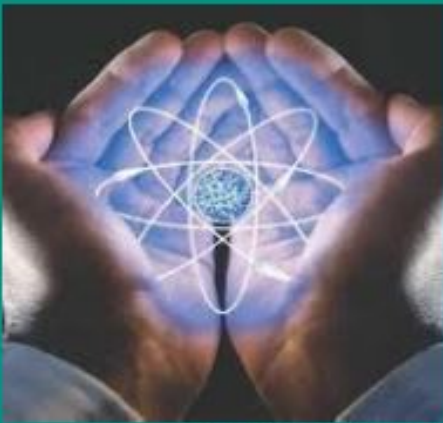


Table Of Content

Journal Cover	2
Author[s] Statement	3
Editorial Team	4
Article information	5
Check this article update (crossmark)	5
Check this article impact	5
Cite this article	5
Title page	6
Article Title	6
Author information	6
Abstract	6
Article content	7

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Study of Temperature Change in Iraq Between 2000-2020 and Its Effects on Rainfall Levels and Agriculture

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Abstract

This study is based on the understanding of the impact of temperature change on the percentage of rainfall in selected areas of Iraq, the data of Iraqi government institutions were relied upon in conducting the statistical assessment on the rates shown by the annual reports of rainfall rates in a number of Iraqi governorates from Mosul in the north to Basra in the south, the period 2000-2020 was chosen, and the CORDEX downsizing project was used, by developing scenario number RCP8.5, it has been shown by using the necessary calculations that rainfall levels will decrease at significant rates in the future if the temperature rises in the same pattern as the current one, which predicts an uncertain future for the nature of the climate in Iraq, this will have a serious impact on the agriculture, industry and all other sectors, this requires the Iraqi government to provide strategic solutions for the coming period.

Highlights :

- Government Data Assessment: Reliance on Iraqi government institutions' data for statistical assessment.
- Future Projections: Use of the CORDEX downsizing project to develop scenario RCP8.5.
- Critical Implications: Calculations reveal significant future decreases in rainfall, posing serious threats to agriculture, industry, and other sectors in Iraq.

Keywords : Temperature Change, Rainfall Levels, Iraq, CORDEX Downsizing, RCP8.5.

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Introduction

Bernard Feltz [1] argues that "climate evolution, one of the greatest challenges of our time, is as much linked to our daily lives as it is to the global geopolitical order." [2] René Descartes says that [3] "nature has been placed at the disposal of man for a sacred purpose" [4] that is, there is no randomness in this world. Environmentalism in the study of nature represents one of the most modern theories, representing an exceptional reversal in the scientific view of nature. Arthur George Tinsley argues that [5] "an ecosystem is a definite medium, with limited stocks, both before and after human intervention, that is severely affected by climate change." [6] Therefore, environmental balance is an essential element in the survival of life in its optimal form. The overuse of fossil fuels and factory activity in China, Europe and America have led to an accelerated deterioration in the nature of the climate system. Recent studies that monitored the significant shift in the global climate system confirmed the increasing temperatures and turbulence of wind and rain movement and their levels around the world. Iraq is one of the countries where global warming and climate change have led to serious repercussions at all levels [7], the most important of which is the change in rainfall levels and environmental diversity, which generated countless problems that affected the type and size of natural wealth in Iraq [8].

In this research, we will study the temperature change in Iraq between 2000-2023, and the impact of environmental repercussions on this change.

Research Importance

Iraq's location within a desert area with little rainfall, its rainfall regime is part of the Mediterranean rainfall regime, the rains begin in October and finally end in early June, the low rainfall in Iraq is due to its location, thus the terrain plays an important role in the variability of rainfall in different locations of the country. In the topography of the Iraqi plain with no elevation, the spatial variation in the amount of rainfall is small, as is the case in the central and southern regions, where the variation in rainfall is very little, in this research, we will study certain areas and governorates between the north and the south, and the purpose is to know the effect of temperature on rainfall levels.

Method

Limits of The Study Area and Research Methodology

Through this research, we will study the impact of temperature differences in the regions of Iraq for the period from 2000-2020. We have been relying on the data of the General Authority for Meteorology in Iraq, a number of statistical and geographical criteria were used in order to detect data, whether between the minimum and maximum temperature or in determining the levels of rainfall in the seasons of the year. The governorates of Mosul, Baghdad, Najaf neighborhood, and other governorates have been identified as study areas to measure temperatures or rain levels. Data monitored for the annual temperature over Iraq were obtained from the Iraqi Meteorological Authority and the <http://www.meteoseism.gov.iq/index.php> Seismological Authority. Data from The period 2000 to 2020 was used to illustrate historical trends of temperature patterns and calibrate the outputs of the expected model for the study area.

THE FIRST TOPIC

CLIMATE DISTURBANCES AFTER THE DEVELOPMENT OF INDUSTRY

The Middle East and North Africa (MENA) region is an arid to semi-arid region with an average annual rainfall of only 166 mm [9], for this reason, the scarcity of water resources in the MENA region, especially in the Middle East, it is a very important factor in the stability of the region [10], recent research suggests that the situation will be more serious in the future [11]. Climate change is one of the main factors responsible for the region's projected future water shortages, by the end of this century, average temperatures in the MENA region are expected to rise by 3°C to 5°C while rainfall will decrease by about 20% [12], runoff will decrease by 20% to 30% in most countries in the MENA region by 2050, water supply could be reduced by 10% or more by 2050 [13].

Recent studies have confirmed that the increase in average temperatures is caused by the increase in greenhouse gas concentrations after the development of industry in Europe, Asia and other continents [14], these studies have also shown that the observed increases in temperatures are beginning to affect different sectors of life, in particular, their impact on water availability [15], food security, human health, and even biodiversity [16], the steady increase in temperatures is the direct cause of the emergence of global warming, an impact that will have significant repercussions at the level of the world and Iraq in particular [17], according to the report of the International Monitoring Agency for Climate and Climate Change (IPCC), the steady change in temperature will lead to a sharp decrease in the annual rainfall rate in the Middle East [18], the report stressed that the region will be vulnerable to climate variability and real changes, its geographical location between the temperate climate zone and the continental climate makes it vulnerable to climatic dynamics [19].

Recently confirmed reports have shown pessimistic forecasts for heat projections in the Middle East, it has been reported that there has been a projected increase of 1.2 to 1.9 °C in the 21st century and that it will soon rise to 1.5-2.3 °C at the end of the century [20], this means that there will be a temperature increase between 1.7-2.6 °C before the middle of this century, and also 3.2-4.8 °C at the end of the century, in Iraq, all forecasts and research indicate that there is an increase in temperatures at the near level ranging between 0.51-1.79 according to the CCSM.2.6 model [21].

The geographical location of Iraq is a major reason for the expected climate changes, as it is one of the most important semi-arid areas that are affected by climatic and regional changes, this, in turn, will affect the amount of rainfall water resources and determine agricultural production and sustainable development [22], recent decades have witnessed an acceleration in the rise in temperatures in Iraq, accompanied by an accelerated decrease in the amount of rain by -13.5 mm [23], which led to a decrease in water cover, it is expected that in the near future the effects of the manifestations of high temperatures will be more severe, it may have unforeseen repercussions in recent studies, both on mental structure, the mechanism of resource utilization and human ability to survive [24].

Based on this extreme importance called for in the study of climate and the variables that accompany high temperatures, research centers in developed countries have invented many mechanisms and systems that help predict and measure, regional models contribute to the accuracy of the analysis by one kilometer, usually less than 25 kilometres, the study of variables and the nature of their impact depends on the study of the diverse characteristics of the Iraqi climate, which need advanced models and regional information to determine the maximum dimensions of impact and vulnerability, for example, many researchers argue that the use of high-resolution climate projections can be obtained from "narrow-banded" regional models, in this study, the spatial boundaries will be limited to the borders of Iraq, which is located in the southwest of the continent of Asia, bordered by a number of countries whose climate is almost suffering from the climate changes that Iraq suffers from, but in different proportions.

This study is based on employing the data obtained from the General Authority for Meteorology for a number of weather monitoring stations for the period from 2000-2023, the homogeneity of the data and the reasonableness of the data have been ensured, so that the anomalous values observed for rainfall percentages were excluded based on three traditional statistical methods, the first of which is monitoring the reasonableness and quality of data, the second is to complete the missing data through mathematical operations by taking the rate between the previous and subsequent reading and dividing by 2, the third is the use of a homogeneity test. We will also use regional models RCMs, as well as CAMIP5, in this research, two models were adopted, the first is the Hadley model NOHC-HadGEM2-ES, the second is the "National Terminal Management Model" GFDL-GFDL-ESM2M NOAA, the RCP8.5 high scenario and the RCP4.5 moderate scenario will also be used, the data was obtained from various sources, including the General Authority of Meteorology, the data has been modified and organized to suit the nature of the study, the descriptive approach and descriptive statistical analysis of the paths of temperature change and rainfall ratios were used, in addition, the comparative approach was employed for the results obtained from websites and previous research, the Candle MK test was used because it is one of the most important tests that reveal climatic variables due to the nature of the arithmetic operations in it that are not affected by outliers, in this paper, we also used the Sen's Slope test to show temperature trends or rainfall ratios, it also reveals their statistical significance, which are usually in probability ratios between 0.001-0.05. GIS was also relied on in mapping, and IDW in determining "spatial domains".

Station Name	LON	LAT	Hight	Tmin	Tmax	PR
Basra	46.52	32.16	2	19.91	32.9	129
Diwaniyah	43.66	32.7	20	18.9	31.6	1.5
Nasserite	45.19	30.98	5	19.6	34.8	122
Al- Nukhaib	42.19	31.17	306	16.3	31.2	79.9
Najaf	45.18	30.91	53	17.9	31.9	92.4
Baghdad	44.26	32.96	32	16.3	30.12	121
Al-Hay	45.92	31.6	17	18.2	34.11	133
Khanaqin	45.31	33.86	175	18.3	30.91	292
Rutba	39.77	32.19	629	14.32	5.69	113
Sulaymaniyah	44.97	34.89	842	15.01	23.59	682
Mousel	44.75	35.52	224	14.3	29.14	352
Kirkuk	44.26	35.31	332	16.82	24.63	342

Table 1.

Table (1): Temperature rates and rainfall percentages according to the astronomical position of the climatic stations of the selected sites in Iraq.

Based on the data of the Iraqi General Authority for Meteorology and Synovial Monitoring, longitude is expressed

in LON, latitude in LAT, minimum temperatures Tmin, and maximum temperatures in Tmax, s for the percentage of rain, it was expressed in pr.



Figure 1. shows the location of the study stations and the indicator of the areas for which measurements were taken according to Table 1. Source: Seismic Monitoring Authority in Iraq

THE SECOND TOPIC

RESULTS FROM THE DATA

First: The general temperature trend in the studied areas:

The data listed in the table below show that the general temperature trend in the studied areas is gradually rising in all areas covered by the measurement and study, this rally has a probability score higher than 0.05, thus, it is statistically significant, with the exception of the city of Nukhayb and the city of Rutba, where the average increase in the first was (0.6-3.8) degrees Celsius during the study period, in addition, the figures show that there is a clear variation in the amounts of change between the study areas, and also in the period when the changes occurred, the temperature in the summer in the city of Nasiriyah, as the amount of change reached 3.9 degrees Celsius, while the magnitude of the change in the highest temperature in the spring in the city of Al-Hay, if it reached 3.1 degrees Celsius, in autumn, the change reached 3.5 °C in the city of Nasiriyah, while in the winter the change reached 2.2 ° C in the city of Basra, the annual calculations of the semesters show that the highest amount of change was in the provinces of Nasiriyah and Najaf, where it reached 2.9 degrees Celsius, as for the rate of change in Iraq in general, it reached 2.3 degrees Celsius, the amount of change from the end of the last century to the second decade of the twenty-first century was about 2.1 degrees Celsius.

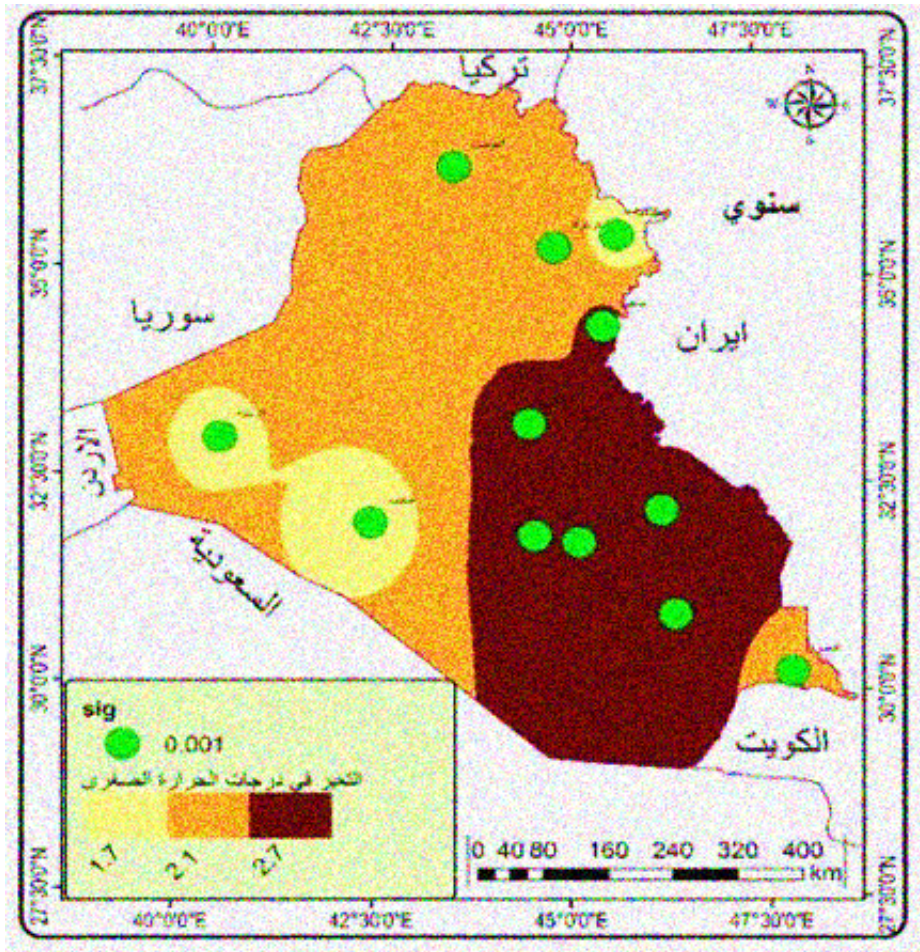


Figure 2. Represents the spatial distribution of the annual and minimum temperature trends in the stations that were monitored in the studied places. Source: General Authority for Meteorology Data (2020)

Station Name	Spring	Sig.	Summer	Sig.	Autumn	Sig.	Winter	Sig.	Annual	Sig.
Basra	1.6	***	3.4	***	1.7	**	2.2	***	2.1	***
Nasseriyah	2.6	***	3.9	***	3.5	***	1.4	*	2.9	***
Najaf	2.8	***	3.4	***	2.8	***	2.1	**	2.9	***
Diwaniyah	3	***	3.3	***	2.3	***	1.8	**	2.4	***
Al-Hay	3.1	***	3.4	***	2.6	***	2.1	**	2.7	***
Al-Nukhaib	1.7	*	1.4	**	1.7	*	1.6	**	1.4	***
Baghdad	2.4	***	3.8	***	2.6	***	1.9	*	2.7	***

Rutba	2.4	***	2.1	***	1.5	**	0.8	0	1.8	***
Khanaqin	2.8	***	3.8	***	3.3	***	0.6	0	2.4	***
Kirkuk	2.3	***	3.2	***	0.9	0	1.7	*	2.1	***
Sulaymaniyah	2.3	***	1.7	**	0.8	0	1.7	**	1.5	***
Mousel	2.5	***	1.9	**	2.4	***	1.5	*	2.2	***

Table 2.

Table (2): Rate of temperature change and general direction of minimum temperature of study stations in the period studied, *** Indication of the significance of the reading with a probability level less than 0.01, * Indication of the significance of the reading with a probability of less than 0.05. Source: Data of the General Authority for Meteorology and Seismic Monitoring, Climate Department, 2020.

Based on the above table, temperature changes are formed in three spatial bands, the temperature in the first range was 1.7 degrees Celsius, which included three governorates: "Al-Nukhayb, Al-Rutba, and Sulaymaniyah". This range is probably the least variable of all other spaces. The second range is the grouping of areas where the temperature tremor reached (2.1). This range represents the largest area in the regions of Iraq, as it includes the northern and northeastern regions, in addition to the southwest. The third band has a rate of change of 2.7, which includes the southeastern regions of Iraq.

Table (3) Rate of change in maximum temperature and direction for the region under study

Station Name	Spring	Sig.	Summer	Sig.	Autumn	Sig.	Winter	Sig.	Annual	Sig.
Basra	1.6	***	3.4	***	1.7	**	2.0	**	2.2	***
Nasseriya	3.4	***	4.1	***	2.6	Δ	2.7	*	3.3	***
Najaf	3.3	***	3.4	***	2.4	*	2.8	***	2.6	***
Diwaniyah	3.2	**	2.1	***	1.3	O	3.1	*	1.8	**
Al-Hay	2.3	***	2.9	***	0.9	Δ	1.4	**	1.9	***
Al-Nukhaib	2.8	**	3.3	***	1.9	*	1.6	*	2.2	***
Baghdad	2.8	***	2.4	***	1.2	Δ	1.8	**	2.2	***
Rutba	1.9	***	1.8	***	1.5	**	1.7	***	1.8	***
Khanaqin	3.8	***	3.8	***	2.2	**	2.4	*	3.1	***
Kirkuk	2.3	***	2.3	***	2.1	***	2.1	***	2.2	***
Sulaymaniyah	3.4	***	2.4	***	0.9	+	3.4	***	2.5	***
Mousel	3.2	**	1.9	***	2.8	**	2.3	***	2.5	***

Table 3.

As for the autumn season, it witnessed an increasing trend, but it is the lowest of the seasons, as it reached the highest rate of change in temperature (2.8) in the city of Mosul, winter recorded the highest rate of change (3.4) in Sulaymaniyah province. The general rate of change in Iraq was (2.5).

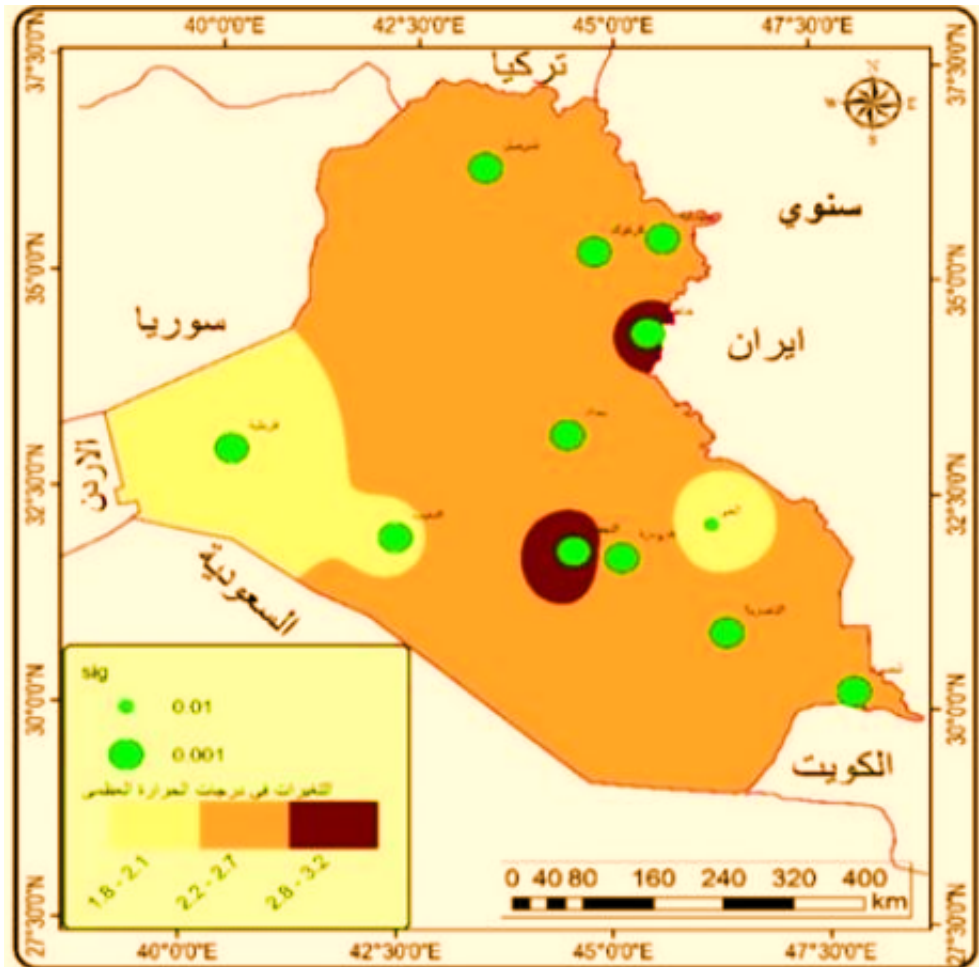


Figure 3. Spatial distribution of maximum temperatures according to the geographical location of the stations under study

Source: General Authority for Meteorology and Seismic Monitoring data for 2020.

Third: The level of change in the amounts of rain:

The analysis of the data in Table (3) below, which shows the general trend of rainfall amounts for the period from 2000-2020, at the forefront of the change in this direction is the discrepancy between increase and decrease in time and space, where the rainfall ranged between -151-21 mm, the spring season recorded a clear decrease in all studied areas except Baghdad Governorate and the neighborhood area, which recorded an opposite trend of 11.6 and 8.6 respectively.

Table (4): Rate of change in rainfall ratios for the studied stations between 2000-2020

Station Name	Spring	Sig.	Autumn	Sig.	Winter	Sig.	Annual	Sig.
Nasseriya	8.1-	N	6.6	N	31.3-	+	51.1-	N
Diwaniyah	7.3-	N	3.5	N	-22.3	N	-15	+
Al-Hay	8.6	*	-1.1	N	-27.3	*	-34	N
Al- Nukhaib	5.1-	N	6.2-	N	-4.4	N	-21	N
Baghdad	11.6	N	5.2	N	-21.5	N	4-	N
Al- Rutba	-8.3	N	1.5	N	-7.2	N	4-	N
Khanaqin	-45.3	*	12.8	N	-133	***	-151	**
Kirkuk	-16.2	N	-21.2	N	-67.4	N	-81	N
Sulaymaniyah	54.2-	N	21.4	N	-42.6	N	-90	N

Mosl	34.2-	N	16.3-	N	-45.3	N	-116	+
Basra	-5.1	N	0.7	N	-43.6	*	-50	*
Najaf	-7.9	N	0.1	N	-25.3	*	-30	N

Table 4.

Based on data from the General Authority of Meteorology and Seismic Monitoring, for the year 2020. N: indicates the lack of significance of the result.

It appears from the data in the table that it does not carry statistical significance for a significant level less than 5%, with the exception of the neighborhood and Khanaqin stations, both of them have obtained significant measurements in statistical analysis, the maximum positive change was in the Baghdad and Sulaymaniyah regions, reaching 11.6 in a positive direction and -54.2 in a negative direction, respectively, the data for the winter season showed that all the readings of the stations were negative and did not get any statistical significance at a significant level of less than 5%, except for three stations, the highest negative rate of change was at Khanaqin-133 station, the result was a statistically significant difference in probability of less than 5%. In the autumn, the results differed, most of the readings of the studied areas recorded a positive trend.

Except for the stations (Kirkuk, Al-Hay, Al-Nukhayb, Mosul), decreasing trends were recorded, the highest positive rate of change was in the Khanaqin station at 12.8, and the lowest negative rate was in Mosul at -16.3.

International bodies in their multiple publications refer to figures close to our study, the United Nations issued in the latest version of the rainfall levels in the last ten years, and they were as follows:

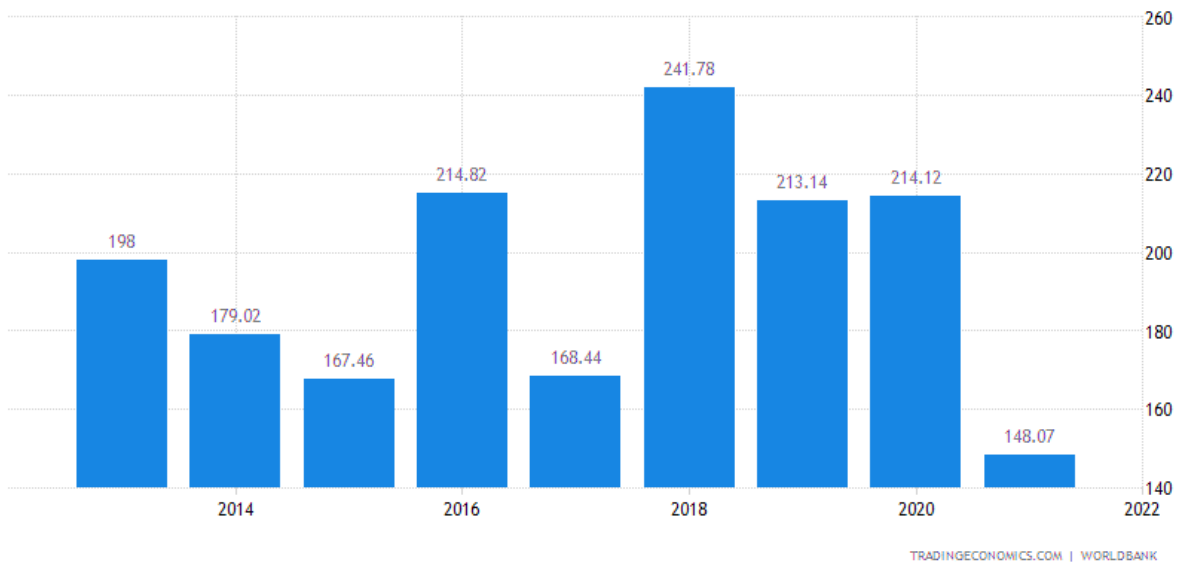


Figure 4. Represents the rate of rainfall in Iraq: Source <https://tradingeconomics.com/iraq/precipitation>

Then comparing the rate of change between years in the global report, we find that it is very close, where it appears from the above figure that 2021 is the least rainy year in Iraq, this predicts the nature of the impact that temperature differences have on agriculture, industry and all areas of wealth growth in Iraq.

FOURTH: THE IMPACT OF TEMPERATURE CHANGE ON NATURAL RESOURCES IN IRAQ:

Recent studies have proven beyond doubt that rising temperatures have brought about a significant change in Iraq and neighboring countries, where high temperatures have a negative impact on the cultivation of crops, vegetables and fruits, because the speed of evaporation of water from the soil leads to its rapid drying, which leads to the death of cultivated and natural plants, this is reflected in the sources of animal nutrition in rural and desert areas in Iraq, it has been noted that the number of animals from sheep and camels has decreased in areas with higher temperatures such as the Muthanna desert, Basra and Nasiriyah compared to the central and northern regions, recent studies issued by the United Nations, especially that Iraq and its surrounding areas, which have been affected by temperature changes so far, have proven that they will be on a date of significant change, there will be more droughts, floods, heat waves and dust storms, food security in Iraq is even more severely threatened than in other regional countries, most local and international studies have unanimously agreed that Iraq will suffer from a future water crisis and climate change may dry up the Tigris and Euphrates rivers, the highest amount of water

revenues in 2019 was 79.73 billion cubic meters, and this amount will become 10.94 billion cubic meters.

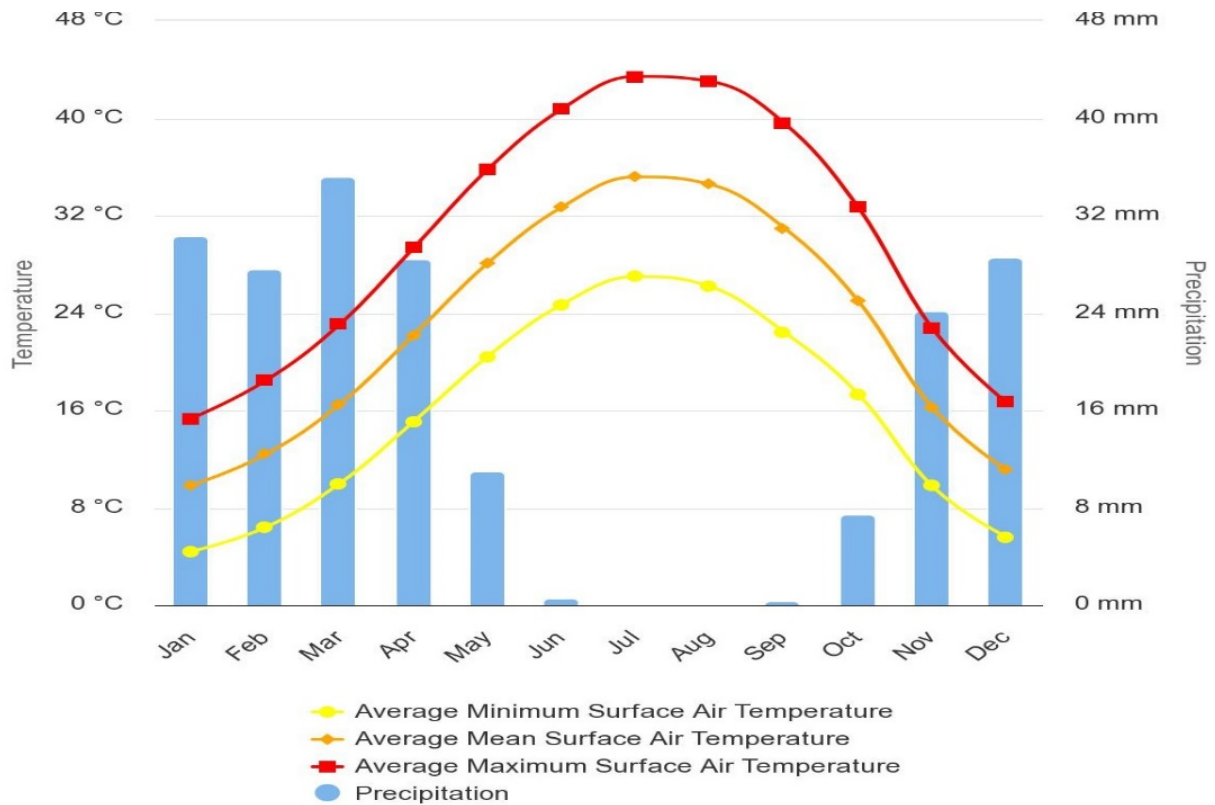


Figure 5. Represents the annual rate of rise and fall in temperatures and their relationship to the rise and fall of rain levels: Source <https://climateknowledgeportal.worldbank>.

Overall, agriculture in Iraq employs 18% of the total workforce, according to the Ministry of Labor and Social Affairs reports for 2021. Agriculture covers more than half (53%) of Iraq's arable land and is almost entirely located in the northern region, it is the region that produces Iraq's most important crops, the large deficit in the north as a result of the decline in rainfall rates significantly affects the northern regions, this is also exacerbated by the decrease in the discharge of rivers from upstream countries, as shown below by the results of the water flow analysis in Fishkhabur:

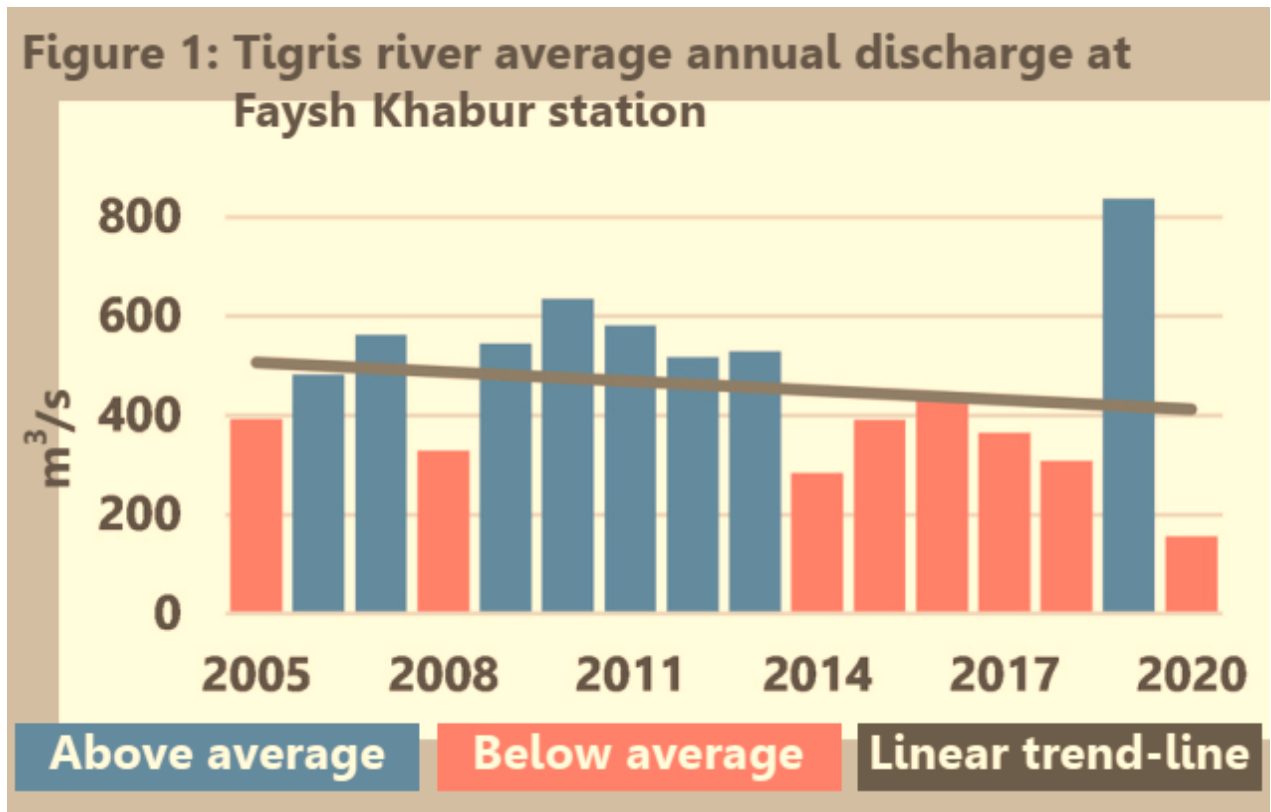


Figure 6. Annual rate of water flow from upstream in the city of Faysh Khabur. Source: REACH_IRQ_Factsheet_Iraq-Precipitation-Deficit-Over-Populated-Areas_Quarter-1-20

This leads to the displacement of farmers who migrate in search of alternative livelihoods, similarly, limited surface water available for irrigation in the center and south also causes tens of thousands of households to leave their farms, recent research center assessments in sub-districts in Diyala, Ninewa, Kirkuk and Anbar governorates have highlighted that agriculture, livelihoods, electricity, domestic water supplies and IDPs' ability to return were among the areas negatively affected by water shortages, ground assessments are needed to determine the full extent of the impact of water shortages on affected communities and the effect of fluctuation in temperature as a qualitative factor.

Results and Discussion

The relationship between temperature change and rainfall change is one of the most important factors that modern countries calculate in their traditional plans, it is usually of a high level of importance in countries with a desert climate, because these changes threaten the growth path in countries, and threaten their economy, the results we obtained indicate that there is an increasing trend in maximum and minimum temperatures and that there is a constant statistical significance for this change, the amount of change ranges between -1.6 and 3.3 degrees Celsius, and this change has also been proven by international studies such as the World Meteorological Organization, in its annual report for 2019, the average temperature change in the Middle East countries ranges from 0.5 to 0.6 degrees Celsius, in the level of Iraq, many studies have shown that the level of temperature change in Iraq in 2019 was from 1.8 to 2.9 between 1971-2019. Summer was the most changeable of the other seasons, it was reported in the study of (Musleh, 2016), (Al-Budairi, 2018) and others that the change in the summer season was statistically significant with a probability of less than 5% that the summer season changed in Iraq in different study periods, in our study, the years between 2009-2012 witnessed the most affected years and temperature changes, this result coincides with many international and global studies, and the fluctuation of the northern region of the globe may be one of the reasons for this change and fluctuation due to the negative development in this region, it has been stated in many international reports that this fluctuation of temperature in the Middle East is due to many reasons, in addition to the reasons mentioned above, it may be the eruption of global volcanoes that scattered their volcanic dust, according to a study (Tayanc et al., 2019). These factors have already done fundamentally in changing rainfall levels and precipitation rates in Iraq, the rates of this precipitation have fluctuated between high and low throughout the year, the winter and spring season in most of the studied stations tended to decline and decrease, with the exception of the city of Baghdad and Al-Hay area, in autumn, most stations recorded increasing numbers, most of the previous studies on the causes of rain fluctuation and the inability to set a fixed rate of increase or decrease and that rain takes the "polarity of the population distribution", that is, it does not follow the "natural

distribution" in its rates, that is, rainfall is not governed by fully studied factors in order to be able to predict with accurate doubt their rates in the future, because the rate of precipitation in Iraq is not only governed by the change in temperature, but there are many factors, and most of these factors Iraq does not have the keys to change, rainfall rates in Iraq are perhaps one of the few examples in the world that are random and fluctuating, whether at the seasonal or annual level, this result is consistent with previous research data such as (Al-Shujairi, 2019), (Al-Budairi, 2018), and others, all these researches and studies agree that global warming is the first reason for the fluctuation of rainfall in Iraq, most studies almost unanimously agree that temperatures are on their way to increase, there will be a rise of 1.3-1.5 ° C in the first half of the 21st century.

Conclusions

1. Temperature Trends:

The study reveals a consistent and statistically significant increasing trend in both maximum and minimum temperatures in Iraq. The observed temperature changes range between -1.6 and 3.3 degrees Celsius. This aligns with international studies, including the World Meteorological Organization's report for 2019, which indicates a similar rising temperature trend in the Middle East.

2. Seasonal Variations:

Summer emerges as the most dynamic season, with statistically significant changes in temperature observed during the years 2009-2012. This aligns with global studies and suggests a potential link to fluctuations in the northern region of the globe. Factors such as negative developments and global volcanic eruptions, as suggested by Tayanc et al. (2019), contribute fundamentally to temperature changes.

3. Impact on Rainfall:

Temperature changes have fundamental implications for precipitation rates in Iraq. Fluctuations in rainfall levels throughout the year are evident, with winter and spring seasons generally experiencing declines, except in Baghdad and Al-Hay area. Autumn records increasing precipitation numbers. The study emphasizes the random and fluctuating nature of rainfall in Iraq, influenced not only by temperature changes but also by various factors beyond Iraq's control.

4. Global Warming Influence:

Consistent with previous research, the study highlights global warming as the primary driver for rainfall fluctuation in Iraq. The anticipated rise of 1.3-1.5 °C in the first half of the 21st century further underscores the urgency of addressing climate change. Global studies and reports support the conclusion that increasing temperatures are a global phenomenon with significant regional impacts. The findings emphasize the interconnectedness of temperature change and rainfall patterns in Iraq. The study underscores the need for comprehensive strategies to mitigate the impact of global warming on the region's climate and highlights the complexity of predicting and managing rainfall in the face of various influencing factors.

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