

## Air Temperature Projections over the Mid and Southern of Iraq during the 21th Century Under Representative Concentration Pathways (RCPs), RCP 4.5 and RCP 8.5 Scenarios

Hassan K. Abdulhussein<sup>1\*</sup>, Alaa M. Al-lami<sup>1</sup> and Bassim M. Hashim<sup>2</sup>

<sup>1</sup> Atmospheric Sciences Department, College of Science, Mustansiriyah University, Baghdad, Iraq

<sup>2</sup> Environment, Water and Renewable Energy Directorate, Ministry of Science and Technology, Baghdad, Iraq

\* Correspondence: hassankhamess@gmail.com

### Abstract

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Global climate conditions and hydrologic processes have changed significantly as a result of climate change, and as long as global warming persists, extreme events will probably more frequently happen. Climate change significantly affects Iraq through variations in air temperature, environment, agriculture and water supply. This study aimed to evaluate the observed period of temperature 1980–2023 and the Projecting future trends of air temperature for mid and southern Iraq using BNU-ESM, CCSM4, HadGEM2-AO, and MIRI0C5 climate models from CMIP5 under the RCP4.5 and RCP8.5 scenarios during the periods 2016–2035, 2046–2065, and 2081–2100. The findings verified that, in each of the two RCPs scenarios temperature would increase with different levels. the results showed that the temperature anomaly increased to +15.6 °C, and +18.8 °C under RCP4.5 and RCP8.5 in the MIRI0C5 model, especially in the last decade of the twentieth century. The areas of Iraq most impacted by high temperatures are the south and southeast (Basra, Missan, Thi-Qar, and Muthanna) provinces. In the first period, On the other hand, the less effect areas for the temperature increase were (Anbar and northeast of Diyala) +2.4°C, and +4.4°C for HadGEM2-AO model under RCP4.5 and RCP8.5 respectively. Through all periods, CCSM4, and MIRI0C5 models were the most identical in results. The findings can aid in the evaluation of future drought risks in Iraq by policymakers. Developing suitable adaptation techniques to counter act climate change can also be beneficial.

**Keywords:** RCP; Temperature; Climate Change; Iraq

### 1. Introduction

Research aimed for identifying climate change caused by humans, its consequences for weather patterns and extreme weather events worldwide that requires immediate attention, reduced agricultural output, a higher chance of famine, a shortage of water, the fast melting of glaciers, heat waves, heavy precipitation, droughts, and tropical cyclones are all examples of how climate change is currently being felt, (IPCC, 2021).

The global warming effect is projected to worsen climate change in the future, a natural response to human activity that threatens human lives and livelihoods (Bayatavrkeshi et al., 2023). As a result of the effects of greenhouse gases, Earth's global temperature is rising continuously (Altemimi et al., 2023). During the past century, the earth's temperature has risen by 0.74 °C. The concentration of greenhouse gases (GHGs) in the atmosphere has increased due to human activity, causing a 1°C increase in global

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temperature since pre-industrial times (Doulabian et al., 2020; Awadh and Ahmad, 2010). Among the countries that are most susceptible to the effects of climate change, Iraq is classified as the fifth most vulnerable across the globe (UNEP, 2016). Being one of the driest countries in the Middle East, Iraq is especially at risk from climate change and other forms of climate variability (Salman et al., 2017; Nedham and Hassan, 2020).

The increase in the temperatures as a result of climate changes causes the changing of the soil properties and processes, such as organic matter decomposition, greater leaching losses, decreased soil water, and degradation through reducing soil moisture, (IPCC, 2007; Awadh, 2023). By 2050, Iraq can expect yearly average temperatures to rise 2 °C and more heat waves. Rising temperatures are leading to drier soils and more arid conditions, which are exacerbated by less precipitation and longer droughts (Demir et al., 2013). The significance of climate for human existence is linked to the positive or negative effects of climate on social and economic aspects and how they interact (Jaafar et al., 2020).

The World Climate Research Programs (WCRP) actively promotes models, which are thought to be the best available instrument for evaluating how the Earth's climate system would react to various radiative scenarios relating to the concentrations of greenhouse gases in the atmosphere (RCPs) (IPCC, 2014).

Analyzing the forecasts of 21 century climate change has never been easier thanks to the Coupled Model Intercomparison Project Phase 5 (CMIP5) repository, which was a contribution to the (IPCC) Fifth Assessment Report (AR5), which states that the atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased (Taylor, 2012). (CMIP5) encompasses more extensive and intricate experiments and (GCMs) that address a broader spectrum of scientific issues through many representative concentration paths (RCPs). The newly released (CMIP6) has a fresh start year (2015) and updated emission, concentration, and land-use scenarios known as shared socioeconomic pathways (SSPs) instead of starting with 2005 for future scenarios in (CMIP5) (Eyring et al., 2016). A set of greenhouse gas concentration and emissions pathways called the Representative Concentration Pathways (RCPs) were created to support research into the effects of and possible policy responses to climate change (Moss et al., 2010; van Vuuren et al., 2011).

Due to the advancement in modeling and significance of the climate system, the general circulation models have become an essential tool for the climate change processes, (Atlas of Global and Regional Climate Projections, 2013). A multitude of institutions and organizations, encompassing national and international governments, as well as local and federal governments, along with non-governmental organizations, have collaborated in diverse ways to precisely forecast prospective climate alterations and their impacts, to enhance people's livelihoods in more favorable and consistent surroundings (Ahmed et al., 2023). According to earlier studies' findings, the effects of simulated climate change in various regions vary widely and are strongly influenced by the emission scenarios and climate models used, future climate change for Turkey using a regional climate model (RegCM4.3.4) and downscaling method from outputs of (HadGEM2-ES), temperature difference values tend to increase from now to until the end of the century (Demircan et al., 2017). Changes in projected temperature and precipitation over the Arabian Peninsula for the twenty-first century using (CMIP6) dataset Projected changes in temperature show a large increase in the annual and summer season (Almazroui et al., 2020). Forecasting Iraq's Future Climate, the (CCSM4) climate model, which is part of (CMIP5), was used to estimate future air temperatures. The results under the (RCP2.6, RCP4.5, RCP6.0, and RCP8.5) scenarios indicate that the direction of temperature expansion is from the south toward the center, west, and north of Iraq (Mohammed et al., 2021). Temperature projections over Iran during the twenty-first century using (CMIP5) models under (RCP4.5) indicate an increase in the average temperature until the end of the century (Usta et al., 2021). The mean air temperature was higher under (RCP) than (SERS) scenarios

under Delta and Middle Egypt, the annual mean air temperature was lower under (RCP) than (SERS) scenarios in 2025 and 2100 (Farag *et al.*, 2016).

The present investigation is an endeavor to comprehend the future climate of Iraq based on the predictions of the (RCP) climate models. The aims of the study are employing two future scenarios, (RCP4.5 and RCP8.5), using (Bun-ESM, CCSM4, HadGEM2-AO and MIRI0C5) models to project changes in temperature during three periods: 2016-2035, 2046-2065 and 2081-2100 during the 21th century.

## 2. Materials and Methods

### 2.1. Study Area

Iraq is located in Western Asia and the northeast of the Arab Peninsula (latitude 29°15' N to 38°15' N and longitude 38°45' to 48°45' E). It has a total area of around 437,072 km<sup>2</sup> (Al-Khalidi *et al.*, 2018). The population of Iraq in 2023 is more than 43 million, and the annual population growth rate is 2.5%. About 50% of the population is concentrated in the governorates of (Baghdad, Nineveh, Basra, and Thi-Qar), and the urban population constitutes 70% compared to 30% of the rural population, (Ministry of Planning, 2023). The Tigris and Euphrates, are two significant rivers in Iraq that originate in Turkey and meet to form the Shatt al-Arab in the south of Iraq, which drains into the Arabian Gulf, (Tao *et al.*, 2022). Turkey supplies 71% of the water in these rivers, with Iran providing 6.9% and Syria providing 4%, whereas Just 8% of the total comes from internal sources, (Al-Ansari and Knutsson, 2011). A basin of the alluvial plain of Mesopotamia is depicted by the topography. The high-altitude areas are in the north and east, where mountains and plateaus chain, then the gradient to low elevation in the southeast and southwest, as shown in (Fig. 1).

The shift in contrasts climate change-related increases temperature, have been observed in the majority of Iraqi stations (Al-Timimi *et al.*, 2021). Iraq's summers (July – October) are hot and dry (over 48 °C) for most of the country. In Iraq, the spring and fall are quite brief (Hameed *et al.*, 2018).

The Middle East and North African (MENA) countries have several common characteristics, including mountainous topography, distinct orography, water scarcity, and long, hot summers. Climate fluctuation is widespread in the MENA area. Dominated by an arid climate, it is the world's driest area, (Saab, 2017). According to the (IPCC), the (MENA) region will face more climate challenges in the coming century (IPCC, 2021). Various mitigation methods have been recommended by national and international agencies. If current trends continue, parts of the (MENA) area might become uninhabitable by the year 2100 (Pal, 2015).

The southern and central parts of Iraq experience dry and semi-arid climates, whereas the rest of the nation experiences a variety of climates, including continental and subtropical. but a Mediterranean climate is prevalent in the mountainous regions of the north and northeast (Al-Ansari *et al.*, 2018; Salman *et al.*, 2020). Precipitation can last up to six months (November–April), however, it typically occurs from December to February (The World Bank, 2006; Al-Lami *et al.*, 2021). Although the country's average annual precipitation is 154 mm, it varies greatly, with 60% of the south and west receiving less than 100 mm and the northeast receiving up to 1200 mm (Al-Ansari, 2013; Al-Yasiry *et al.*, 2023).

The current study concentrated on the mid and the southern region of Iraq which consist of 12 provinces (Anbar, Baghdad, Diyala, Karbala, Babylon, Wassit, Najaf, Dewanya, Thi-Qar, Missan, Muthanna and Basra). Drought is becoming a fixture in this landscape, due to a drying trend of the Mediterranean and Middle East Region which is fueled by global warming (Holthaus, 2014). Between 1970 and 2013, the transportation sector's (CO<sub>2</sub>) emissions increased dramatically due to the growth of

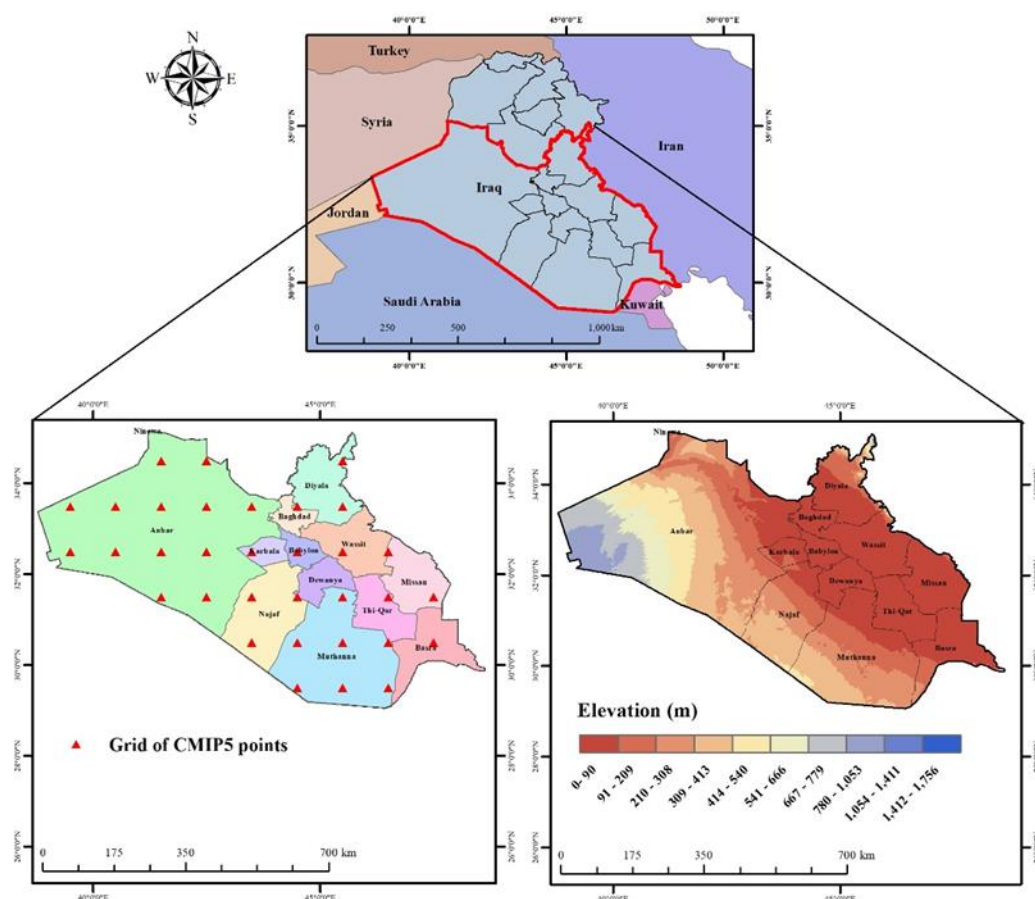


**Fig. 1.** The study area of mid and southern Iraq, Elevation of study area (DEM), and grid of CMIP5 points in Iraq

various transportation modes and high fuel consumption (Hashim et al., 2016). As a result of extreme weather events, altered climatic patterns, longer droughts, sand and dust storms, land degradation, flash floods, water scarcity, heat waves, intense precipitation, rising temperatures, and increased variability and unpredictability of rainfall. water flows from the Euphrates and Tigris, which provide up to 98% of Iraq's surface water, have decreased by 30-40 %. The historic marshlands in the south, a natural heritage wonder, are drying up. Iraq's temperatures are soaring, with the highest of nearly 54°C recorded in Basra (United Nations News, 2022; Muhammed and Al-Dabbas, 2022).

## 2.2. Data Sources

The (CMIP5) projection for the middle and southern regions of Iraq under (RCP4.5) and (RCP8.5) was utilized in the present study for three future periods: the near future (2016–2035), the mid future (2046–2065), and the far future (2081–2100). Table 1 describe the models that have been used in the current study.

**Table 1.** Summarized of CMIP5 –RCPs models used in current study (Doulabian et al., 2020)

| No. | Model identifier | Institution (Modeling Center)                                                                                                                                                    | Spatial resolution |
|-----|------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|
| 1   | BNU-ESM          | College of Global Change and Earth System Science, Beijing Normal University (GCESS)                                                                                             | 2.8°×2.8°          |
| 2   | CCSM4            | National Center for Atmospheric Research, USA (NCAR)                                                                                                                             | 1.25°×0.9°         |
| 3   | HadGEM2-AO       | Met Office Hadley Centre (MOHC)                                                                                                                                                  | 1.875°×1.25°       |
| 4   | MIROC5           | Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies and Japan Agency for Marine-Earth Science and Technology (MIROC) | 1.4°×1.4°          |

Historical and future data of annual temperature anomaly inputs were retrieved from the Canadian Centre for Climate Modelling and Analysis (CCCMA) at <https://climate-scenarios.canada.ca/gridded-data>. The multi-model ensembles of projected changes in temperature and precipitation are expressed as anomalies, with respect to the reference period of 1986-2005. Used data from Shuttle Radar Topography Mission (SRTM3) <https://www.webgis.com/srtm3.html> to derive the digital Elevation Model (DEM) for the study area. The annual average temperature data was collected from the Iraqi Meteorological Organisation and Seismology (IMOAS) (<https://meteoseism.gov.iq>). Data on temperature in Iraq were collected from (8) meteorological stations between 1980 and 2023.

### 2.3. Methodology

The Mann-Kendall test is a commonly used nonparametric test that is effective in detecting trends in hydrological and meteorological time series using Sen's slope (Partal and Kahya, 2006). This method offers numerous benefits as it is a nonparametric test that does not necessitate the data to follow a normal distribution. This test is not very sensitive to unanticipated interruptions that caused by inhomogeneous time series (Tabari et al., 2011).

Based on the (CMIP5) database, two (RCP) scenarios (RCP4.5 and RCP8.5) were chosen to project the temperature changes over the middle and southern Iraq for the four models in the future. The upcoming periods are 2046–2065, 2081–2100, and 2016–2035. The data was derived from the (CCCMA) dataset in the format of Network Common Data Form (NetCDF), under (CMIP5). In the second step, the data is processed with ArcGIS Pro, which turns it into vector data in the form of shapefiles. It is then downscaled to fit inside the borders of the provinces in the middle and southern Iraq. Table 2 shows the location and coordinates of grid (CMIP5) points in the middle and southern of Iraq that were achieved in the present study.

### 2.4. RCP Scenarios

The (RCP) provides the preliminary values and predicted emissions for each category up to 2100, based on assumptions about economic activity, energy sources, population increase and socio-economic factors. These scenarios were intended to be included in the (IPCC) 5th Assessment Report. Four scenarios of (RCPs) having the desired properties were identified in compliance with this decision, (TSMS, 2015), the two scenarios used in this study are described in Table 3.

### 3. Results

#### 3.1. Temperature Data Recorded in Iraq from 1980 until 2023

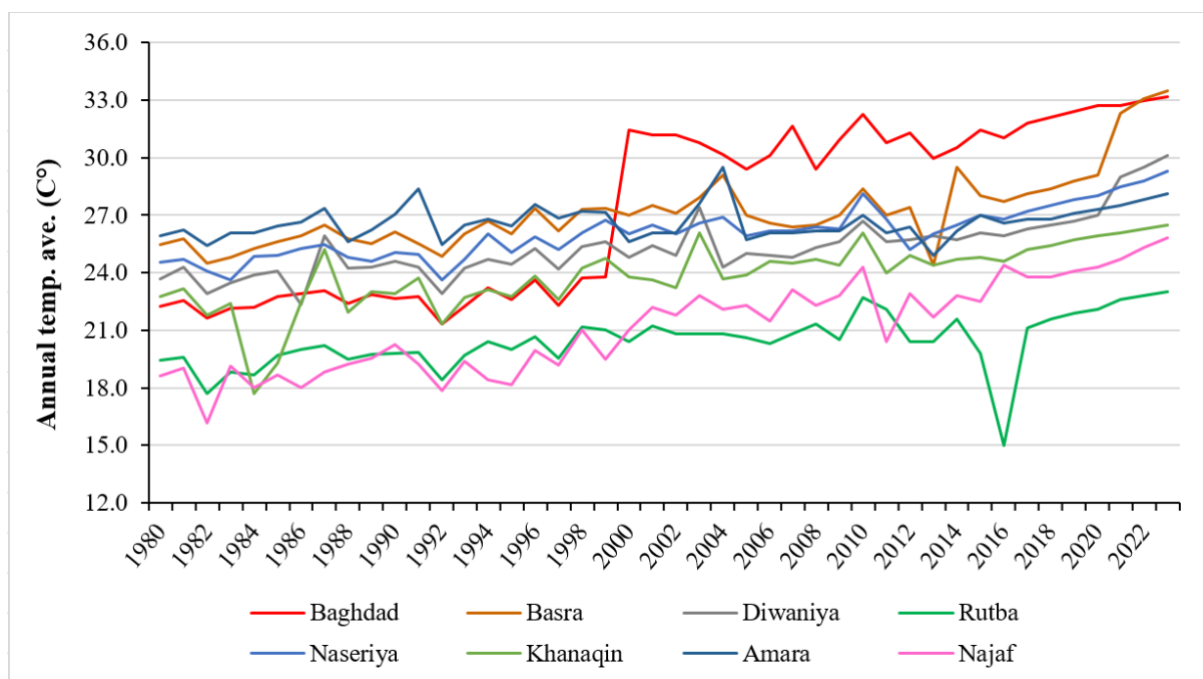
The study of temperature trends in Iraq was conducted from 1980 to 2023 to analyze the temperature patterns from the mid-twentieth century. Fig. 2 displays the yearly average temperatures observed at Iraqi meteorological stations from 1980 to 2023, varying between 15 and 33.5 °C. The western areas of Iraq, particularly Anbar, had the lowest average temperature recorded, while the highest average temperature was recorded in southeastern Iraq, specifically in Basra. The central and northern portions of Iraq experienced a mild average temperature ranging from 25.8 to 28.1 °C.

**Table 2.** A description of the location and coordinates of grid (CMIP5) points in mid and southern Iraq

| Grid point number | province | Location (Decimal Degrees) |             | Elevation (m) |
|-------------------|----------|----------------------------|-------------|---------------|
|                   |          | Longitude                  | Latitude    |               |
| 1                 | Anbar    | 41.485746°E                | 34.516312°N | 368           |
| 2                 | Anbar    | 42.490986°E                | 34.516312°N | 144           |
| 3                 | Diyala   | 45.466497°E                | 34.502909°N | 544           |
| 4                 | Anbar    | 39.515475°E                | 33.524475°N | 583           |
| 5                 | Anbar    | 40.467102°E                | 33.484265°N | 479           |
| 6                 | Anbar    | 41.485746°E                | 33.524475°N | 310           |
| 7                 | Anbar    | 42.490986°E                | 33.470862°N | 131           |
| 8                 | Anbar    | 43.536436°E                | 33.457459°N | 46            |
| 9                 | Baghdad  | 44.528273°E                | 33.497669°N | 46            |
| 10                | Diyala   | 45.493304°E                | 33.497669°N | 44            |
| 11                | Anbar    | 39.502071°E                | 32.519235°N | 783           |
| 12                | Anbar    | 40.507312°E                | 32.532638°N | 583           |
| 13                | Anbar    | 41.525955°E                | 32.479025°N | 406           |
| 14                | Anbar    | 42.517792°E                | 32.505831°N | 170           |
| 15                | Karbala  | 43.496226°E                | 32.532638°N | 62            |
| 16                | Babylon  | 44.528273°E                | 32.505831°N | 27            |
| 17                | Wassit   | 45.493304°E                | 32.505831°N | 21            |
| 18                | Missan   | 46.498331°E                | 32.495936°N | 228           |
| 19                | Anbar    | 41.483545°E                | 31.527496°N | 392           |
| 20                | Anbar    | 42.529849°E                | 31.542443°N | 270           |
| 21                | Najaf    | 43.471522°E                | 31.512549°N | 144           |
| 22                | Dewanya  | 44.507331°E                | 31.494708°N | 21            |
| 23                | Muthanna | 45.526812°E                | 31.500591°N | 10            |
| 24                | Thi-Qar  | 46.491842°E                | 31.500591°N | 8             |
| 25                | Missan   | 47.470276°E                | 31.513994°N | 8             |
| 26                | Najaf    | 43.476121°E                | 30.522157°N | 310           |
| 27                | Muthanna | 44.508168°E                | 30.522157°N | 152           |
| 28                | Muthanna | 45.513408°E                | 30.495351°N | 10            |
| 29                | Muthanna | 46.532052°E                | 30.508754°N | 2             |
| 30                | Basra    | 47.470276°E                | 30.481948°N | 1.5           |
| 31                | Muthanna | 44.521571°E                | 29.516917°N | 327           |
| 32                | Muthanna | 45.513408°E                | 29.503514°N | 222           |
| 33                | Muthanna | 46.505246°E                | 29.490111°N | 165           |

**Table 3.** Details of (RCPs) (Based on IPCC, 2007)

| Name of RCPs | Radiative forcing     | Time period                 | Pathway shape                   | Concentration (ppm)                                    |
|--------------|-----------------------|-----------------------------|---------------------------------|--------------------------------------------------------|
| RCP 4.5      | ~4.5 W/m <sup>2</sup> | At stabilization after 2100 | Stabilization without overshoot | ~650 CO <sub>2</sub> -eq (at stabilization after 2100) |
| RCP 8.5      | >8.5 W/m <sup>2</sup> | In 2100                     | Rising                          | >~1370 CO <sub>2</sub> -eq in 2100                     |

**Fig. 2.** Annual average temperatures recorded from Iraqi meteorological stations between 1980 and 2023

The outcome that is displayed in Fig. 3 is for utilizing the Correlation coefficient for temperature annual averages on 8 meteorological stations from 1980 to 2023. The results showed a strong significant relationship to temperature with a correlation coefficient of ( $R^2 = 0.8358$ ), which indicates a clear increase in temperature during 1980-2023.

### 3.2. Historical Period of Temperature Anomaly (1900–2005)

The historical anomaly of temperature over the middle and southern of Iraq from 1900 -2005 for (CMIP5) multi-models (Bun-ESM, CCSM4, HadGEM2-AO, and MIRIOC5) was illustrated in Fig. 4. The results under BNU-ESM showed that the highest temperature recorded in provinces of Muthanna, south of Najaf and west of Anbar, is ranged 8.1-9.1 °C. While the lowest temperature recorded in the northeast of Diyala is about 3.4-4.5 °C. The temperature anomaly based on (CCSM4) is increased in Missan and Basra provinces at 10.9-12.4 °C. In western Iraq, the temperature recorded the lowest value is ranged 4.2-5.8 °C. In the same context, Anbar and north of Diyala recorded the lowest temperature under (HadGEM2-AO) among other models about -0.4 to 0.8 °C. Meanwhile, the temperature increased in the southeast of Iraq, especially in Basra and Missan with a value of about 4.5-5.6 °C. On the other hand, (MIROC5) recorded the highest temperature anomaly in the historical period that ranged 12-13.2 °C, concentrated in the southern provinces of Iraq as in Basra, Thi-Qar, and Muthanna. While northeast of Diyala recorded the lowest temperature which ranged 6.9-8.2 °C.

### 3.3. Temperature Anomaly According to RCP4.5

#### 3.3.1. Near future period (2016-2035)

The temperature anomaly values under (RCP4.5) for the near future (2016-2035) based on (CMIP5) multi-models (Bun-ESM, CCsM4, HadGEM2-AO, and MIRIOC5) are shown in Fig. 5. The finding illustrated that the highest values of temperature recorded in (CCSM4, HadGEM2-AO, and MIRIOC5)

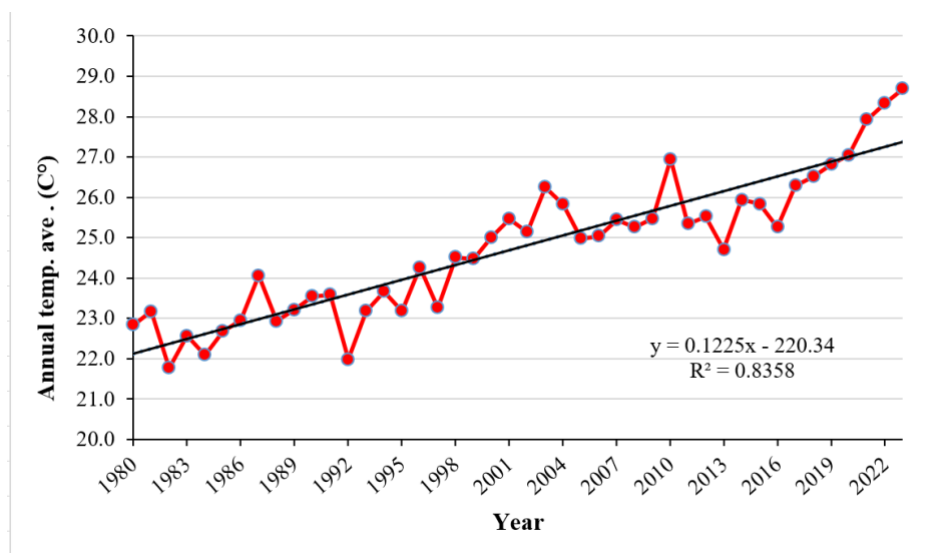


**Fig. 3.** Correlation coefficient on temperature annual average for the period 1980–2023

are concentrated in the south and southeast parts of Iraq. The temperature values are found to be ranged 11.5-13 °C, 7.3-8.1°C, and 13.3-14.5 °C, respectively. As a result of the BNU-ESM model, Muthanna and Southwest of Anbar and Najaf recorded an increased temperature anomaly of about 8.4-9.1 °C. Noted that (MIROC5) recorded the highest value of temperature in the near future period. The northeast part of Diyala, on the other hand, recorded the lowest temperature anomaly for (HadGEM-OA, BNU-ESM, and MIROC5), that ranged 3.8-4.7 °C, 5-5.8 °C, and 7.8-9.1 °C, respectively. In a different way, Anbar province recorded the lowest temperature of about 5-6.6 °C under the (CCSM4) model.

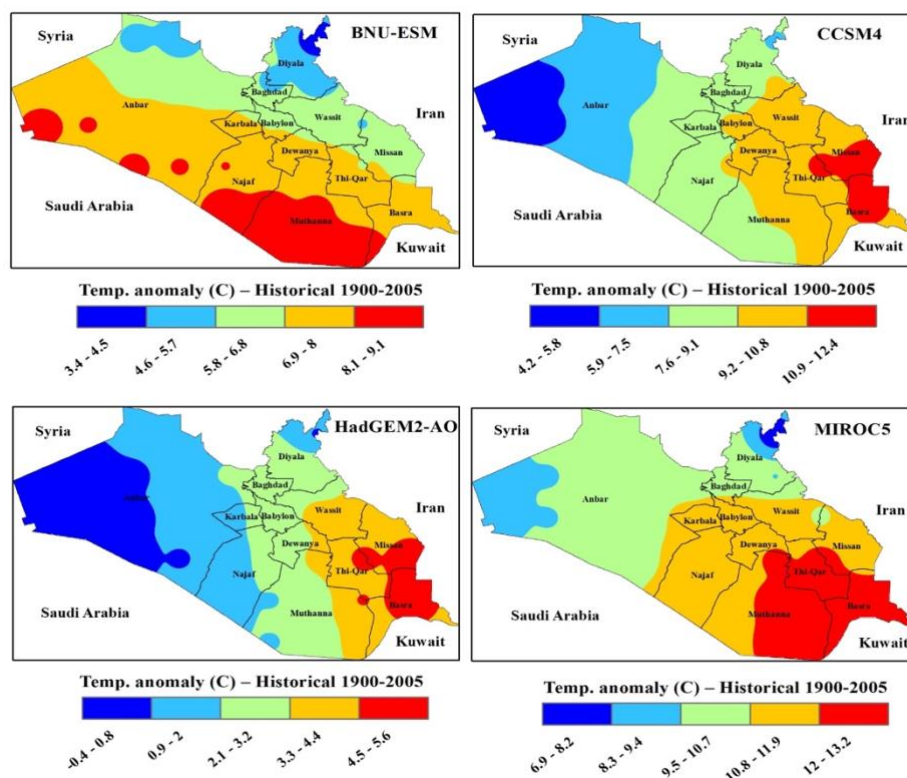


**Fig. 4.** Temperature anomaly (°C) from 1900-2005 for mid and southern Iraq based on CMIP5 multi models (Bun-ESM, CCSM4, HadGEM2-AO, and MIRIOC5)

### 3.3.2. Mid future period (2046-2065)

The temperature anomaly values for mid future (2046-2065) based on (RCP4.5) scenarios, under (Bun-ESM, CCSM4, HadGEM2-AO, and MIRIOC5) models, as shown in (Fig. 6). The results showed that the highest temperature recorded in the southeast part of Iraq under the three models, (MIROC5, CCSM4 and HadGEM2-AO), are about 14.6-15.7 °C, 13.4-14.8 °C, and 8.2-9.5 °C, respectively. In the BNU-ESM model, the west of Anbar recorded the highest temperature value at 13.9 14.6 C. On the other hand, the lowest temperature recorded in western Iraq is found to be ranged 2.4-3.8 °C under (HadGEM2-AO). The other three models (CCSM4, MIROC5, and BNU-ESM) recorded the lowest temperature anomaly in the northeast of Diyala and west of Iraq which is about 7.5-9 °C, 9.7-10.9 °C, and 10.4-11.2 °C, respectively. The result of (HadGEM2-AO) of temperature anomaly recorded the lowest value among other models during 2046-2065 that is in Anbar province in which it is ranged between 2.4-3.8 °C.

### 3.3.3. Far future period (2081-2100)

The temperature anomaly values under (RCP4.5) during the far future period (2081-2100), under (CMIP5) models (Bun-ESM, CCSM4, HadGEM2-AO, and MIRIOC5), as shown in Fig. 7. The results illustrated that three models (MIROC5, CCSM4, and HadGEM2-AO) are recorded the highest temperature in which it is ranged between 14.2-15.6°C, 13.9-15.4°C, and 9.1-9.9°C. These temperature values are concentrated in the south and southeast of Iraq, especially in Basra, Thi-Qar Missan, and Muthanna provinces. For the BNU-ESM model, the highest temperature recorded in the south and west of Iraq, Muthanna, and Anbar ranges from 9.2 to 10°C. Two models, (HadGEM2-AO and CCSM4) recorded the lowest temperature value in Anbar province, which is ranged 5.5-6.4°C, and 7.6-9.2°C, respectively. In the same context, the northeast part of Diyala recorded the lowest temperature that is

ranged from 5.7 to 6.6°C, and 8.1–9.6°C, based on assumptions of (BNU-ESM and MIRCO5), respectively.

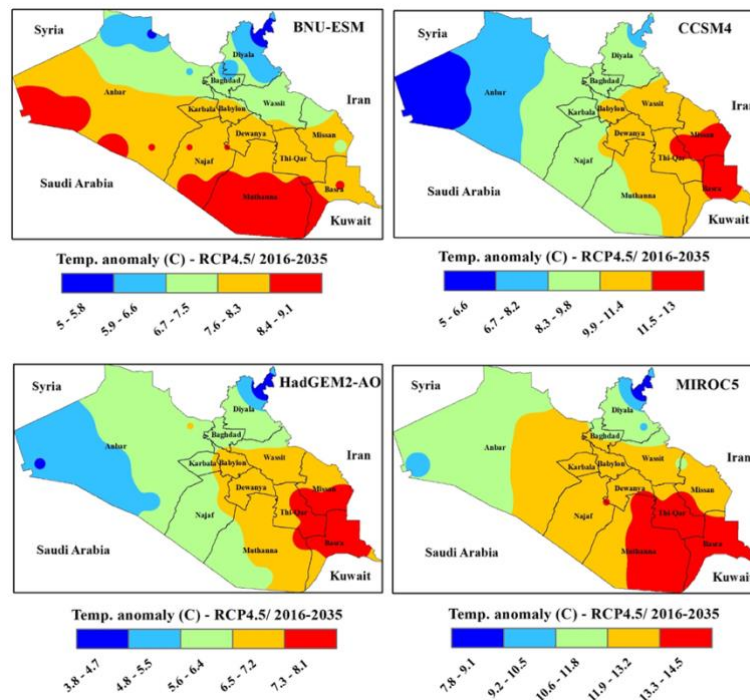


**Fig. 5.** Temperature anomaly (°C) values for near future 2016-2035, based on RCP4.5

### 3.4. Temperature Anomaly According to RCP8.5

#### 3.4.1. Near future period (2016–2035)

Values of temperature anomaly under (RCP8.5) for the near future (2016-2035), under (CMIP5) models (Bun-ESM, CCSM4, HadGEM2-AO, and MIRIOC5), as shown in Fig. 8. The results illustrated that the highest temperature recorded in southeast part of Iraq under three models (MIROC5, CCSM4 and HadGEM2-AO), which are about 10-12.3 °C, 11.5-12.8 °C, and 7.7-8.4 °C, respectively in Basra, Thi-Qar, Missan and Muthanna provinces. In the same context, the highest temperature in the BNU-ESM model recorded in the south and west of Iraq, especially in Muthanna and Anbar provinces, which ranged 7.1-8 °C. In contrast, the northeast part of Diyala recorded the lowest temperature anomaly for (BNU-ESM, HadGEM-OA, and MIROC5) is found to be ranged 3.1-4.1 °C, 4.6-5.4 °C, and 4.7-6.2 °C. For the (CCSM4) model, the lowest temperature recorded in the west of Iraq in Anbar is ranged 5.9-7.3 °C.

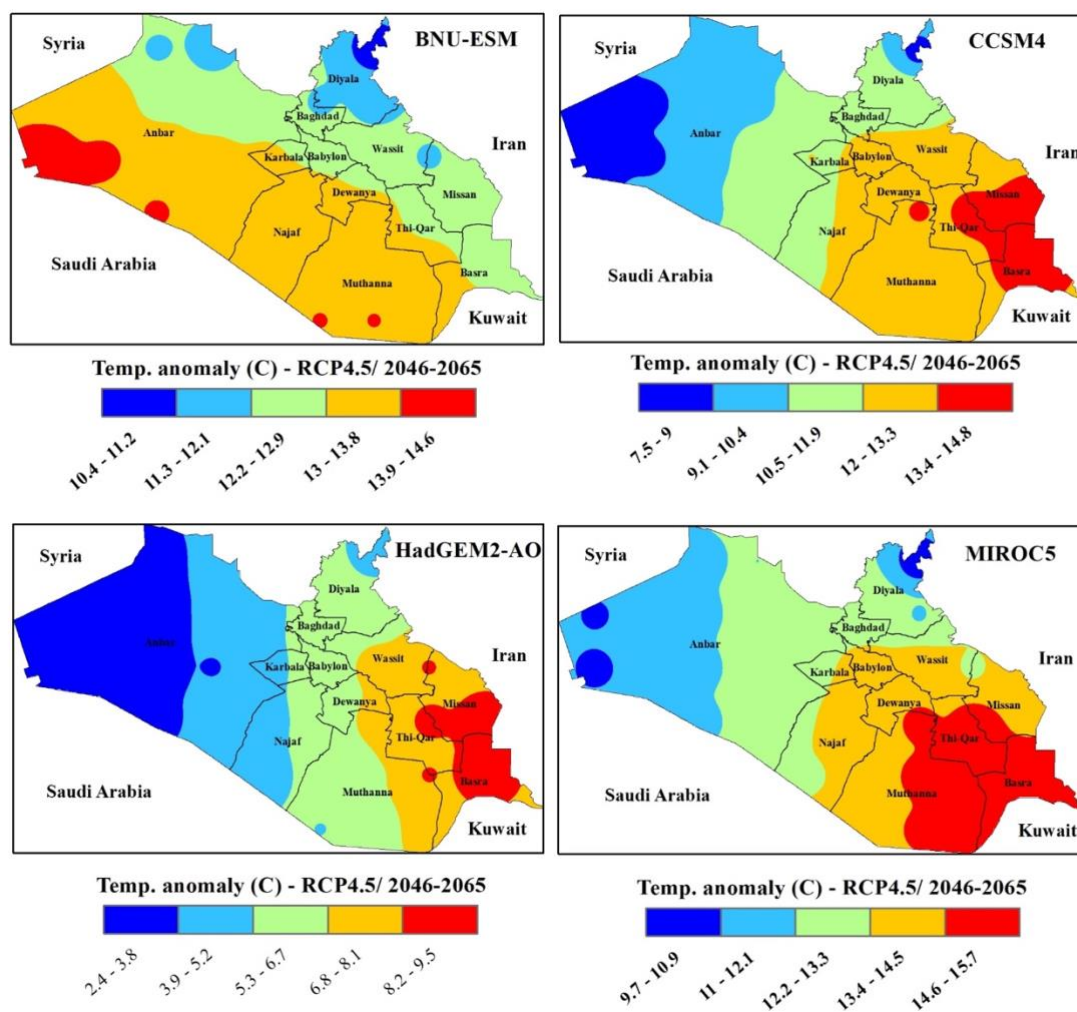


**Fig. 6.** Temperature anomaly ( $^{\circ}\text{C}$ ) values for mid future 2046-2065, based on RCP4.5

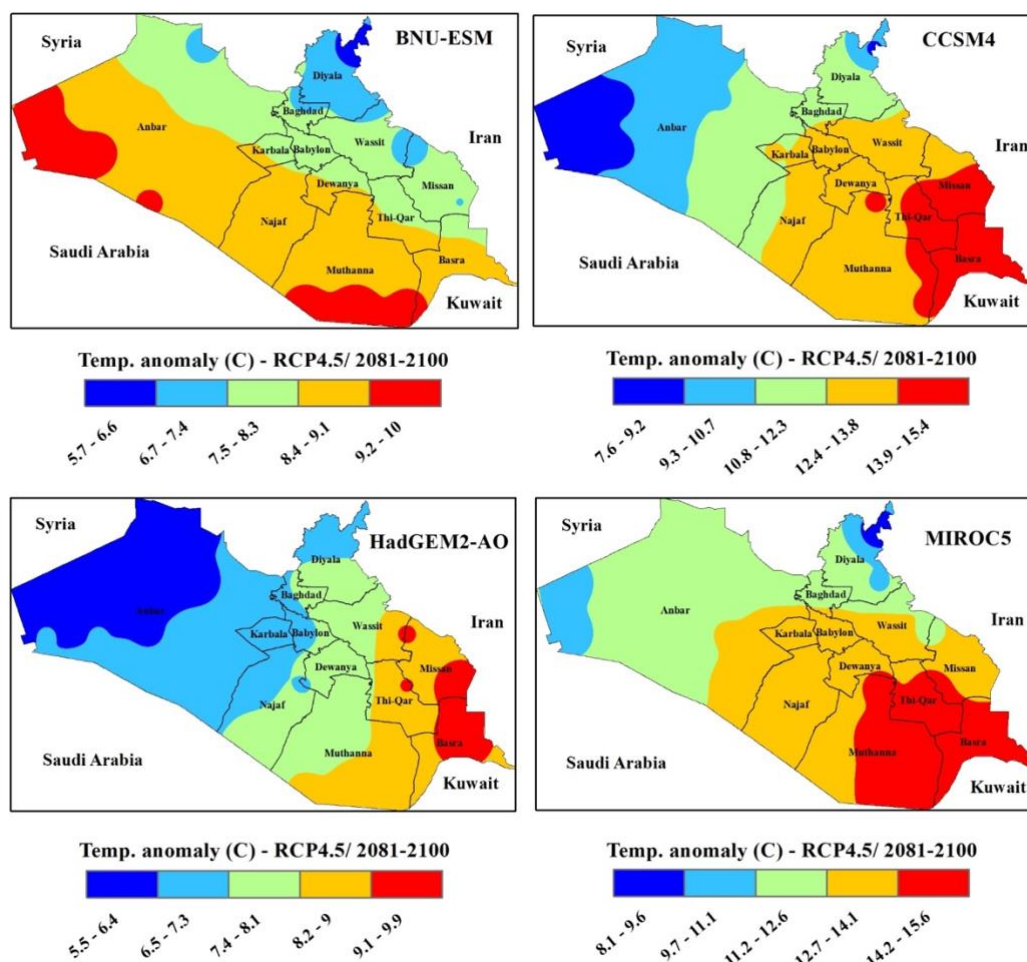


Fig. 7. Temperature anomaly (°C) values for far future 2081-2100, based on RCP4.5

### 3.4. Temperature Anomaly According to RCP8.5

#### 3.4.2. Mid future period (2046–2065)

The temperature anomaly values under the (RCP8.5) scenario during mid future period (2046-2065), for multi models (Bun-ESM, CCSM4, HadGEM2-AO, and MIRIOC5), are shown in Fig. 9. The findings illustrated that the highest values of temperature recorded in (CCSM4, MIRIOC5, and HadGEM2-AO) are ranged 14.2-15.6 °C, 14.2-15.3 °C, and 7.1-7.7 °C, respectively, and concentrated in the southeast of Iraq, especially in Basra, Thi-Qar, Misan, and Muthanna provinces. On the other hand, the BUN-ESM model recorded the highest temperature in Anbar in the west of Iraq, ranged about 13.9-14.6 °C. Two models, (HadGEM2-AO and CCSM4) recorded the lowest temperature value in Anbar province, which is about 4.4-5.1 °C, and 8.1-9.6 °C, while the (MIRIOC5 and Bun-ESM) models recorded 9.1-10.3 °C and 10.4-11.2 °C in the northeast part of Diyala.

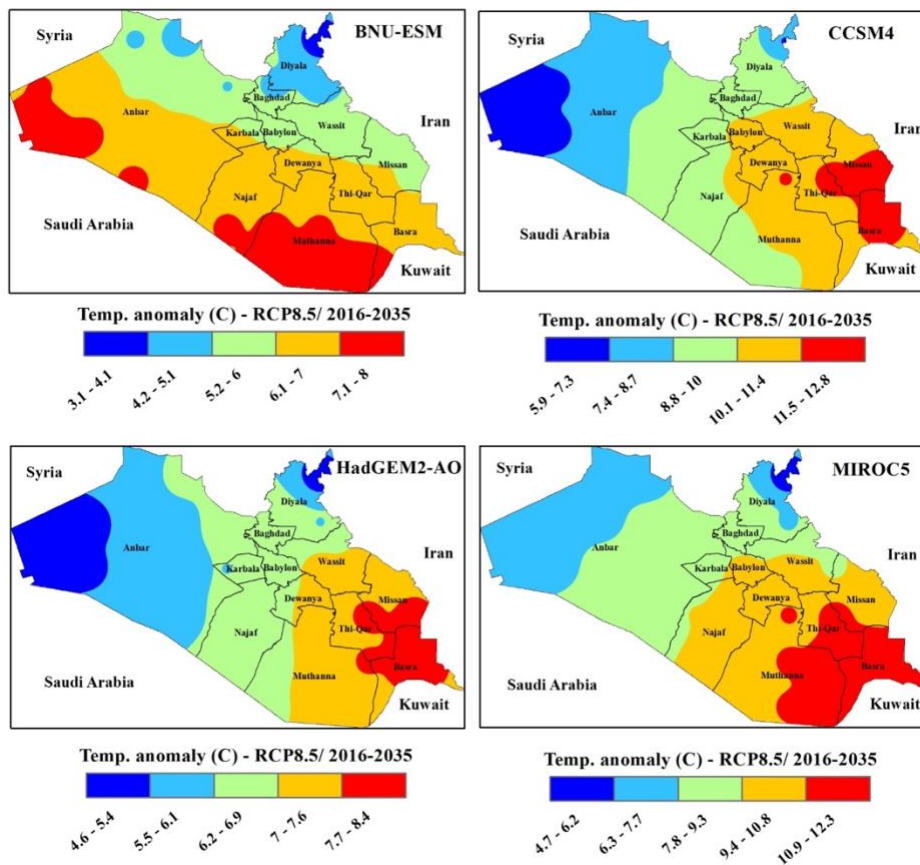


**Fig. 8.** Temperature anomaly(°C) values for near future 2016-2035, based on RCP8.5

#### 3.4.3. Far future period (2081–2100)

The temperature anomaly values for far future (2081-2100), based on (RCP8.5), under (Bun-ESM, CCSM4, HadGEM2-AO, and MIRIOC5) models, as provided in fig. 10. The results illustrated the three models (MIROC5, CCSM4, and HadGEM2-AO), recorded increasing in temperature that concentrated in the southeast of Iraq, especially in Basra, Thi-Qar, Missan, and Muthanna provinces, are ranged 17.4-18.8 °C, 16.2-17.6 °C, and 11.7-12.5 °C, respectively. While the Bun-ESM model recorded the highest temperature is located in the south of Iraq, especially in Muthanna, and southwest of Basra, ranged 14.8-16 °C. The models, (HadGEM2-AO, CCSM4, and MIRIOC5) showed a decrease in temperature anomaly appeared in the northeast part of Diyala, and west of Anbar which is about 7.9-8.8 °C, 9.9-11.4 °C, and 11.5-13 °C, respectively. In the same context, the lowest temperature recorded in the north of Anbar, Baghdad, and Diyala, is ranged 9.5-10.8 °C, based on assumptions of (Bun-ESM).

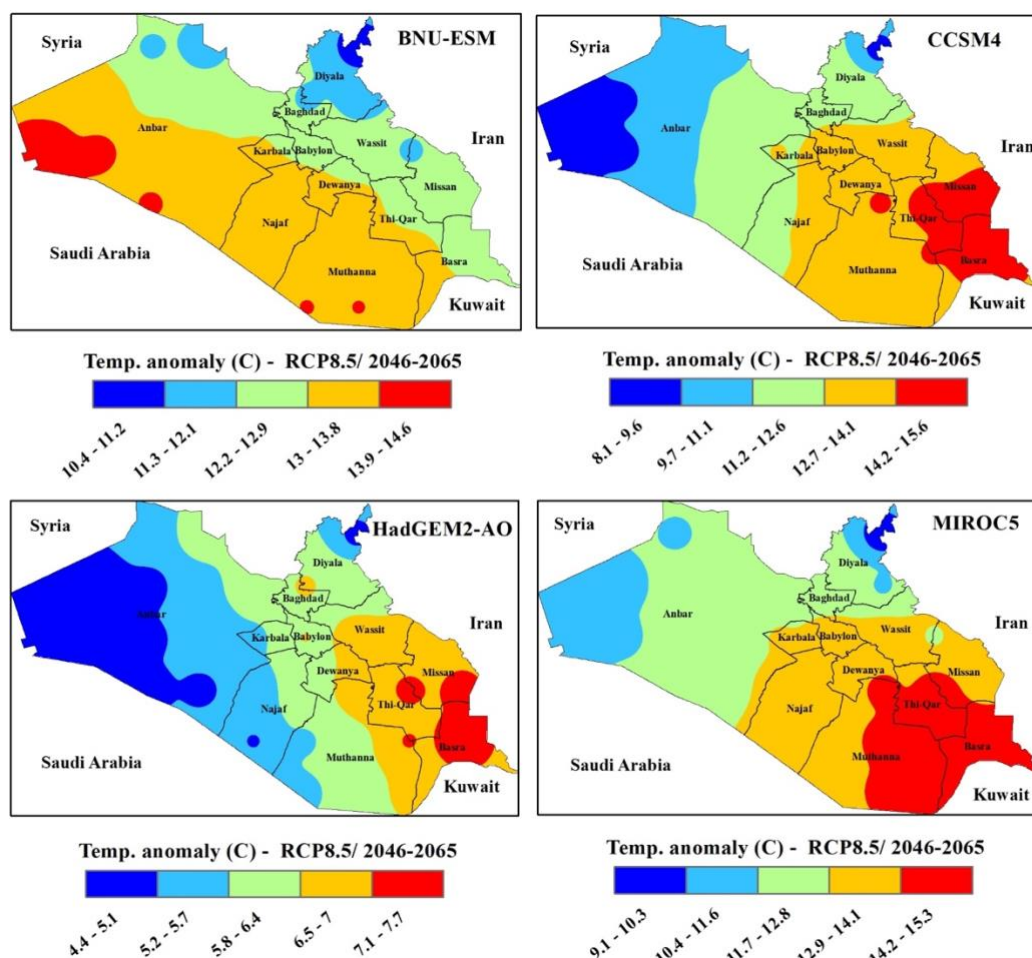


**Fig. 9.** Temperature anomaly (°C) values for mid future 2046-2065, based on RCP8.5

### 3.5. Overall Period of Temperature Anomaly (2006–2100)

#### 3.5.1. Temperature anomaly based on RCP4.5

The overall period (2006-2100) of temperature anomaly, according to (RCP4.5), based on (CMIP5) multi-models (Bun-ESM, CCSM4, HadGEM2-AO, and MIRIOC5) as shown in Fig. 11. The findings illustrated that there is an increase in temperature anomaly values which recorded based on (CCSM4, and MIRIOC5) models, in Basra, Thi-Qar, Missan, and Muthanna provinces and ranged 14.4-15.6 °C, and 12.8-13.9 °C, respectively. For the (HadGEM2-AO) model, the highest temperature recorded in the southeast of Iraq was about 6.4-7.4 °C. While and based on the Bun-ESM model, the highest temperature is concentrated in the south and southwest of Iraq, especially in Muthanna, Najaf, and Anbar, at about 8.7-9.7 °C. The lowest temperature recorded in the (HadGEM2-AO) model, in the Anbar, Najaf, and the northeast part of Diyala, is ranged 3.4-4.2 °C. (Bun-ESM, MIRIOC5, and CCSM4) models, on the other hand, recorded the lowest temperature that is located west of Anbar and northeast of Diyala provinces and found to be ranged 4-5.1 °C, 7.9-9.1 °C, and 8.9-10.2 °C, respectively.

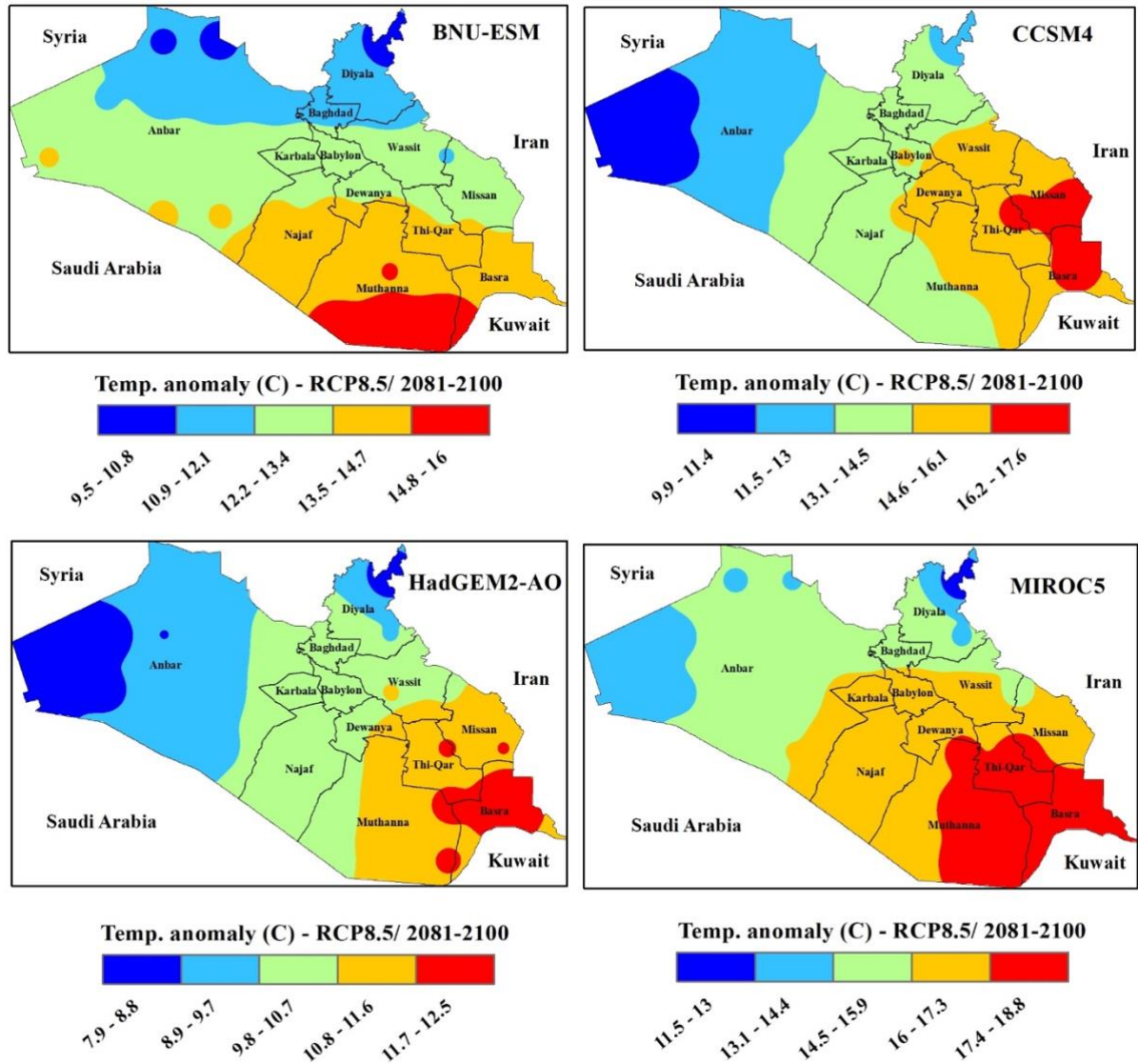


**Fig. 10.** Temperature anomaly (°C) values for far future 2081-2100, based on RCP8.5

### 3.5.2. Temperature anomaly based on RCP8.5

The projected temperature anomaly values under (RCP8.5), during 2066–2100, for mid and southern parts of Iraq, under multi models (Bun-ESM, CCSM4, HadGEM2-AO, and MIRIOC5), are shown in Fig. 12. The results showed that the highest temperature are recorded in the southeast part of Iraq, especially in Basra, Thi-Qar, Missan, and Muthanna provinces. Under three models (CCSM4, MIROC5, and HadGEM2-AO), the Temp. is ranged 14.4-15.8 °C, 12.6-13.7 °C, and 7.1-7.7 °C, respectively. In the same context, the Bun-ESM model recorded the highest temperature located in Muthanna, Najaf, and Anbar which is found to be ranged 7.6-8.5 °C. On the other hand, northeast of Diyala recorded the lowest temperature under (Bun-ESM, MIROC5, and CCSM4) models along with parts of Anbar, is ranged 3.5-4.5 °C, 7.6-8.8 °C, and 8.3-9.8 °C, respectively. While, the lowest temperature anomaly concentrated in the northeast of Diyala, Muthanna, Najaf, and Anbar is ranged 4.1-4.8 °C, based on the (HadGEM2-AO) model.

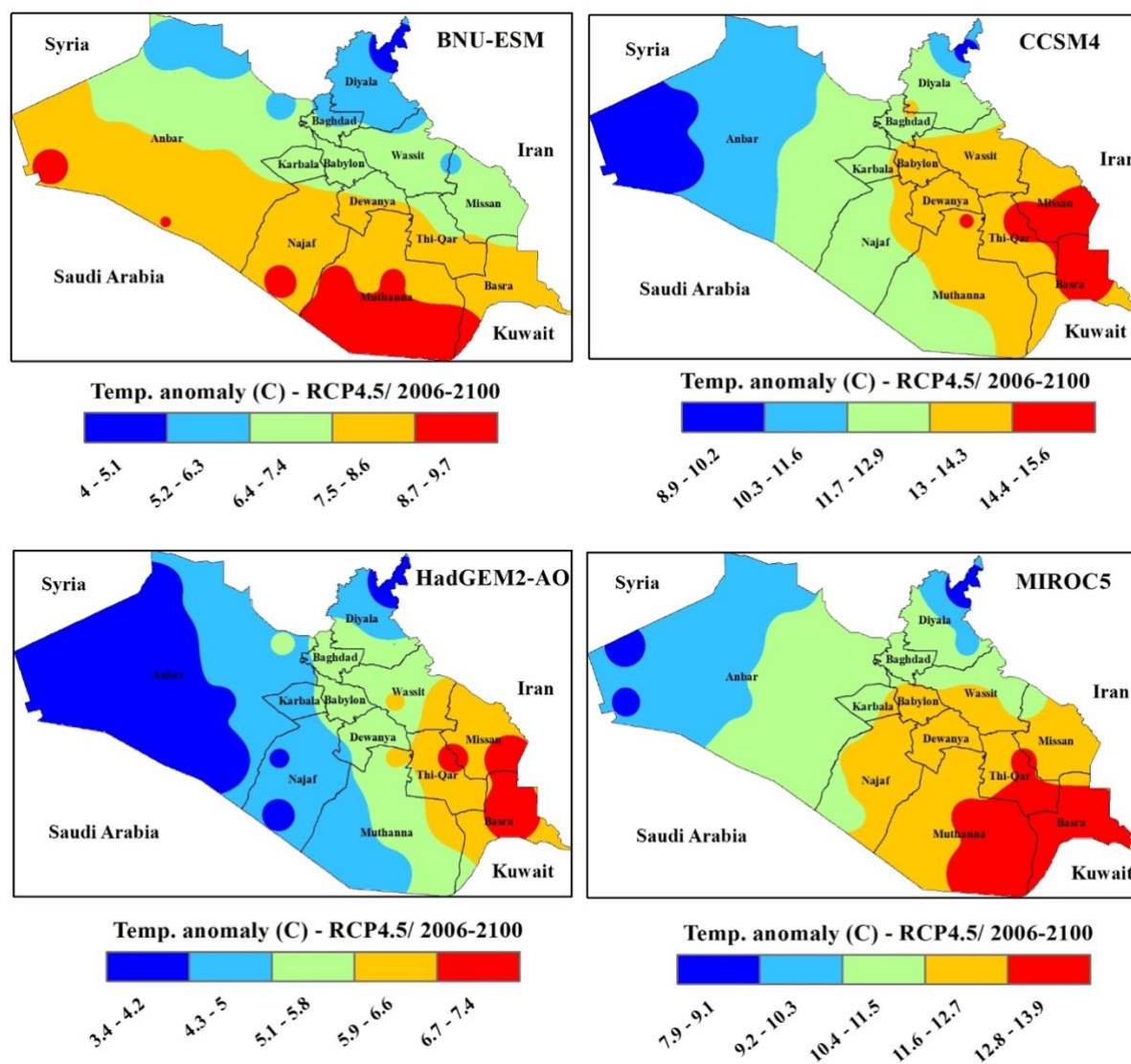


**Fig. 11.** Temperature anomaly (°C) from 2006-2100, based on (Bun-ESM, CCSM4, HadGEM2-AO, and MIRIOC5) under RCP4.5

#### 4. Discussion

The data indicated that the greatest annual temperature averages from 1980 to 2023 were recorded in Basra even located in the southern region of Iraq, reaching 33.5 °C. The current study which is used the climate models for evaluating the effects of climate change on the mid and southern of Iraq by employing (CMIP5) dataset under (RCP) scenarios have been achieved. In order to simulate future global climatic conditions under various scenarios, four (GCMs) models have been created to serve as a global representation of future climate circumstances. In this study, we analyzed the temperature anomalies for the mid and southern of Iraq for the 21th century. (Bun-ESM, CCSM4, HadGEM2-AO, and MIRIOC5) are categorized as modeled data to evaluate the future of temperature under (RCP 4.5), and (RCP 8.5) scenarios for 2016–2035, 2046–2065, and 2081–2100 periods. The results show that the most significant increase in temperature anomaly was in the last period (2081-2100) ranging from 9.9 to 18.8 °C and the less effect period was (2016-2035), ranging from 8 to 15.7°C for both scenarios in all models and this is due to (RCPs) settings that indicate an increase in (GHGs) emissions by the end of the

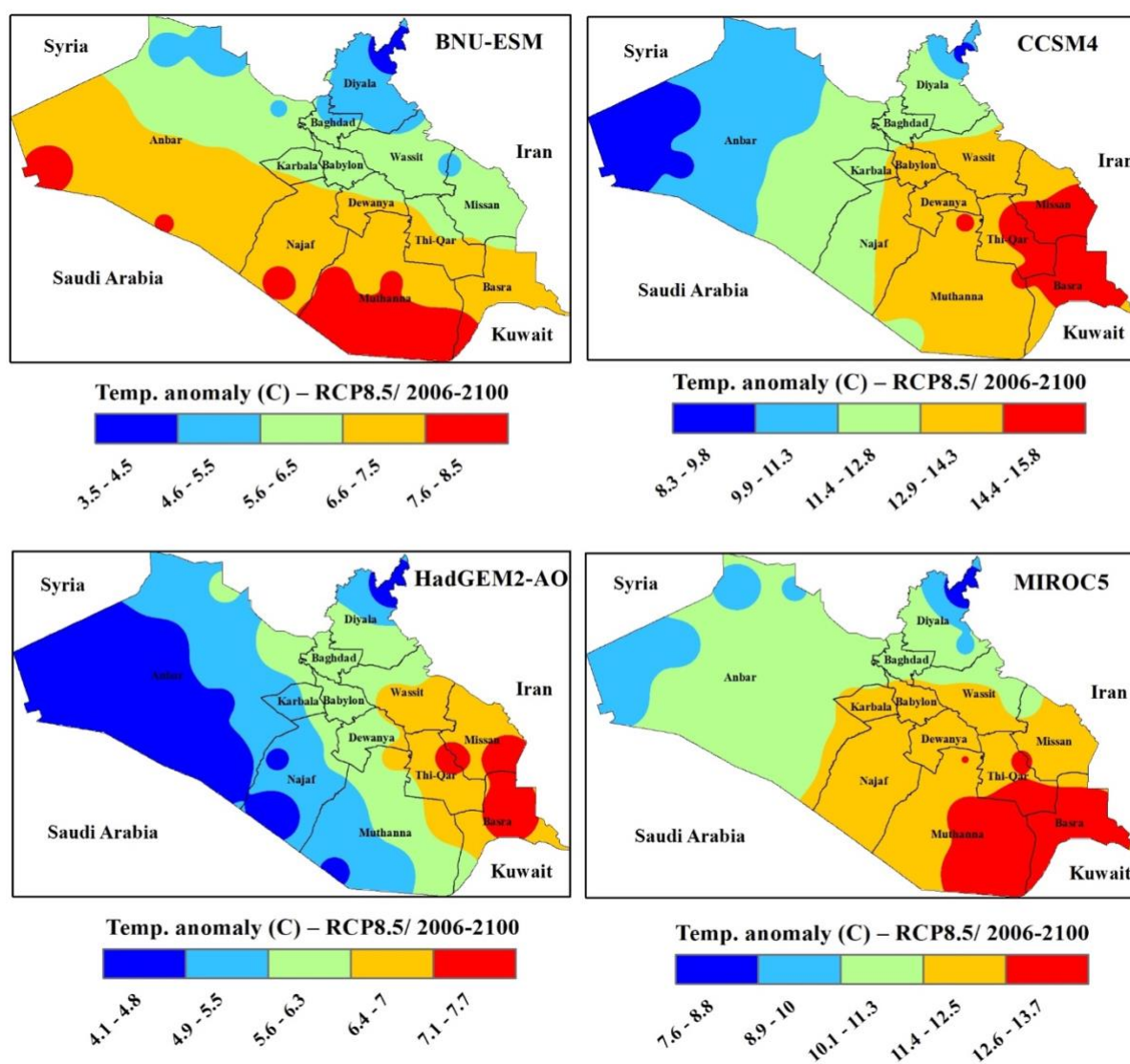


**Fig. 12.** Temperature anomaly (°C) from 2006-2100, based on (Bun-ESM, CCSM4, HadGEM2-AO, and MIRIOC5) under RCP8.5

century. The most affected area of that increase was the southeast part of Iraq (Basra, Misan, Thi-Qar, and Muthanna), on the other hand, the less affected area was Anbar and northeast of Diyala provinces. This investigation backs an increasing trend in temperature which is particularly found in the southern region of Iraq, according to several earlier studies. This study aids in the development of strategies by which decision-makers may combat desertification and climate change in the most vulnerable areas by lowering greenhouse gas emissions and utilizing renewable energy sources. Nonetheless, It was not possible to compare the four models and determine the best one, especially since there was a discrepancy in the results.

## 5. Conclusions

The data indicated that the annual temperature averages in Iraq from 1980 to 2023 are fluctuated during the second half of the 20th century and above are the general average for the country.

The temperature anomaly values for the historical period were found to be the highest in the south and southeast region provinces (Basra, Missan, Thi-Qar, and Muthanna), while Muthanna, Najaf, and Anbar provinces were recorded the highest in the (BNU-ESM) model. According to (RCP4.5) during three future period (2016-2100), the results showed that the highest values of the temperature anomalies were recorded in the regions of southern and southeastern Iraq, especially in the governorates of Basra, Missan, and Thi-Qar, under (CCSM4, HadGEM2-AO, and MIRIOC5) models. However, (BNU-ESM) model was recorded the highest temperature in the south and west provinces of Iraq (Muthanna and Anbar).

Comparing to the (RCP 4.5) scenario, the results of (RCP8.5) showed higher temperature anomaly which are concentrated in south and southeast provinces, such as for Basra, Missan, Thi-Qar and Muthanna, in (CCSM4, HadGEM2-AO, and MIRIOC5) models for the same period (2016-2100), in the same context the BNU-ESM model showed that the highest temperature is found in Muthanna especially during the far future period (2081-2100) as well. The study can help planners and policymakers to set national strategies for dealing with future climate change in Iraq.

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