2010 (2.13 °C - Extremely hot),

2014 (1.07 °C - Moderately hot), 2018 (1.31 °C - Moderately hot), 2021 (1.31 °C - very hot). Thus, it is clear that winter's average temperature has significantly changed and risen from cold to hot. Another result is that the record period of temperature increases from year to year continues to be shorter, and due to this, the warmest years came in succession in the last years (2010 and 2021) (See Fig 3-C & D).

Moreover, in the implementation of the movement average test, it was found that the average winter temperature from the beginning of 1973 to 1992 was at a normal fluctuation, but since 1992 until nowadays, the deviations have slowly continued to rise (See Fig 3-E).

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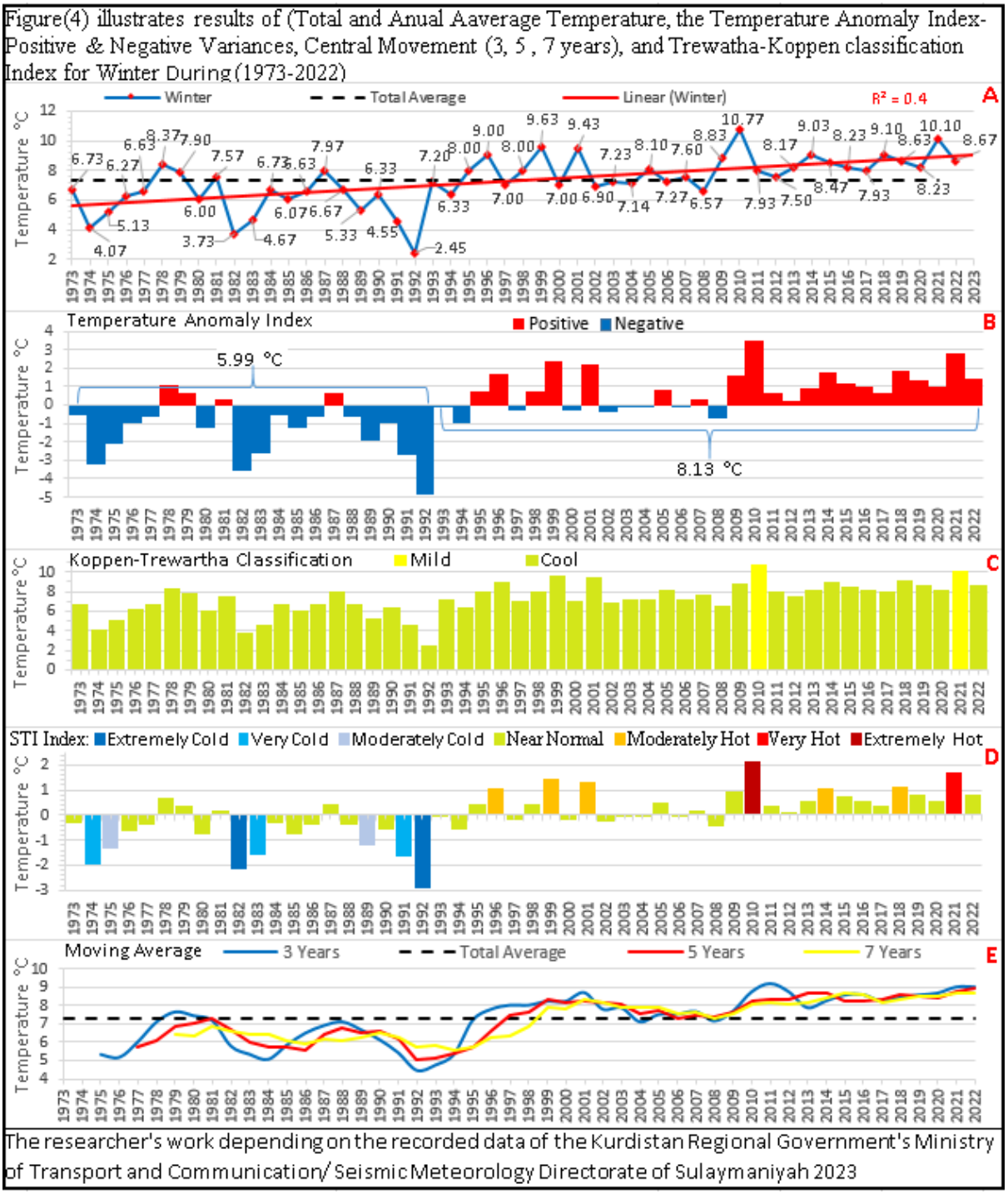


Second: Temperature Change in Spring:

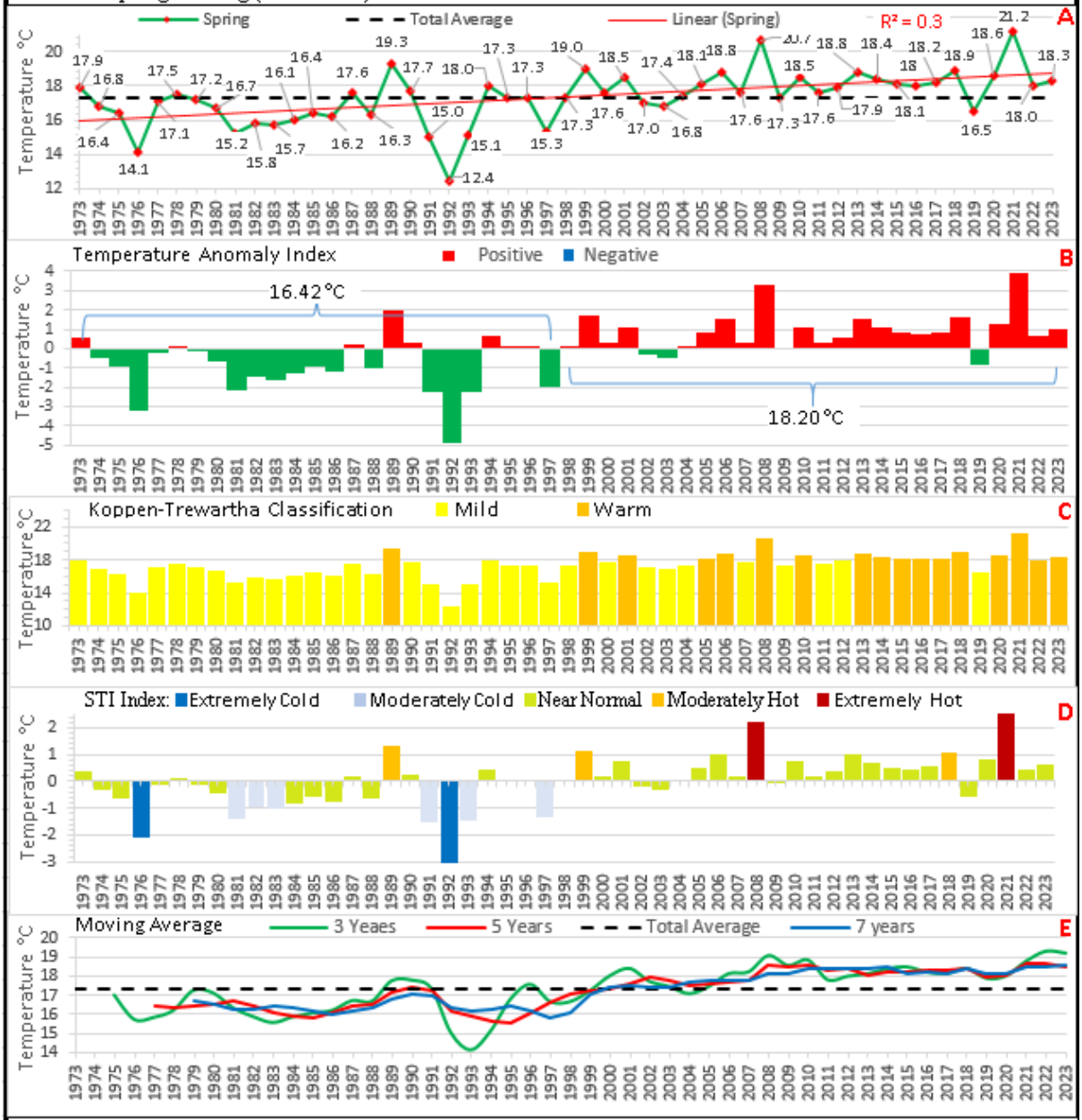
As shown in Fig (5-A & B), during the first stage (1973-1997), the average temperature has significantly and more trendy decreased in the form of short-term climatic fluctuations in which the average temperature was recorded at a low level in some years, and others have experienced many declines. However, during the second stage (1998-2023), the average temperature has continuously risen in degrees.

The use of linear trend showed a deviation of (0.3°) from the average seasonal temperature per year, but at stage level, especially at the second stage (1997-2023), a 27-year continuous increase has been recorded. As a result, it seems that the average temperature of spring is in the third place of temperature rise compared to other seasons. Another consequence is that (See Fig 4-B) the overall average spring temperature in the first stage was (16.42 °C), but in the second stage, it rose to (18.20 °C), Which means the average temperature increased by about (1.78 °C) in the last 26 years. This is because the average temperature is above the average in most of the years of the second stage in the spring. Also, based on the Koppen-Trewartha Classification, the study area's climatic characteristics have changed from mild to warm, comparing the average temperature change between stages one and two (See Fig 4- B & C). Using the Köppen- Trewartha classification, it was found that, in most years after 1997, the seasonal temperature of spring has gradually increased. As well as, the temperature of spring has been changed step by step from mild to warm temperature including 1989 (19.33 °C), 1999 (19.03 °C), 2001 (18.47 °C), 2005 (18.13 °C), 2006 (18.83 °C), 2008 (20.67 °C), 2010 (18.47 °C), 2013 (18.83 °C), 2014 (18.40 °C), 2015 (18.13 °C), 2016 (18.03 °C), 2017 (18.20 °C), 2018 (18.93 °C), 2020 (18.60 °C), 2021 (21.20 °C), 2022 (18 °C), 2023 (18.30 °C) (See Fig 4-A & C).

The Standardized Temperature Index (STI) found a significant change in the recorded spring average temperature, especially after 1997. Based on the results, the average temperature trends in most of the years have risen gradually compared to the total seasonal average of spring. For instance, the average temperature recorded in cold temperature in (8) years from 1973 to 1997 including 1976 (-2.11 °C- Extremely Cold), 1981 (-1.39 °C - Moderately Cold), 1982 (-0.98 °C - Moderately Cold), 1983 (-1.04 °C – Moderately Cold), 1991 (-1.50 °C – Moderately Cold), 1992 (-3.21 °C- Extremely Cold), 1993 (-1.46 °C- Moderately Cold), 1997 (-1.31 °C- Moderately Cold), however, there were (4) years that average temperature have recorded at highest degree compared with the usual seasonal temperature including 1999 (1.11 °C- Moderately hot), 2008 (2.18 °C - Extremely hot), 2018 (1.05 °C - Moderately hot), 2021 (2.53 °C - Extremely hot). Thus, it is clear that the average temperature of spring has risen from cold (first stage) to hot (second stage). Due to this, the warmest years have been recorded in stage two till nowadays (See Fig 3-C & D).

Moreover, in the implementation of the movement average test, it was

Figure(5) illustrates results of (Total and Anual Aaverage Temperature, the Temperature Anomaly Index-Positive & Negative Variances, Central Movement (3, 5 , 7 years), and Trewatha-Koppen classification Index for Spring During (1973-2023)



The researcher's work depending on the recorded data of the Kurdistan Regional Government's Ministry of Transport and Communication/ Seismic Meteorology Directorate of Sulaymaniyah 2023

found that the average spring temperature from the beginning of 1973 to 2004 was at normal fluctuations, but since 2005, the deviations have slowly continued to rise (See Fig 3-E).

Third: Temperature Change in Summer:

As shown in Figs (6-A & B), the Average temperature of summer during the first stage (1973-1994) has continuously decreased. Otherwise, during

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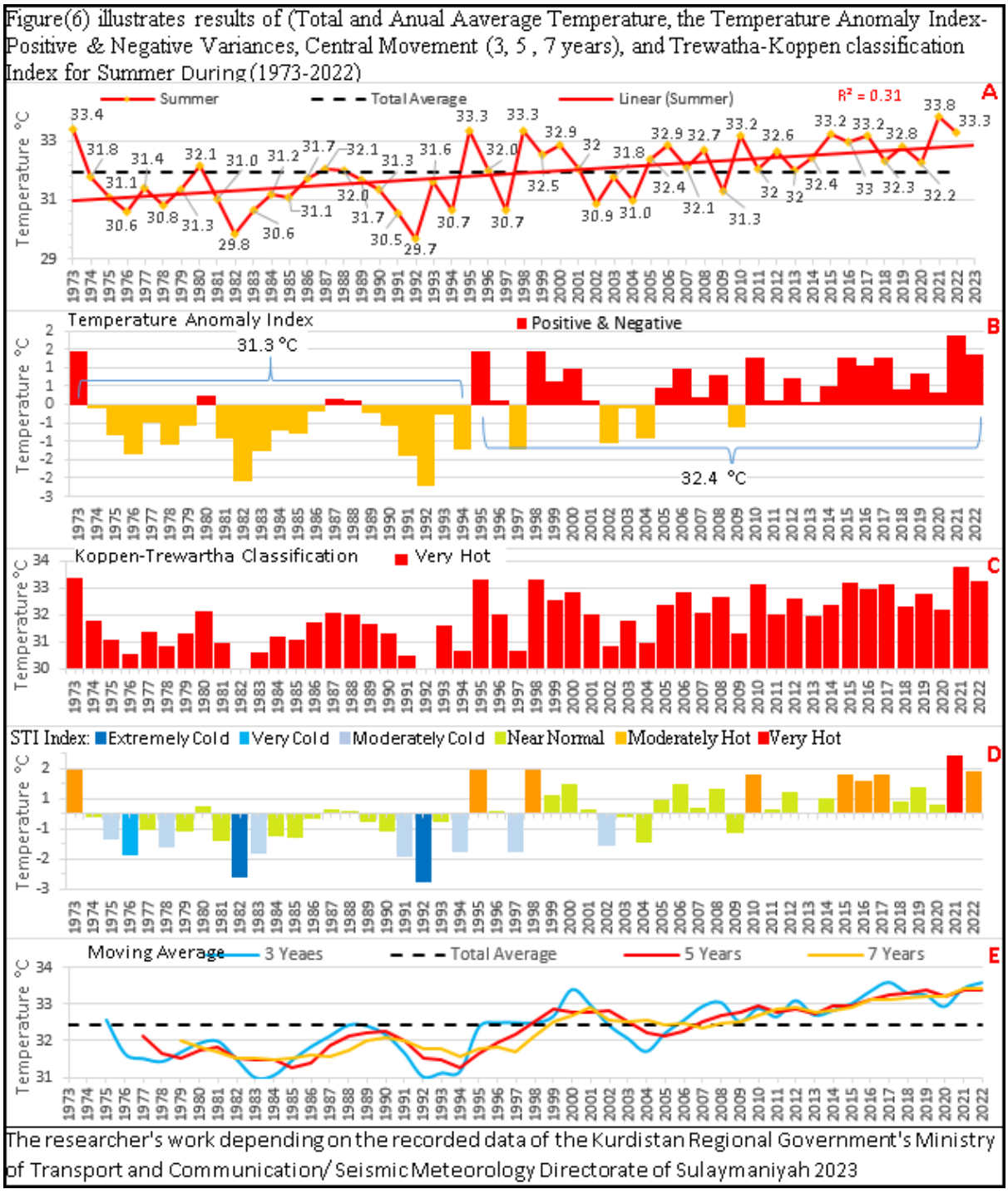
the second stage (1995-2022), it has been recorded as a continuous rise in degrees. It is clear that the characteristic of temperature in the study has been trendily changed from short-term fluctuations to long-term climate change.

The use of a linear trend showed a deviation of (0.31°) from the average seasonal temperature per year, but at the stage's level, especially at the second stage (1995-2022), a 28-year continuous increase has been seen. As a result ،it seems that the average seasonal temperature of summer is in the second place of temperature rise compared to other seasons. Additionally, the average summer temperature of the first stage was (31.3 °C), which rose to (32.4 °C) in the second stage. It means the average temperature has increased by about (1.1 °C) in the last 28 years because it is above the seasonal average in most years of the second stage (See Fig 4-B). Using the Köppen- Trewartha classification, it pointed out that although the average summer temperature (especially after 1994) slowly and gradually recorded higher, it stayed at the same variety of temperatures known as very hot. (See Fig 6-A and C).

Moreover, the Standardized Temperature Index (STI) found a significant change in the average temperature of the summer, particularly after 1994. Accordingly, the average temperature trends in most of the years have risen gradually compared to the total seasonal average of summer. For instance, in the first stage, the average temperature has recorded in cold temperature in (7) years from 1973 to 1994 including 1975 (-0.86 °C- moderately Cold), 1976 (-1.37 °C - Very Cold), 1978 (-1.10 °C - moderately Cold), 1982 (-2.12 °C – Extremely Cold), 1983 (-1.30 °C – Moderately Cold), 1991 (-1.42 °C- moderately Cold), 1992 (-2.26 °C- Extremely Cold), 1994 (-1.27 °C- moderately Cold). However, there were (8) years that the average temperature risen higher than the normal seasonal temperature, including 1995 (1.45 °C- Moderately hot), 1998 (1.45 °C - Moderately hot), 2010 (1.28 °C - Moderately hot), 2015 (1. 32 °C - Moderately hot), 2016 (1.08 °C - Moderately hot), 2017 (1.28 °C - Moderately hot), 2021 (1.93 °C - very hot), and 2022 (1.39 °C - Moderately hot). Thus, it is clear that the average temperature of summer has significantly changed and risen from cold to hot and that the record period of temperature increases from year to year continuously to be shorter (See Fig 6-C & D). The implementation of the moving average test (3, 5, and 7 years) found that the average summer temperature from the beginning of 1973 to 1997 was at a normal fluctuation, but since 1998 until nowadays, the deviations have slowly continued to rise (See Fig 6-E).



Figure(6) illustrates results of (Total and Anual Aaverage Temperature, the Temperature Anomaly Index-Positive & Negative Variances, Central Movement (3, 5 , 7 years), and Trewatha-Koppen classification Index for Summer During (1973-2022)

The researcher's work depending on the recorded data of the Kurdistan Regional Government's Ministry of Transport and Communication/ Seismic Meteorology Directorate of Sulaymaniyah 2023

Forth: Temperature Change in Autumn:

The average temperature in autumn during the first stage (1973-1993) has gradually decreased in the form of short-term. However, during the second stage (1994-2023), the average temperature has been recorded as a continuous rise in degrees (See Fig (7-A & B)). A linear trend showed a deviation of (0.14°) from the average seasonal yearly temperature. As a result, the average temperature of autumn is in the fourth place of

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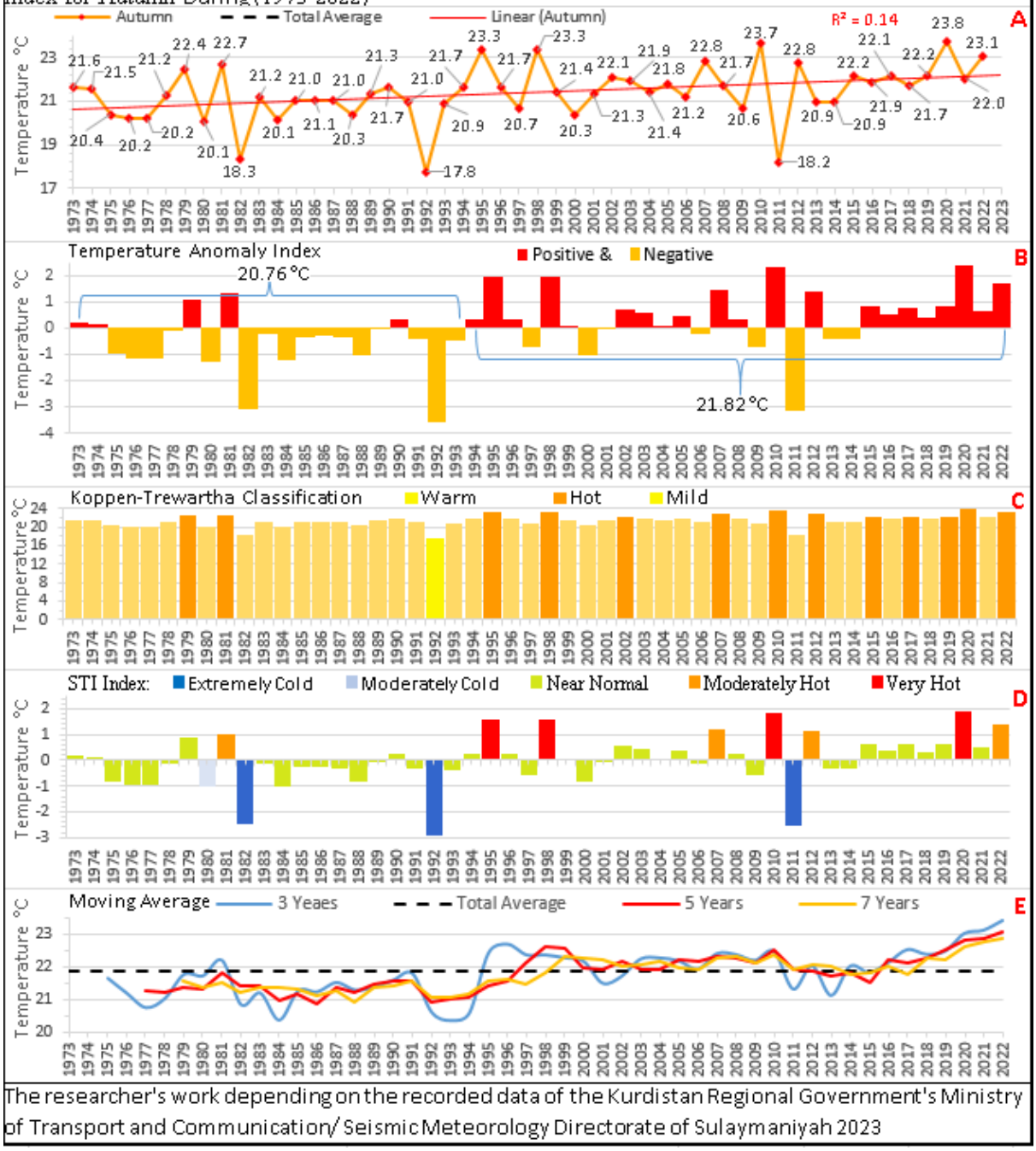
temperature rise compared to winter, spring, and summer. Another result is that (See Fig 7-B) the overall average spring temperature in the first stage was (20.76 °C), but in the second stage, it rose to (21.82 °C), Which means the average temperature has increased by about (1.06 °C) in the last 29 years because the average temperature is above the total average in the majority of the years. Based on the Koppen-Trewartha Classification, the study area's climatic patterns have changed from mild to warm temperature, comparing the average temperature change between stages one and two (See Fig 7- B & C). Using the Köppen- Trewartha classification showed that although the average temperature of the autumn (especially after 1993) has slowly and trendy risen, it stayed in the same category of temperature known as Warm temperature. (See Fig 7-A and C).

In addition, the Standardized Temperature Index (STI) found a significant change in the autumn temperature, particularly after 1994. According to this, the average temperature trends in most years have gradually risen compared to the total seasonal average of summer. For instance, in the first stage (1973-1993) there were about (3 years) that the average temperature recorded in cold temperature including 1980 (-1.04 °C- moderately Cold), 1982 (-2.46 °C - Extremely Cold), 1992 (-2.90 °C - moderately Cold), 1982 (-2.12 °C – Extremely Cold), 1983 (-1.30 °C – Moderately Cold), 1991 (-1.42 °C- Extremely Cold). On the other hand, there were (7) years that average temperature has recorded more higher than the average seasonal temperature including 1995 (1.57 °C- Very Hot), 1998 (1.57 °C – Very Hot), 2007 (1.27 °C - Moderately Hot), 2010 (1. 84 °C – Very Hot), 2012 (1.12 °C - Moderately Hot), 2020 (1.92 °C – Very Hot), and 2022 (1.36 °C – Moderately Hot). Hence, it is clear that the average temperature of autumn has significantly changed and risen from cold to hot and that the hot years increase decade by decade (See Fig 7-C & D). The implementation of the moving average test (3, 5, and 7 years) found that the average autumn temperature from the beginning of 1973 to 1994 was at normal fluctuations and decreasing slowly, and from 1995 to 2015, raised a little bit within normal temperature fluctuations, but since 2016 the deviations have been quickly raised (See Fig 7-E).

Figure(7) illustrates results of (Total and Anual Aaverage Temperature, the Temperature Anomaly Index-Positive & Negative Variances, Central Movement (3, 5 , 7 years), and Trewatha-Koppen classification Index for Autumn During (1973-2022)



The researcher's work depending on the recorded data of the Kurdistan Regional Government's Ministry of Transport and Communication/ Seismic Meteorology Directorate of Sulaymaniyah 2023

In general perspectives of seasonal temperatures, it is clear that the average temperature has been raised, especially in the second stages, so that continuous increases can be predicted for the future of (50-100) years. Also, it seems to have reached a dangerous level of temperature change, and its harmful impacts will be more complex from the natural and human perspective of the study area, including (environment, soil, agriculture, health, wealth, and other human activities). Temperature

changes led to a rise in average annual evaporation and a decrease in precipitation. Due to this, desertification, soil erosion, and drought will be widespread over the study area decade by decade. On the other hand, a change in the temperature of the seasons has gradually increased, and the weather characteristics of the seasons have been warming so that the duration of the hot seasons has expanded and lengthened, whereas the cold seasons have been shorter. Of course, these changes in the temperature of the seasons can be another sign of climate change in the study area.

5.Changes in Warmest and Coldest Days

Fig 7 shows the coldest days and lowest temperatures of the year. According to the data, the coldest days of the year are in numbers towards cold loss decade after decade. This means it has changed from very cold to moderate - and low –cold, especially after 2009. For example, in 1992, the number of cold days was not recorded at (0 °C or below), and step by step the number of cold days increased until 2008 the number of days with temperatures reaching 0 and below was (31 days). Since then, the number of cold days has decreased gradually especially after 2011 when the number of cold days dropped significantly in 2023in a way that only (1) day temperature has recorded at (0 °C or below). Moreover, using the linear trend for the coldest days of all the years in the study periods found that the number of coldest days has gradually decreased run by (0.12) per year in the long-term period, But at the level of the stages, the results showed that in the first stage (1992-2011) it increased by (0.04) and otherwise it decreased by (0.36) in the second stage (2011-2023). This shows that on the one hand, climate change towards warming is faster than cooling, and on the other hand, the duration of warming and rising temperatures is shorter.

In the analysis of the data on the number of days at which temperatures reached (44 °C or higher) (See Fig 7), it was found that the number of frequencies was higher gradually between 1992 and 2023. For instance, during the first six years between 1992 and 1997, the highest daily temperature reached this level was only (1 day) in 1995. But since 1995, the number of highest daily temperatures (44 °C or higher) has risen in the last years (after 2014), and the number of frequencies has reached the highest level of increasing by about (22 days) in 2015, (22 days) in 2021 and (21 days) in 2023 which is the first time in the history of the study area. In addition, the same result was supported using the linear trend equation when the results showed that the hottest days were rising at a rate of 0.26 per year.

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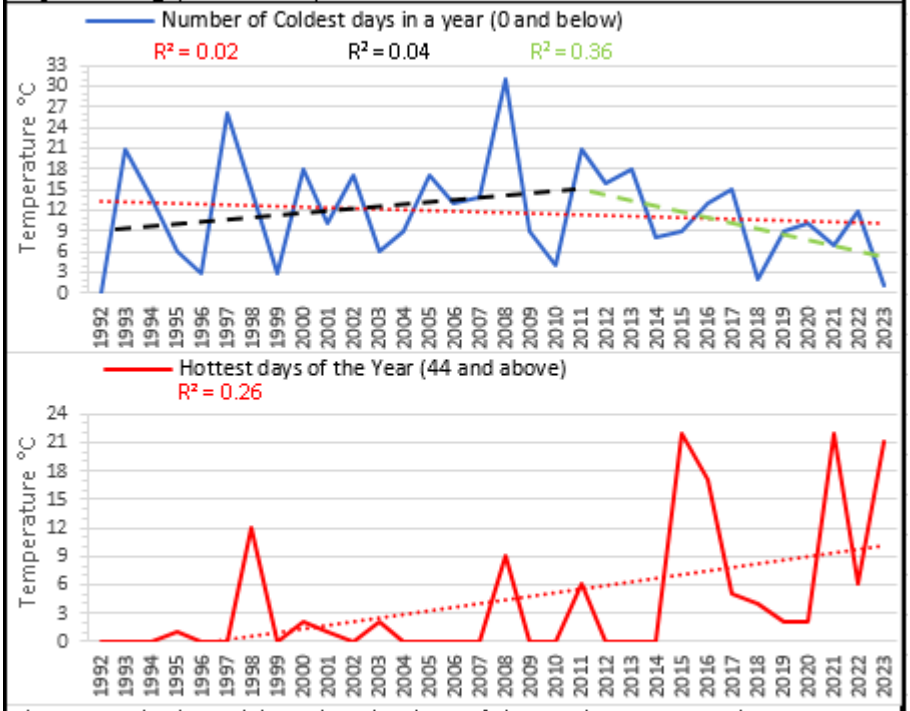
In general, these changes in the lowest (0 or below) and the highest (44 ºs and upwards) daily temperatures in the region will be a sign of long-term climate change, and they will have a more significant impact on the area, including rising temperature, increasing the number of hottest and decreasing coldest daily temperature. Also, it will increase risks and damages to the lives and human activities in the study area, such as the disruption of the population's collective health due to rising temperatures, agriculture and other economic activities, and the central and local authorities will be forced to reduce work times and days. As a result, all of these will cause significant damage to the public and private sectors in the study area.

Figure(8) Shows Frequences of Coldest Days (0 &Lower) and Hottest Days During (1992-2023)



The researcher's work based on the data of the Kurdistan Regional Government-Ministry of Transport and Communication/ Seismic Meteorology Directorate of Sulaymaniyah and the Sulaymaniah International Airport/weather, 2023

6.Changes in Highest Average Temperature:

Fig (8) includes an annual average of the highest temperature in 1973-2022. Accordingly, the average annual maximum temperature has steadily risen. For example, using the linear trend, the highest average temperature in the study area has changed significantly by (0.5) tilt per year in the direction of rising temperature. However, as shown in Fig 8-B, it is evident that the use of temperature anomaly- positive and negative deviations showed that these significant changes occurred in three stages that in most years of the first stage (1973-1994), the average temperature

had recorded negatively (except 1989). It was seen as a short fluctuation in which in some years they are below the annual average and in many years above it. However, in the third stage (2005-2022), the average highest temperature has long-term shifted from hot to very hot. In addition ،in terms of the total average change among the stages, it is clear that the temperature change has continuously recorded at a high level in a way that the total average of the first stage was (23.8°C), then, in the second stage it was raised to (25.2°C), and it reached the highest level in the third stage (26 °C). This means that the highest average temperature has risen about (2.2 °C) compared to the first stage, which is a significant change and is the first time in the history of the study area's meteorological record (See Fig 8-A and B).

In addition, the Standardized Temperature Index (STI) found that the average highest temperature, especially after 2014 in most years, has exceeded the total annual average. For instance, the average temperature from 1973 to 1993 declined, and there were about (6 years) that the average temperature recorded in cold temperatures including 1974 (-1.1 °C- moderately Cold), 1976 (-1.4 °C - moderately Cold), 1977 (-1.3 °C - moderately Cold), 1980 (-1.1 °C – moderately Cold), 1982 (-1.7 °C – Very Cold), 1992 (-2.9 °C- Extremely Cold). On the other hand, the highest average temperature steadily rose from 1995 to 2022, especially after 2013, when the temperature rose dramatically. Due to this, there were (10) years which the average temperature has recorded more higher than the total annual average temperature including 1995 (1.2 °C- Moderately Hot), 1998 (1.2 °C – Moderately Hot), 2014 (1.2 °C - Moderately Hot), 2015 (1. 5 °C – Very Hot), 2016 (1.4 °C - Moderately Hot), 2017 (1.1 °C – Moderately Hot), 2018 (1.7 °C – Very Hot), 2020 (1.1 °C – Moderately Hot), 2021 (2.7 °C – Extremely Hot) and 2022 (1 °C – Moderately Hot). Hence, it is clear that the highest average temperature has significantly changed from normal to very cold and extremely cold, then to hot and extremely hot, which the hot years increasing decade by decade (See Fig 8- D). As shown in Fig 9-E, the implementation of the moving average test (3, 5, and 7 years) found that the highest average temperature from 1993 to 2022 increased slowly.

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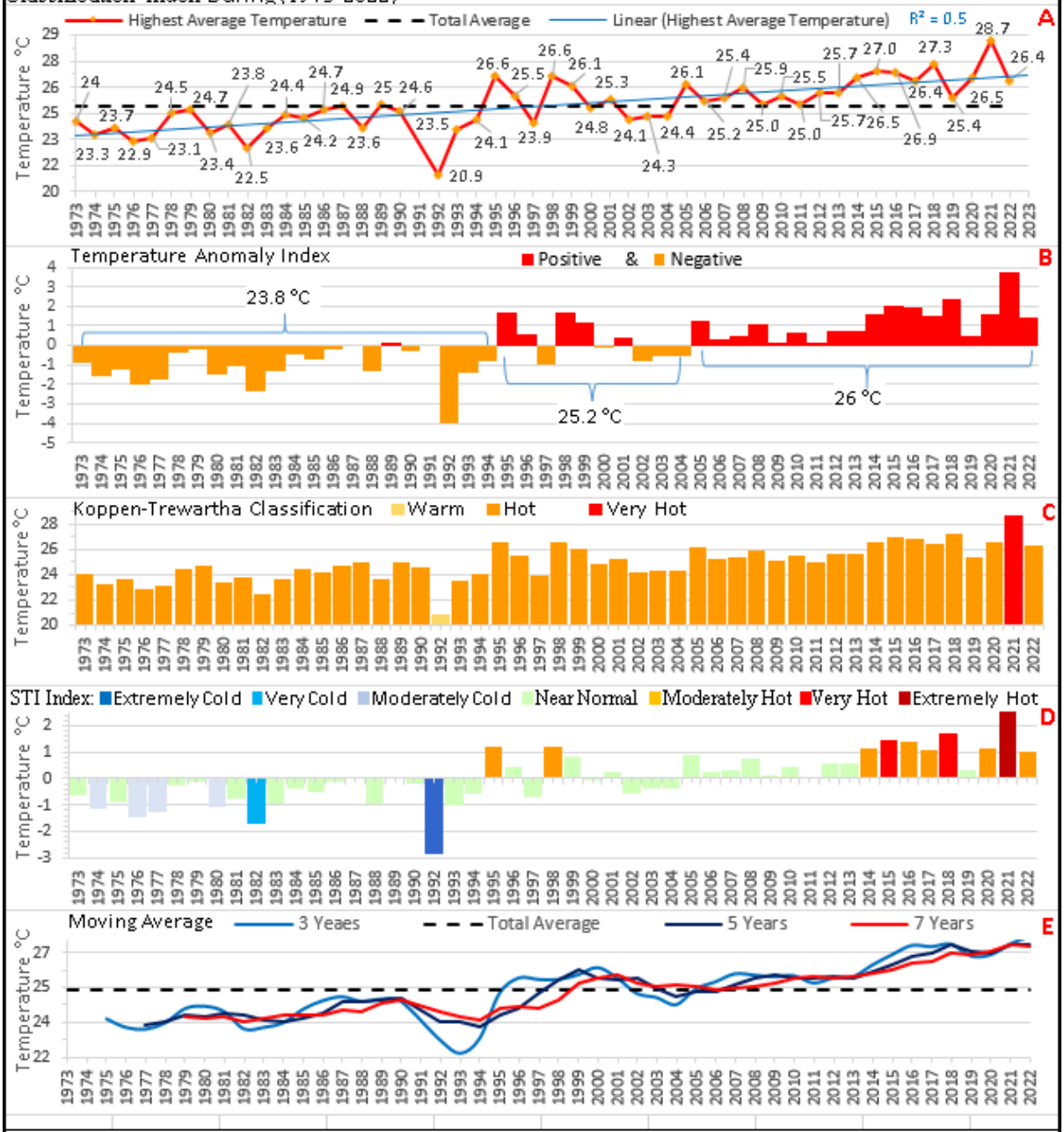
Figure(8) illustrates results of (Highest and Total Anual Aaverage Temperature, the Temperature Anomaly Index-Positive & Negative Variances, Central Movement (3, 5 , 7 years), and Trewatha-Koppen Classification Index During (1973-2022)



The researcher's work depending on the recorded data of the Kurdistan Regional Government's Ministry of Transport and Communication/ Seismic Meteorology Directorate of Sulaymaniyah 2023

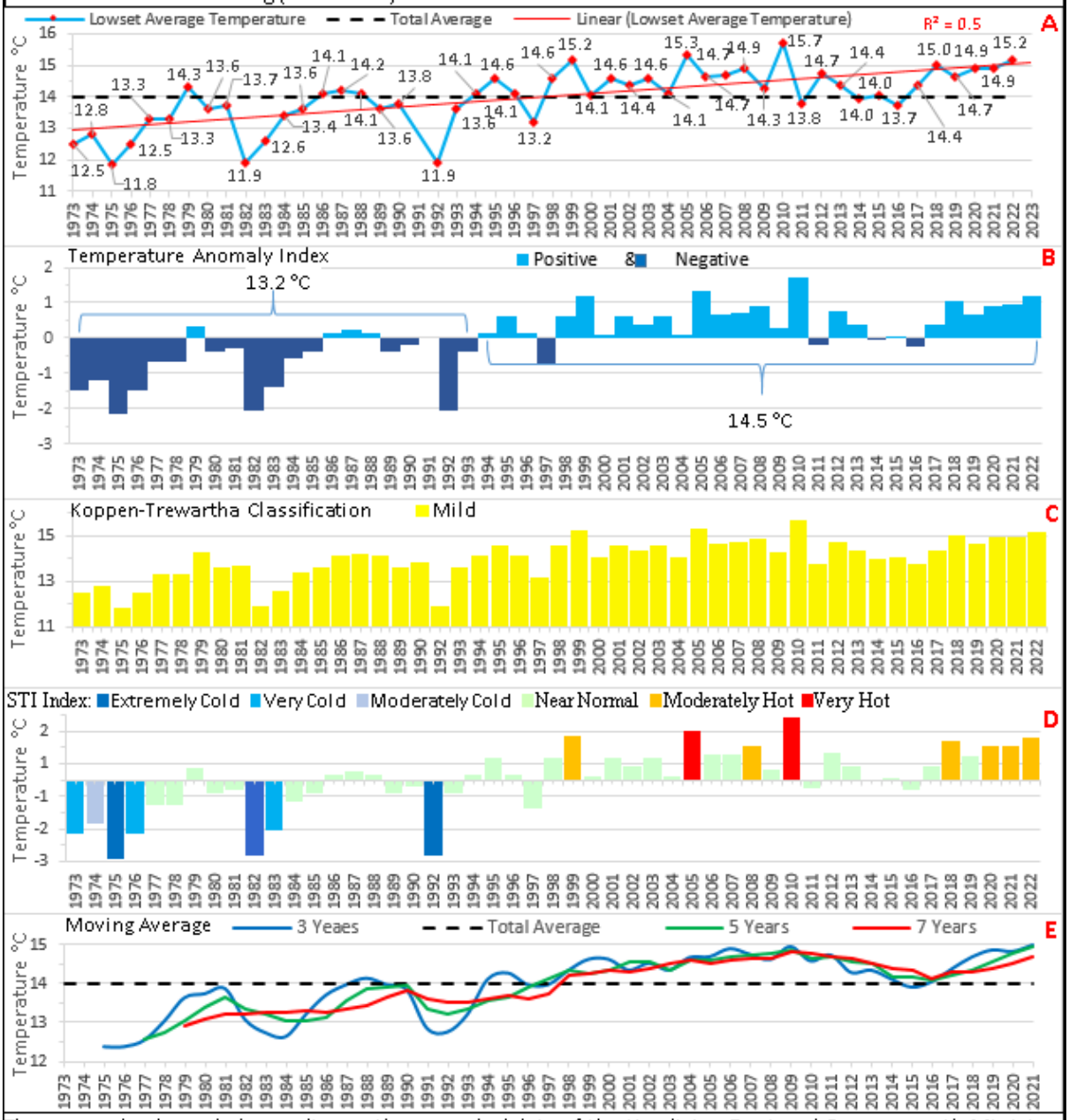
7.Changes in Lowest Average Temperature:

Fig (8) shows the annual average of the lowest temperatures from 1973 to 2022. According to data analysis, the lowest average temperature has slowly but surely risen. For instance, the linear trend illustrates that the lowest average temperature in the study area has changed significantly by (0.5 degrees) per year in the direction of rising temperature. However, as

shown in Fig 9- B, it is clear that the use of temperature anomaly-positive and negative deviations showed that these significant changes were recorded in two stages which in most years of the first stage (1973-1993), the average temperature had negatively decreased, and in some years were seen at below the annual average. On the contrary, in the second stage (1994-2022), the average lowest temperature has continuously shifted from negative to positive and or from cold to hot and very hot. Additionally, in terms of the total average change, it is clear that the temperature change has continuously recorded at a high level in a way that the total average of the first stage was (13.2 °C), but in the second stage, it was raised to (14.5 °C). It could mean that the lowest average temperature has risen about (1.3 °C) compared to the first stage (See Fig 8-A and B).

The use of (the STI) test found that the average lowest temperature in most years (particularly after 2014) has transcended the total annual average. For instance, the average temperature from1973 to 1993 declined, and there were about (6 years) that the average temperature was listed as moderate, very and extremely cold such as 1973 (-1.7 °C- Very Cold), 1974 (-1.3 °C - moderately Cold), 1975 (-2.4 °C -Extremely Cold), 1976 (-1.7 °C –Very Cold), 1982 (-2.3 °C –Extremely Cold), 1983 (-1.6 °C- very Cold) and 1992 (-2.3 °C -Extremely Cold). However, the lowest average temperature was step by step raised from the time of 1999 to 2022. Due to this, there were (8) years in which the lowest average temperature was recorded higher than the total annual average including 1999 (1.4 °C- Moderately Hot), 2005 (1.5 °C – Very Hot), 2008 (1 °C - Moderately Hot), 2010 (1. 9 °C – Very Hot), 2018 (1.2 °C - Moderately Hot), 2020 (1.2 °C – Moderately Hot), 2021 (1 °C – Moderately Hot) and 2022 (1.3 °C – Moderately Hot). As a result, it is clear that the lowest average temperature has significantly changed from cold and extremely cold to hot and extremely hot (See Fig 9- D). Finally, the implementation of the moving average test (3, 5, and 7 years) found that the lowest average temperature from 1973 to 2022 was slowly raised (See Fig 9-E).

Figure(9) illustrates results of (Lowest and Total Anual Aaverage Temperature, the Temperature Anomaly Index-Positive & Negative Variances, Central Movement (3, 5 , 7 years), and Trewatha-Koppen Classification Index During (1973-2022)



The researcher's work depending on the recorded data of the Kurdistan Regional Government's Ministry of Transport and Communication/ Seismic Meteorology Directorate of Sulaymaniyah 2023

8.DISCUSSION OF RESULTS ACCORDING TO PREVIOUS RESEARCH

Compared to the literature review, the results of this study show that although there are some differences, the results of this study agree with those conducted in the research area, Iraq, the Middle East, and the world. Initially, at the regional level, a study by Mohammadamin (2013) using

data from 1973-2011 pointed to a significant change in monthly temperature, especially in the highest and lowest averages over periods such as the 1970s and 80s of the last century were cooler than the first decade of the 21st century. Another result was that the increase in temperature has been weakly and chronically found. Also, the highest annual and seasonal (summer) average temperatures decreased between 2003 and 2012. However, in this study, the mean seasonal and the highest and lowest temperatures have been continuously raised. Of course, there are some possible explanations for this discrepancy. First, this study examined data from 1937 to 2023, a lengthy period compared to the literature. Second, the majority of the characteristics of climate change have been observed over the past two decades, which this study examined by the end of 2022. In another study (Ahmed and Al-Manmi, 2021), researchers concluded that significant changes have occurred to the climate patterns in Sulaymaniyah, such as reducing precipitation, rising temperature and evaporation that has adversely affected agricultural systems and structures. In addition, they believed that due to these changes, the number of greenhouses and farming diseases have been increased.

Moreover, in the study of Noor, Ghassumlounia and Noori (2023) regarding the water harvesting management in Sulaymaniyah governorate, they found that climate change has been at a high level in the study area, which caused rising temperatures, evaporation, prolonged drought, water shortage and some weather events (e.g., floods). The researchers believed this phenomenon has made water harvesting and adaptation strategies harder to manage significantly and fluently in the study area. Further, researchers Al-temimi, Hashim and Al-Lami (2023), after evaluating the relationship between the snow cover and the surface temperature in Sulaymaniyah, showed that the snow cover decreased decade after decade due to the continuous rise in temperature, particularly between 1987 and 2022.

At the national level, Several studies have shown that a significant change in the Iraqi climate has taken place. For example ،a study by Azooz and Talal (2015) on the evidence of climate change in Iraq focused on climate change relating to the north, middle, and south sides of Iraq, including Kirkuk, Mosul, Baghdad, and Basra. The results show clear signs of climate change in all four cities, and the two main characteristics of this change are rising temperatures and decreasing rainfall. Similarly ،Osman et al. (2017), in their study on climate change and the future precipitation in Iraq, concluded that rising temperatures due to climate change are the main reason for decreasing precipitation in Iraq.

At the level of the Middle East, Adamo and Al-Ansari (2018) and Lelievld et al. (2012), in their research on the Middle East and North Africa, focused on Iraq. They also pointed out that Iraq is one of the countries experiencing water shortages, and its climate characteristics have changed from dry to very dry. It was due to the persistent rising of annual temperature and evaporation. Furthermore ،the researchers (Lelievld et al., 2012), using several climate models, have predicted that annual and seasonal temperatures in Iraq will be raised by nearly (1-3 °C) in the near future (2010-2039), (3-5 °C) between (2040-2069) and (3.5-7 °C) by the end of this century (2070-2099). Finally, another study by Masson-Delmotte (the IPCC Special Report) (2018) experienced that temperature will continue to rise globally, particularly in the Middle East and North Africa (MENA countries), where Iraq is one of those countries. This is, of course, because of cumulating GHGs and global warming, leading to the rise in monthly and seasonal temperatures.

9.CONCLUSIONS:

This study focused on Temperature Changes as a consequence of climate change in the north of Iraq/ a case study of Sulaymaniah. Based on the analyzed data (1973-2023) and discussion results, the study conducted several results, including Over the past 50 years, the average temperature has steadily increased with long-term changes recorded. The study divided the period into two stages, with the first stage having an average annual temperature of 18.62 °C. The second stage saw a 1.51 °C increase in the last 28 years due to high temperatures. The Köppen-Trewartha classification revealed that the average temperature has risen over time, and the (STI) test showed that annual average temperature increases from year to year duration continue to be shorter, and due to this, it resulted that the warmest years came in succession in the last years (2020, 2021 and 2022).

Furthermore, at the level of seasons, the average temperature in winter (as first place= 0.4), in summer (second place= 0.31), in spring (third place= 0.3), and in autumn (as fourth place= 0.14) has slightly risen. The coldest days of the year have experienced a decline in cold loss over decades, and it changed from very cold to moderate-to-low-cold, particularly after 2009. The frequency of days with temperatures reaching 44°C or higher increased between 1992 and 2023. The average annual maximum temperature has steadily risen from hot to very hot. During 1973-2023, the lowest average temperature increased steadily, transforming from cold to extremely hot. These results have assisted in forming the future trends of temperature in the study area. It also would benefit policymakers to accelerate the mitigation and adaptation strategies to deal

with the adverse impacts of climate change across Iraq, especially in the study area.

1.Funding: No funding was obtained for this study.

2.Availability of data and material: The data supporting the study's findings are not publicly available because the Seismic Meteorology Directorate of Sulaymaniyah does not share the row data to public. However, to be certain of the findings, the data can be submitted openly to reviewers.

3.Declaration of competing interest: The author declares that he has no known competing financial interest or personal relationship that could have appeared to influence the work reported in this paper.

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