



Trends Analysis of Climate Change Indicators and Future Projections in Iraq

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DOI: <https://www.doi.org/10.29194/NJES.29030581>

Received: March 20, 2025

Revised: April 20, 2025

Accepted: May 14, 2025

Published: Sep. 20, 2026

Abstract

Historical records (1901–2021) of Iraq's air temperature and precipitation were studied and compared. A climatic multi-model ensemble and four emission scenarios with representative concentration pathways (RCP2.6, RCP4.5, RCP6.0, and RCP8.5) are used in this research to explain the changes in future climate indicators in Iraq. The results showed a rise and decline in temperatures and precipitation over the past century, with an average of 1.3 °C and 57mm since 1901. A remarkable rise and decline in temperatures and precipitation occurred at 0.36 °C and 4mm per decade over the past thirty years (1990–2020). A greater increase in temperatures occurred in the southern regions than in the northern regions during summer. A temperature increase of 1.5 °C was observed in Basra City and 1.3 °C in Duhok City. The projected temperature over Iraq is higher than historical temperatures in all scenarios, with a rise of about 0.6°C every ten years. Days in June and September with temperatures exceeding 40 °C have a greater probability of experiencing temperature increases. Iraq is expected to have a decrease in annual precipitation under the high emission scenarios of RCP8.5. The predictions of the medium emission scenarios RCP4.5 and RCP6.0 are noticeably different from the measurements of Iraqi weather stations, especially in 2006. Precipitation decreases from November to May from the historical period in high emission scenarios (RCP8.5) for the foreseeable future. Increased air temperatures and a lack of precipitation have significant effects on the ecosystem because of droughts and frequent dust storms. Therefore, the most important decision that senior management must make is the formulation of policies and procedures for water routing and storage.

Keywords: RCPs, Multi-Model Ensemble, Temperature, Precipitation, Trend, Iraq.

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1. Introduction

Iraq is one of the most vulnerable countries in the world to climate change and desertification [1], due to the high rate of drought and summer temperatures exceeding fifty degrees Celsius for weeks, as well as a significant decrease in Iraq's water resources, where the Tigris and Euphrates rivers are experiencing a water shortage, coinciding with the rivers high rate of drought, particularly over the past two decades. Trend examination of climatic variables on various scales has become a major concern over the past few decades as a consequence of global climate change [2, 3].

Lee et al and Gardiner et al [4, 5] warned that the air temperature in the world is set to reach 1.5°C (2.7°F) above the pre-industrial level within the next two decades. These changes are contributing to long and intense severe weather, dust storms, disasters, and rising sea levels. Current global efforts are insufficient to limit warming to 1.5°C. Increasing temperatures are expected to accelerate by the end of the twenty-first century. If there are no rapid, strong, and sustainable reductions in greenhouse gas emissions from now on, reducing warming will be impossible and will contribute to an environmental catastrophe [6]. Future climate projections are primarily accomplished using general climate models (GCMs) [7, 8]. GCMs are the most effective tool for examining climate scenarios for both the present and the future

[9]. Also, to comprehend the sensitivity of the global climate system and forecast future climate change [10].

Taylor et al [11] showed that the CMIP5 (Coupled Model Intercomparison Project Phase 5) used a new set of scenarios called representative concentration pathways (RCPs) for the foreseeable use of atmospheric greenhouse gases, pollutants, and the environment. This version includes simulations of twentieth-century climate (known as historical experiments) and projection experiments of twenty-first-century climate under the new RCPs scenarios [12, 13, 14, 15] RCPs are mitigation scenarios that develop emission pathways in response to various assumed policy choices that will alter the temporal evolution of future greenhouse gases [13]. CMIP5 results have recently been used by researchers to examine potential future climate changes under RCP scenarios. Saleem et al [16] used the modified statistical trend test to estimate the tendency in climatic water availability in Iraq. According to this study, the rise in temperature is the primary cause of Iraq's rising agricultural water stress and significant rise in crop water demand. Zakaria [17] illustrated the changes in average temperatures and rainfall in the Middle East and North Africa region between the years 1900 and 2009 and in the years 2020 to 2099, with a focus on Iraq. Since the monthly average temperature varied, it is obvious that there will be a rise in temperature in the future. Mustafa [18] evaluated climatic changes over Iraq by 2040 by using the Regional Climate Model (RegCM-V4) and RCP (8.5) scenarios created by

the International Center for Theoretical Physics. According to the study, there is a lot of ambiguity around the center and southern parts of Iraq's regional climate change index, which is projected to be rather moderate. Based on the information obtained from the scenarios additionally to the coordinated zonal downscaling experiments. Al-Budeiri [19] demonstrated that future climatic changes will result in an increase in minimum and maximum temperatures as well as a decrease in rainfall across Iraq, especially in the southern regions. The estimates are offered briefly based on a multi-model ensemble of CMIP5 results with the goal of providing references or suggestions for further understanding the influence of GHGs on future climate change across the region [20].

This study seeks to achieve several objectives, including the analysis and assessment of the spatial distribution of historical observed temperature and precipitation in Iraq. It used the multi-model ensemble of CMIP output under RCP scenarios to project future climate factors such as temperature and precipitation in Iraq during the period 2021–2099.

2. Study Area

Iraq is located in southwest Asia (Latitude: 29.25°N–38.25°N; Longitude: 38.75°E–48.75°E) and has a total area of 438,320 km². The land covers 433,41 km² of the total area, while the water covers 4,910 km² [21]. Turkey shares a northern border with Iraq, a southern border with Saudi Arabia and Kuwait, an eastern border with Iran, and a western border with Syria, as shown in Fig.1. Due to its geographical location, It is one of the most susceptible countries to the effects of global warming in numerous dimensions [22].

According to the type of land cover, Iraq can be divided into the Mountain Region, Mesopotamian Plain, Jazira, and Western Plateau Regions [23]. According to the Köppen climatic classification system, Iraq's climate can be divided into three zones: zone 1 has a Mediterranean climate in the northern mountains; the southern upland region has a subtropical steppe climate (zone 2); and the middle and southern Iraqi areas have a subtropical desert climate (zone 3) [24].

average highs of over 45°C in July and August and lows of 25°C at night [26, 23].

3. Materials and Methods

3.1 Data sources

This paper attempts to study the annual and seasonal variability of historical (1901–2021), station-based, and future (2021–1999), model-based, air temperature and precipitation over Iraq. The annual and monthly data for both temperatures and precipitation have been collected from the Climatic Research Unit (CRU), which considers a grid time series covering the land at coordinates of half a degree latitude and half a degree longitude.

It is calculated by extrapolating monthly climate anomalies from massive networks of weather station readings. It is derived from monitoring data from international meteorological stations, including those in Iraq. Thousands of weather stations throughout the world are used to estimate unavailable data. This data was used to understand climatic conditions and estimate future climate scenarios with the expected change [27, 28, 29, 30].

Four scenarios of RCP (2.6, 4.5, 6.0, and 8.5) were chosen. The RCP2.6 scenario indicates very significant emissions reductions. RCP 8.5 refers to a high emission scenario, while RCP 4.5 and RCP 6.0 relate to a medium emission scenario [31].

Projected data were acquired from the output of the multi-model ensemble under CMIP5, which was tested against the four RCP scenarios of 2.6, 4.5, 6.0, and 8.5. The four alternative time frames, 2020–2039, 2040–2059, and 2080–2099, are used to calculate monthly and annual precipitation and temperature data. Zhou and Yu, Huang et al [32, 33] concluded that using a combination of models gives more reliable results with a lower error ratio..

3.2 Statistical Methods

Describe and analyze the observed and projected climate indicators (temperatures and precipitation) in the twenty and twenty-first centuries. Compare project results from the model with results from local measurements at Iraqi weather stations. A statistical model is fitted to study trends in the long-term temperature and precipitation of Iraq for different periods.

The mean and linear trend in equations (1) and (2) are applied to air temperature (T) and precipitation (p) factors over Iraq during the study period.

$$(\bar{x}) = \frac{1}{n} \sum_{i=1}^n (x_i) \quad (1)$$

where $\bar{x}$ = samples mean; n = sample size; x_i = samples;

By considering a historical data set of climate factors, simple linear regression, an empirical method for solving statistical issues, can be carried out. A straightforward linear regression model is limited to two variables. The trend is computed for annual temperature and precipitation by using the formula:

$$\text{trend line} = y_i = ax_i + b \quad (2)$$

where a, b = regression coefficients; a = slope and b = intercept of regression line

To measure how well data can be represented in the regression line, the coefficient determination (R^2) is used. It's a vital tool for assessing how well variables in regression analysis are linearly correlated [34, 35, 36].

$$R^2 = 1 - \frac{\sum_{i=1}^n (x_i - y_i)^2}{\sum_{i=1}^n (\bar{y} - y_i)^2} \quad (3)$$

A temperature or precipitation anomaly is a deviation from the reference value, which is computed as a defined time period average called the baseline value. The positive (above the baseline) or negative (below the baseline) values indicate the observed

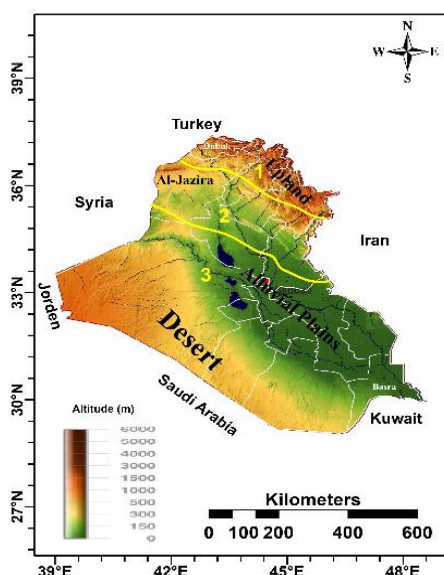


Figure (1): Iraq topography and climate zones [25]

Rainfall typically falls in the alpine region from November to April or from December to February. The average daytime temperature in winter is around 16°C, with nighttime lows of 2°C and the chance of frost. But in the summer, it is extremely hot, with

temperature was warmer or cooler than the reference value, and the precipitation was rising or declining from the reference value. The spatial derivation method IDW (inverse distance weighing) is used in ArcGIS to describe spatial historical and future climate changes in temperature and precipitation in Iraq.

4. Results

Annually, temperatures vary greatly according to elevation. The mountainous regions witness lower temperatures than the central and southern regions. The arid southern regions regularly experience temperatures in excess of 26°C. It is noted in Table 1 that the mean annual temperature (T) in Iraq was 22.23 °C and the mean annual precipitation (P) was about 174.75 mm.

Table 1. Summary statistics for mean annual climate variables in Iraq during the period 1901-2021

Climate Variables	1901-2021
T (°C)	22.23
P (mm)	174.75
Max T (°C)	29.44
Min T (°C)	15.06

On a monthly basis, as shown in Fig.2, the monthly mean of temperatures ranges between 35 °C in June and July and 9.9 °C in January. The highest precipitation occurs from November to April, and extremely low levels of precipitation occur from June to September.

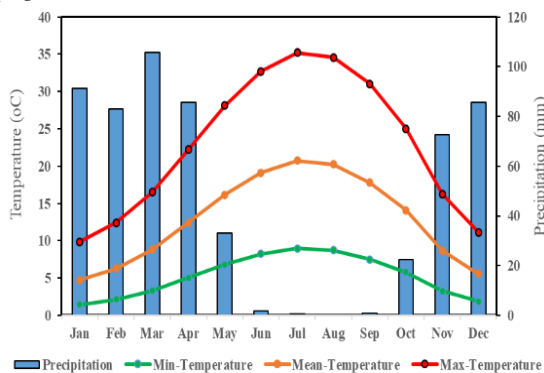


Figure 2. Monthly mean, maximum, minimum temperature, and precipitation in Iraq during the period (1991–2020)

The observed annual mean temperature and precipitation in Iraq from 1991 to 2020 are depicted in Fig.3 as spatial variations. Its notice the inverse relationship between temperature and precipitation, especially in the northern and northeastern regions, where it's found temperatures lower than in the central and southern regions, while the amount of precipitation was higher.

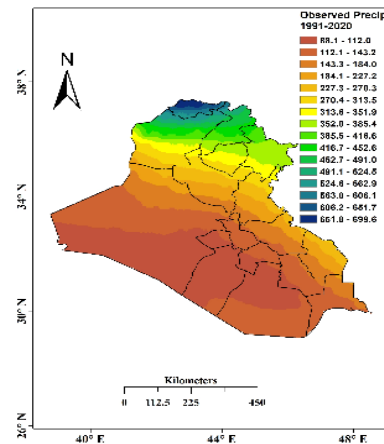
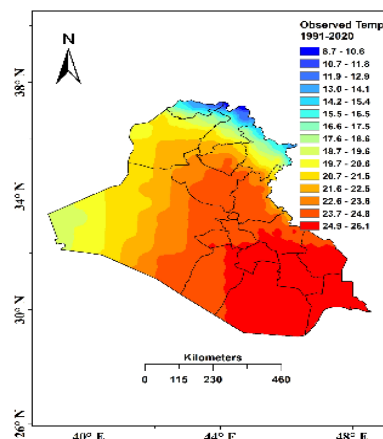


Figure (3): Spatial distributions of annual observed (a) temperature and (b) precipitation in Iraq 1991–2020

4.1 Temperature Trends in Iraq

Iraq has witnessed a rise in temperatures over the past century, with an average temperature increase of 1.3°C since 1901 (Fig.4). Iraq has also witnessed a remarkable rise in temperatures over the past thirty years, 1990–2020, with temperatures rising by 0.36 °C per decade.

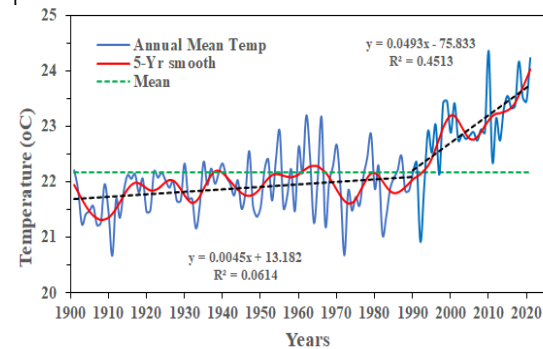


Figure 4. Annual mean temperature for Iraq (blue line), 5-year smooth (red line), mean (1901-2021) (green dash line) and trends in (black dash line)

In the southern regions of Iraq, a greater increase in temperatures than in the northern regions occurred during the two periods (1901–1930) and (1991–2020), where a temperature increases of 1.5 °C was observed in Basra city while the increase was 1.3 °C in Duhok city. The highest temperature was during the summer season, and the lowest was in the autumn, as shown in Table 2..

Table 2. Increase in seasonal observed temperature between periods 1901–1930 and 1991–2020

	Win	Spr	Sum	Atu	Mean
Iraq	1.3	1.3	1.7	0.9	1.3
Basra	1.2	1.4	2.1	1.2	1.5
Dahuk	1.3	1.0	1.1	0.4	0.9

The annual temperature anomalies are in relation to the baseline of the period from 1901 to 1930 depicted in Fig. 5.

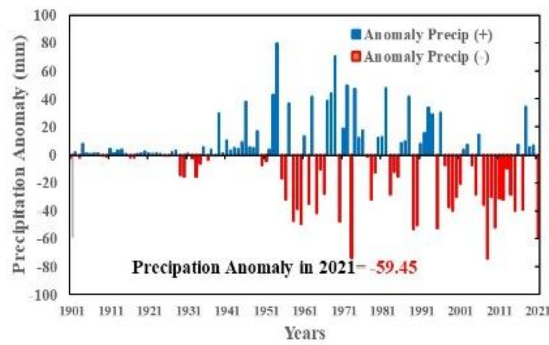


Figure 5. Observed mean temperature anomaly for Iraq, 1901–2021

The red bar represents years with temperatures higher than the baseline, while the blue bar represents years with temperatures lower than the baseline. The 2010 temperature anomaly was the highest for the period of 1901 to 2021, measuring 2.6 °C, while the average temperature anomaly in 2021 was 2.47 °C.

4.2 Precipitation Trends in Iraq

The last three periods (1931–1960), (1961–1990), and (1991–2020) have seen significantly more variation in precipitation in Iraq than the previous generation (1901–1930), which saw very low annual precipitation levels. Since the 1990s, severe droughts have affected all of Iraq, and there has been a notable decline in precipitation compared to the average for the period from 1901 to 2020, as shown in Fig. 6.

Precipitation in Iraq has decreased over the last four decades, from 1901 to 2020, with an average precipitation increase of 57 mm since 1901. Precipitation in Iraq has also increased dramatically over the last thirty years, from 1990 to 2020, increasing by 4 mm per decade.

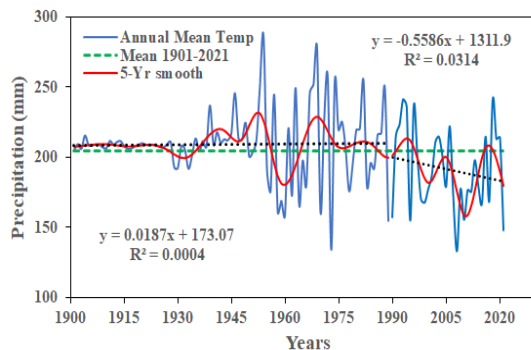


Figure 6. Observed precipitation in Iraq from 1901 to 2021. The annual mean is shown in blue, and five smoothing averages are displayed in red. mean (1901–2021) (green dash line), black slash line trend

The graphic in Fig. 7 displays the amount of annual average precipitation that has been above or below the average baseline for the years 1901–1930. Years below the baseline are displayed in red, while years above the baseline are displayed in blue. Fig. 7 illustrates the scarcity of precipitation in Iraq, particularly over the previous 30 years.

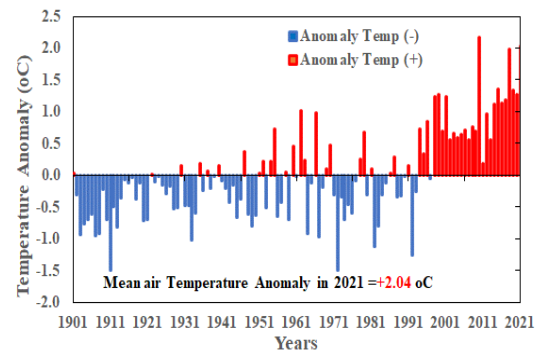
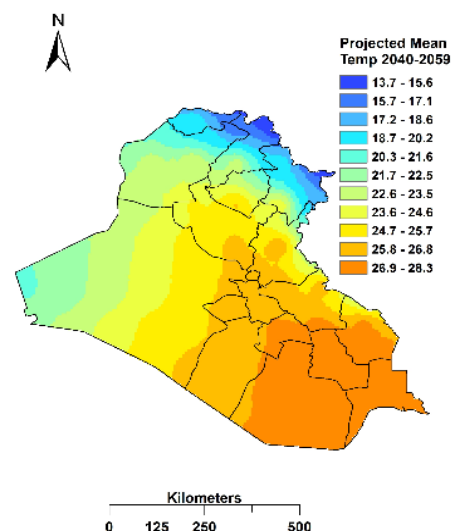
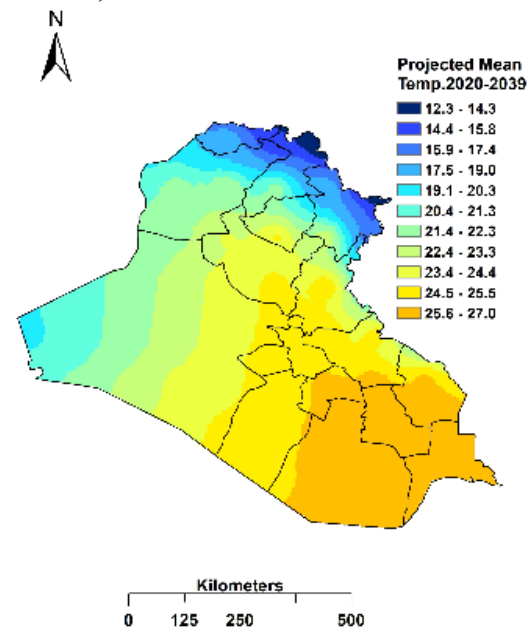


Figure 7. Observed annual precipitation anomalies for Iraq from 1901 to 2021 compared to the baseline from 1901 to 1930. temperature over a baseline is displayed in blue bars, and years with low temperature are displayed in red bars.

4.3 Climate Future in Iraq

Key climate indicators (temperature and precipitation) have been estimated using CMIP5 over four different time horizons according to the high emissions scenario (RCP8.5).

Fig. 8 and Fig. 9 show the expected changes in annual temperatures and precipitation for each of the periods 2020–2039, 2040–2059, 2060–2079, and 2080–2099 for the CMIP5.



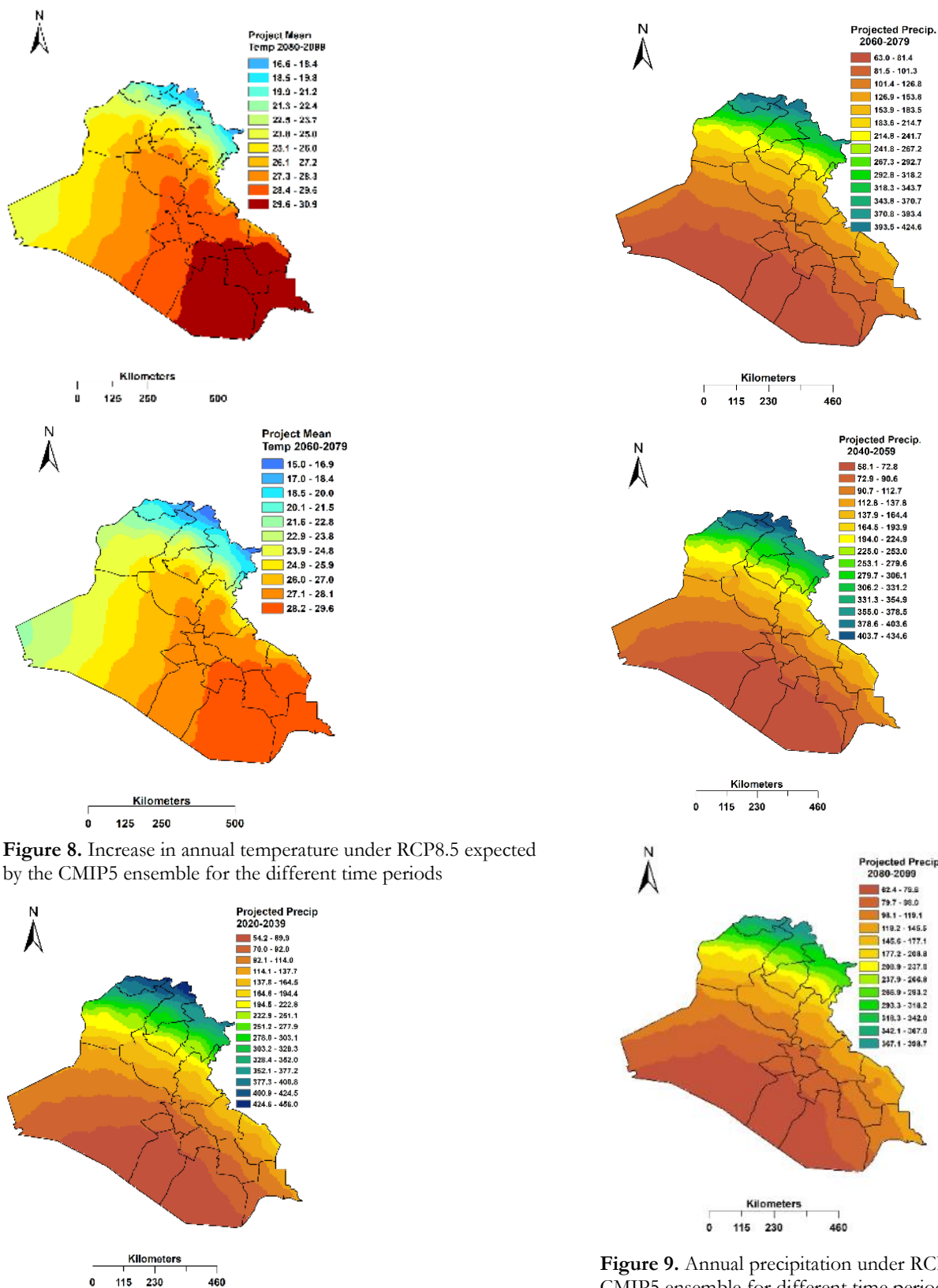


Figure 8. Increase in annual temperature under RCP8.5 expected by the CMIP5 ensemble for the different time periods

Figure 9. Annual precipitation under RCP8.5 is expected by the CMIP5 ensemble for different time periods.

4.4 Temperature Future Trends

According to projections, Iraq's temperature will rise by about 0.6°C every ten years. By the 2050s, the average monthly temperature is predicted to rise by 1.2°C and will increase to 4.1°C by the end of the 21st century. Increased temperatures are also probably going to cause more evaporation, which will further exacerbate the drought in Iraq. Through the end of the century, Iraq's temperatures will increase under all emission scenarios. By the middle of the century, average temperatures are predicted to

rise significantly under the high emission scenario, as illustrated in Fig. 10.

On a monthly basis, the projected temperature over Iraq is higher than the historical temperature (1986–2005) in all scenarios (RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5), as shown in Fig. 11. Over the duration of the seasonal cycle, days in June and September with daytime temperatures exceeding 40 °C have a greater probability of experiencing temperature increases (Fig. 12). Significant effects on the ecosystem from droughts and frequent dust storms will result from an increase in temperatures.

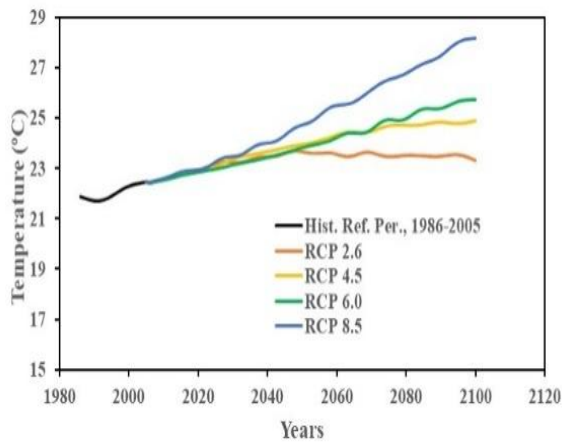


Figure 10. Historical and projected average temperature for Iraq in the period from 1986 to 2099.

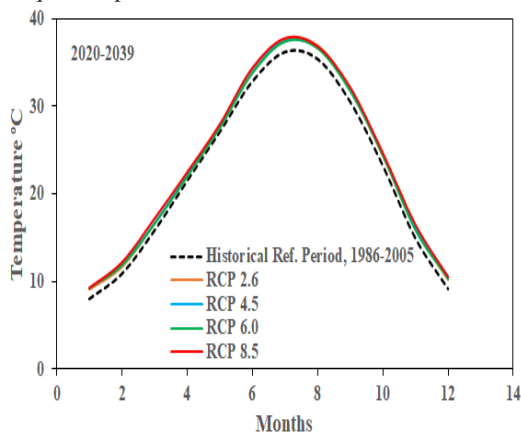


Figure 11. Historical (1986–2005) and projected (2020–2039) temperature according to all scenarios for Iraq

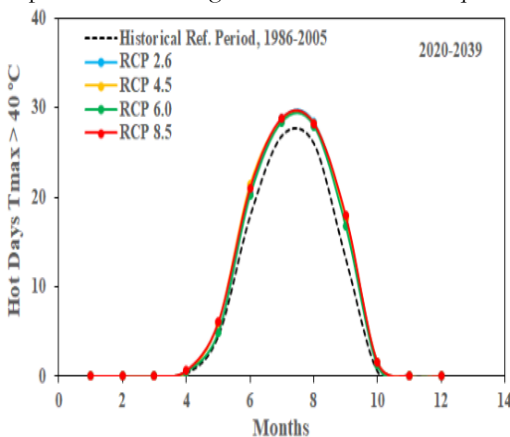


Figure 12. Historical (1986–2005) and projected (2020–2029) hot days $T_{max} > 40^{\circ}\text{C}$ according to all scenarios for Iraq

4.5 Precipitation Future Trends

Iraq is expected to have a decrease in precipitation in general under the high emission scenarios RCP8.5, while the medium emission

scenarios RCP4.5 predict an increase in precipitation compared to other scenarios, as depicted in Fig. 13. Also, RCP6.0 predicts a significant increase in precipitation, especially in 2006. This is contrary to what was stated in the observations of the Iraqi Metrological Organization and Seismology at that time.

Precipitation trends in Iraq vary across the months of the four different periods (2020–2039, 2040–2059, 2060–2079, and 2080–2099) under high emission scenarios. The predicted decrease in Iraq's monthly average precipitation from the historical period (1986–2005) is depicted in Fig. 14. It will be clear in the following decades: 2040–2059, 2060–2079, and at the end of the century, 2080–2099, especially from November to May.

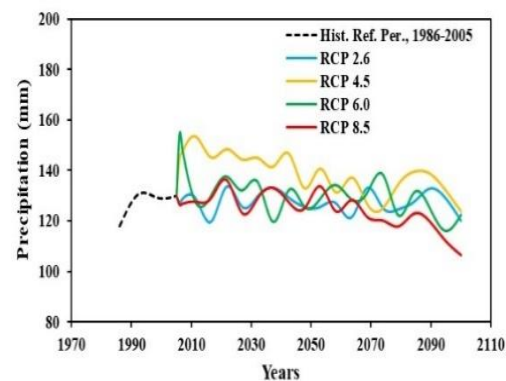


Figure 13. Historical (1986–2005) and projected (2006–2099) annual average precipitation for Iraq under four different scenarios.

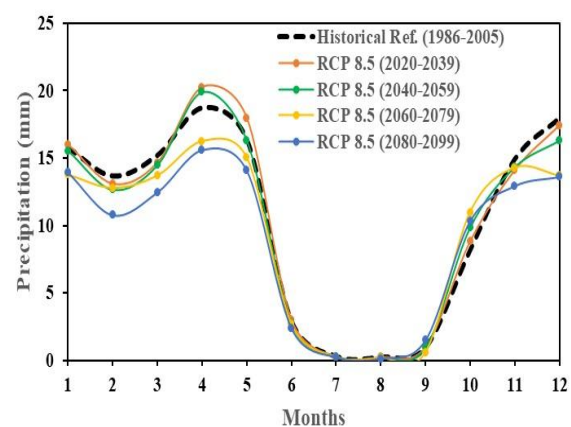


Figure 14. Monthly historical (1986–2005) and projected monthly average precipitation for the four different time periods under the high emissions scenario (RCP8.5) for Iraq.

5. Conclusions

The analysis of historical and expected climatic indicators has shown the following:

- Trends in temperature vary more than those in precipitation; drier weather is common in Iraq, especially in central and southern areas.
- Iraq is expected to suffer higher temperatures and a lack of rainfall in the future, making it more susceptible to droughts and severely impacted by them.
- A continuous warming trend, with an increase in the number of hot days and summer months in Iraq
- The results from the climatic multi-model ensemble under CMIP5 over Iraq correspond to the results of previous research that relied on one model.
- It is expected that the decrease in precipitation will have a significant effect on the growing season and on agriculture in Iraq; therefore, one of the most important decisions that the top

management must make is the formulation of policies and procedures for water routing and storage.

Acknowledgements

The author is grateful to the Climate Change Knowledge Portal, the Iraq Meteorological Organization, and Seismology for providing support.

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