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ORIGINAL PAPER

Temperature and precipitation trend analysis of the Iraq Region under SRES scenarios during the twenty-first century

Bassim Mohammed Hashim[1] · Ali Al Maliki[1] · Esam Abd Alraheem[1] · Ahmed Mohammed Sami Al-Janabi[2] · Bijay Halder[3] · Zaher Mundher Yaseen[4,5,6,7]

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Abstract
Iraq is classified as the fifth most vulnerable country in the world to decreased water and food availability, extreme temperatures, and associated health problems. The current study aims to analyze the historical and current climate of Iraq by studying the climatic characteristics of annual, monthly, and seasonal averages of temperature and precipitation for the observed period 1971–2020. The Coupled Global Climate Model (CCSM3) based on the National Center for Atmospheric (NCAR) used to study the changes of temperature and precipitation during the twenty-first century, under the Special Report on Emissions Scenarios (SRES), which includes the low B1, medium A1B, and high A2 future emission scenarios. During 1971–2020, the results showed that the temperature anomaly increased to +2.1 °C, and precipitation anomaly decreased to −84 mm in 2020, especially in the last decade of the twentieth century, due to drought and increase temperature and climate change consequences. The southern and southwestern regions of Iraq are the most affected by both high temperatures and lack of precipitation. The temperature is projected to increase by 0.4 °C, 1.2 °C, and 2.4 °C for B1, A1B, and A2, respectively, in 2099, while the precipitation is projected to greatest decrease under A1B from 121 mm in 2050 to 104 mm in 2099. Understanding and predicting climate change is vital to clarifying its potential future consequences for society and policy-making, as Iraq is one of the five most vulnerable countries in the world against climate change.

Keywords SRES · NCAR · CCSM3 · Temperature · Precipitation · Iraq

1 Introduction

The global warming issues in the arid regions have recently received much attention, due to the associated water scarcity and its consequences on food security (Bucchignani et al.

✉ Zaher Mundher Yaseen
zaheryaseen88@gmail.com

Bassim Mohammed Hashim
bassim_saa22@yahoo.com

Ali Al Maliki
alyay004@mymail.unisa.edu.au

Esam Abd Alraheem
esam_abdalraheem@yahoo.com

Ahmed Mohammed Sami Al-Janabi
ahmed.aljanabi@tiu.edu.iq

Bijay Halder
halder06bijay@gmail.com

1 Environment and water Directorate, Ministry of Science and Technology, Baghdad, Iraq

2 Department of Civil Engineering, Faculty of Engineering, Tishk International University-Erbil, Erbil, Kurdistan Region, Iraq

3 Department of Remote Sensing and GIS, Vidyasgaar University, Midnapore, India

4 Adjunct Research Fellow, USQ's Advanced Data Analytics Research Group, School of Mathematics Physics and Computing, University of Southern Queensland, Toowoomba, QLD 4350, Australia

5 New Era and Development in Civil Engineering Research Group, Scientific Research Center, Al-Ayen University, Thi-Qar 64001, Iraq

6 College of Creative Design, Asia University, Taichung City, Taiwan

7 Institute for Big Data Analytics and Artificial Intelligence (IBDAAI), Kompleks Al-Khawarizmi, Universiti Teknologi MARA, Shah Alam, Selangor 40450, Malaysia

2018; Bin Luhaim et al. 2021). Climate change has affected the atmosphere, water cycle, and socioeconomic systems globally, and the impact will likely continue to increase in the twenty-first century (Tanzeeba and Gan 2012; IPCC W 2013; Bayatvarkeshi et al. 2021). The Middle East and North Africa (MENA) are expected to be strongly affected by climate warming, enhancing the already hot and dry environmental conditions (Almazroui 2013; Basha et al. 2015; Ozturk et al. 2015). It is the first region in the world expected to run out of fresh water (Al-Delaimy 2020). The higher temperatures affecting the region are leading to lower soil moisture and more arid conditions, which are exacerbated by lower precipitation and longer drought periods (Penghui et al. 2020).

General climate models (GCMs) are mainly used for future climate projection (Noor et al. 2019; Homsi et al. 2020). Global climate models are the most powerful tool used widely to investigate climate scenarios for both the present and future (Doulabian et al. 2021; Li et al. 2021). Changes in climate extremes and their impacts on the natural physical environment were examined by the Intergovernmental Panel on Climate Change (IPCC) (Feyissa et al. 2018). In the Fourth Assessment Report (AR4) of the IPCC published in 2007, the climate projections were based on the Special Report on Emissions Scenarios (SRES), which cover the whole of the twenty-first century (Goosse et al. 2010). Those SRES climate scenarios of GCMs are obtained from the Coupled Model Intercomparison Project (CMIP3) multimodel database of IPCC under the World Climate Research Programme (WCRP) (Jiang et al. 2017).

Iraq is an arid country and considered as vulnerable to climate change in the Middle East region and most sensitive to climate variability (Salman et al. 2017). It may have increased in temperature and decreased in future precipitation (Oleiwi et al. 2018; Abdaki et al. 2021). Water scarcity, desertification, drought, high temperatures, low precipitation, heat waves, and sea-level rise represent some of the climate change scenarios in Iraq in the recent years (Sayl et al. 2016; Awadh et al. 2020). Several international studies have examined the use of SRES scenarios in the study of future temperature and precipitation, as shown in Table 1 (Cayan et al. 2008; Hao et al. 2013; Dastorani and Poormohammadi 2016; Jiang et al. 2017; Feyissa et al. 2018). According to projected climate changes (USAID 2019), Iraq will face an increase in annual average temperatures of 2 °C by 2050, with more frequent heat waves in the future. The higher temperatures are leading to lower soil moisture and more arid conditions, which are exacerbated by lower precipitation and longer drought periods. Despite its great importance to know the future climate of Iraq, unfortunately, there are no studies regarding the use of SRES and other IPCC climate models in Iraq. The gap in data and tools appears clear in Iraq compared to neighboring countries in the Middle East with regard to assessing the future climate and its relationship to sustainable development. Therefore, the current study is an attempt to understand what the climate of Iraq will be like in the future according to the hypotheses of SRES, leading to the use of newer climatic models such as RCP.

The current research study was conducted to carry out the evaluation of mapping the past and climate in Iraq, by studying the annual, monthly, and seasonal averages of temperature and precipitation, as observed data from 1971 to 2020. The future precipitation and temperature for 2000–2099, 2020–2039, and 2040–2059, through three future scenarios, B1, A1B, and A2, using CCSM3, were investigated. Projected changes of precipitation and temperature are expressed as percentage (%) and degree Celsius during the twenty-first century. Also, Iraq is classified into regions according to its impact on climate change during the twentieth century, and the affected areas are affected.

2 Data description and methods

2.1 SRES scenarios

The impact of climate change is commonly assessed using the A1B, A2, and B1 SRES scenarios as follows (Bernstein et al. 2008):

2.2 *Low B1 scenario 2000–2099*

Attributable to low population growth and strong interregional convergence but makes a faster introduction of resource-efficient technologies compared to A1.

2.3 Medium A1B scenario 2000–2099

Paints a future of rapid economic and population growth that peaks in mid-century and falls thereafter; it also makes a rapid introduction of more well-organized technologies. The difference between the three Al groups is in their technological emphasis: AlF1 is fossil intensive, A1T is nonfossil intensive, and A1B emphasizes a balance across all sources (Nakicenovic et al. 2000).

2.4 High A2 scenario 2000–2099

Corresponds to a slow convergence among regions and high population growth. The technological changes are more slowly implemented than in the other storylines, with more disparity between the regions (Goosse et al. 2010).

2.5 Study area

Iraq is a country in the eastern part of the Middle East that is bordered in the east by Iran and Turkey in the north; Syria

Table 1 Summary of the previous studies used the SRES in future temperature and precipitation

References	Country	Parameters	Duration of the study	Results
(Cayan et al. 2008)	USA	Temperature and precipitation under a B1 and A2 scenarios	Twenty-first century	The temperature of California is significantly warm during the twenty-first century. Relatively small (less than ~10%) changes in overall precipitation are projected
(Dastorani and Poormohammadi 2016)	Iran	Temperature and precipitation under A2 and B1 scenarios	2010–2099	The highest increase in temperature occurs in western parts of the country; precipitation would vary temporally and spatially in different parts of the country depending on the scenario used and the time period selected
(Hao et al. 2013)	Tibetan Plateau	Temperature and precipitation under a B1, A1B, and A2 scenarios	2000–2099	The temperature and precipitation will both increase in all three periods under different scenarios, with scenario A1 increasing the most and scenario A1B increasing the least
(Jiang et al. 2017)	Canada	Temperature and precipitation under a B1, A1B, and A2 scenarios	2020–2080	SRES projections indicated that seasonal precipitation of Alberta could change from −25 to 36%, while the temperature would increase from the 2020s to 2080s, with the largest increase (6.8°C) in DJF (December, January, and February)
(Feyissa et al. 2018)	Ethiopia	Daily maximum temperature, minimum temperature, and precipitation	2020–2080	The maximum temperature increases were in the range of 0.9 C in 2020 to 2.1 C (CGCM3A2) in 2080 at Addis Ababa. The highest precipitation change projected by CGCM3A2 an increase about 11% by 2080

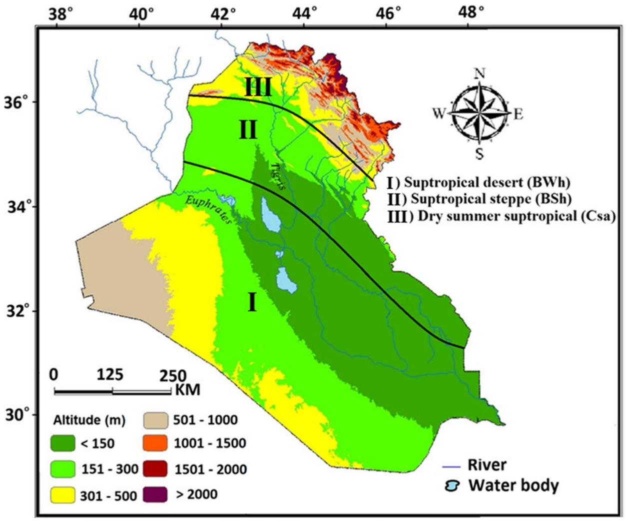

Fig. 1 Topographic and climatic zones of Iraq (Salman et al. 2020)

and Jordan are the west neighbors while Kuwait and Saudi Arabia are at the southern border; the Gulf is located southeast of Iraq (Al-Ansari 2013). Iraq has a narrow coastal strip of about 58 km on the Arabian Gulf (El Raey 2010). Most parts of the country experience mainly continental, subtropical semiarid climate while a Mediterranean climate is experienced in the north and northeastern mountainous regions (Bruinsma 2003). The winter temperature in the northern parts of Iraq varies between 0 and 5 °C; a subtropical desert (BWh) climate dominates most parts of Iraq, followed by the subtropical steppe (BSh) and dry summer subtropical (Csa) climate as shown in Figure 1 (Salman et al. 2020). The country is home to more than 41 million people, with the growth at a rate of 2.32% per year, adding just under 1 million people every year. Most of the people in Iraq live in the urban areas (World Population Review 2020). Iraq is mostly hot and dry during most days of the year due to the lack of wide water bodies to reduce the summer heat (Ministry of Health and Environment 2016). Summers in Iraq are dry, hot in the northern parts, and extremely hot (higher than 48 °C) across the rest of Iraq. Spring and fall are very short in Iraq (Hameed et al. 2018).

2.6 Data sources

There are two sources used to implement the current study in Iraq:

i. The observed data of monthly averages of temperature and precipitation has been obtained from the Iraqi Meteorological Organization and Seismology (IMOAS) (http://meteoseism.gov.iq/). The data were obtained during 1971–2020 over 10 meteorological stations for temperature and 12 meteorological stations for precipitation throughout Iraq, as shown in Figure 2a. However, there are some gaps as missing data in the observed data in some stations in 2003, due to the second Gulf War, also, from 2014 to 2017, because of ISIS occupation of Sinjar, Baiji, and Mosul in 2014. To reduce uncertainty, the extrapolation method is used to fill these gaps in the observed data.

ii. Modeled data: National Center for Atmospheric Research- Coupled Global Climate Model 3 (NCAR-CCSM3) has been used in the study. It is one of the global climate models included in the AR4. NCAR's GIS program provides GIS-compatible user access to CCSM3 AR4 global (1.4° or 155 km) [http://gisclimatechange.ucar.edu/]. Temperature and precipitation data were downloaded from the NCAR database in the form of shapefiles, after selecting Iraq as a region for the current study, as shown in Fig. 2b. Then the nature of the data (monthly or yearly averages) is determined. Finally, the period and the required climate elements are determined. ArcGIS 10.8 is used in the implementation of the study outputs, which include collecting climate data on temperature and precipitation in Iraq, spatially analyzing it, and producing its maps for the current study period 1971–2099. Table 2 shows summarized the input data in terms of sources, format, and spatial resolution in the current study.

2.7 Trend analysis methods

2.7.1 Mann-Kendall trend test

The Mann-Kendall test is one of the widely used nonparametric tests, which is significantly identifying the trends in hydrological and meteorological time series with Sen's slope (Partal and Kahya 2006; Modarres and de Paulo Rodrigues da Silva 2007). This method has many advantages like it is a nonparametric test, which does not require the data to be normally distributed. Another part is this test has low sensitivity to unexpected disruptions due to inhomogeneous time series (Tabari et al. 2011). The Mann-Kendall statistic S of the series x is given by (Qutbudin et al. 2019):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\left(x_j - x_i\right) \quad (1)$$

where sgn is represented the signum function. The variance associated with S is estimated from Eq. 2:

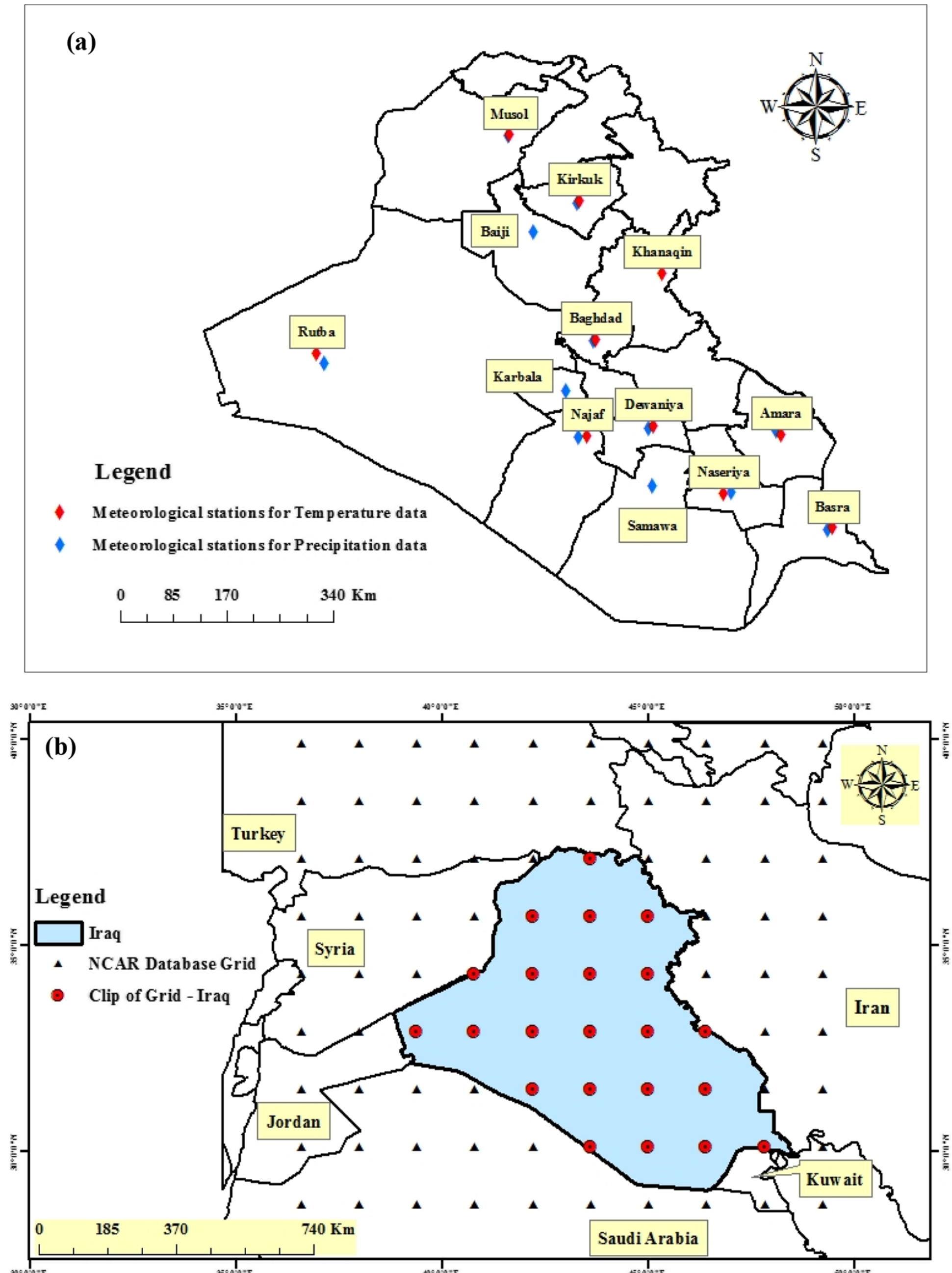

Fig. 2 **a** Meteorological stations used in the current study in Iraq; **b** clip of NCAR data grid of Iraq

Table 2 Summarized the input data in terms of sources, format, and spatial resolution

Type of data	Source	Country	Duration and data format	Grid number	Resolution
Observed data	Iraqi Meteorological Organization and Seismology/IMOAS	Iraq	1971–2020 Excel format	10 meteorological stations for temperature data 12 meteorological stations for precipitation data	---
Modeled data (NCAR-CCSM3)	NCAR (National Center for Atmospheric Research [http://gisclimatechange.ucar.edu/]	USA	2000–2099 Shape file format	22	1.4° x 1.4°

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{k=1}^{m} t_k\left(t_k - 1\right)(2t_k + 5)}{18} \quad (2)$$

where m is denoted the number of tied groups and t_k is represented the number of data points in group k. The standardized test statistic Z is calculated as (Bougara et al. 2020):

$$Z_S = \begin{cases} \frac{S-1}{\sqrt{Var(s)}} if\ S > 0 \\ 0\ if\ S = 0 \\ \frac{S+1}{\sqrt{Var(s)}} if\ S < 0 \end{cases} \quad (3)$$

The positive values of Z_S indicate the increasing trends of the results, and the negative Z_S values denote the decreasing trends of the results. The null hypothesis (H0) attitudes for an important trend, while the alternative hypothesis (H1) signifies no statistically significant trend (Hamlaoui-Moulai et al. 2012).

2.7.2 Sen's slope estimator

In estimating the slope of the significant trends, Sen's method was widely used, and the variance of the residuals must be continuous in time scale. The Sen's method is calculated using Eq. 4 (Gocic and Trajkovic 2013):

$$Q_i = \frac{x_{j-}x_k}{j-k} f\ or\ i = 1, \ldots\ldots\ldots, n \quad (4)$$

where X_j and X_k represent the data values in the times series j and k, respectively, and n is denoted the number of time periods. In this study, two nonparametric methods (Mann-Kendall and Sen's slope estimator) were used to detect the meteorological variable trends focused on changes in air temperature and precipitation in Iraq during 1971–2020. Addinsoft's XLSTAT software (version 2021.2.) was used for performing the statistical Mann-Kendall test and Sen's slope estimator.

3 Applications results and analysis

3.1 Recorded air temperature in Iraq 1971–2020

The period for studying temperature in Iraq has been done from 1971 to 2020, to determine the temperature behavior from the mid-twentieth century. The results shown in Fig. 3 present the annual temperature average recorded in Iraqi meteorological stations for the period 1971–2020, ranging between 20 and 26.4 °C. It was recorded the lowest average

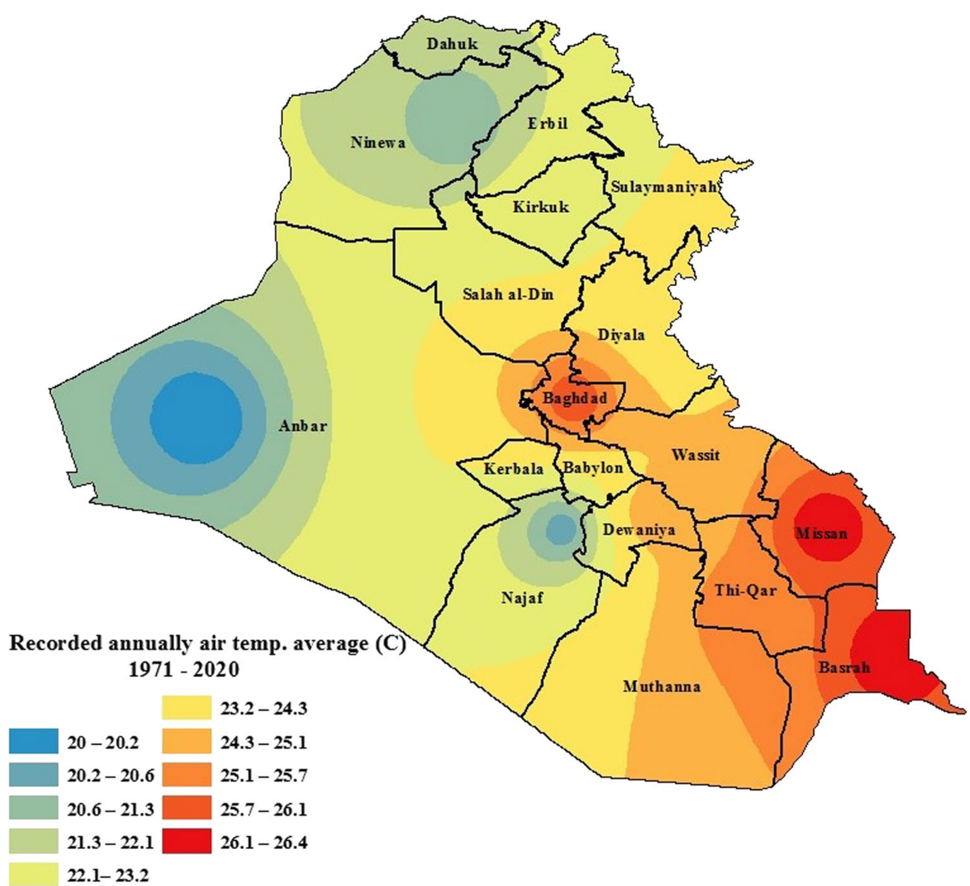

Fig. 3 Annually average temperature in Iraqi meteorological stations from 1971 to 2020

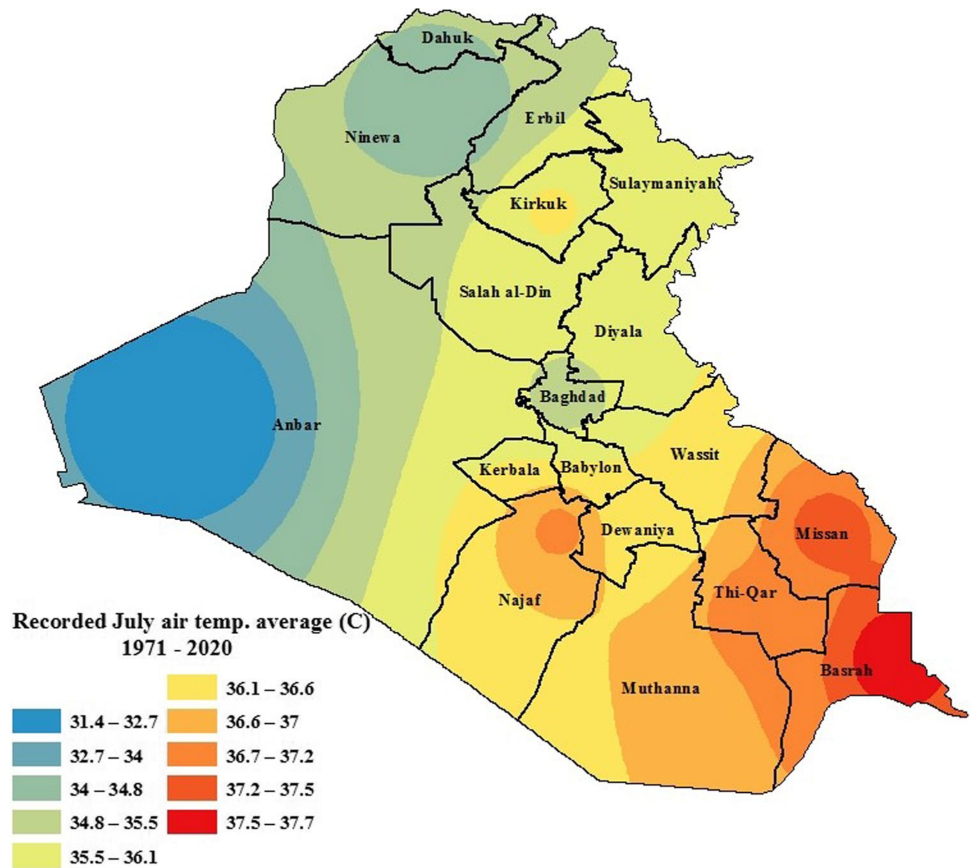

Fig. 4 July average temperature recorded in Iraq during 1971–2020

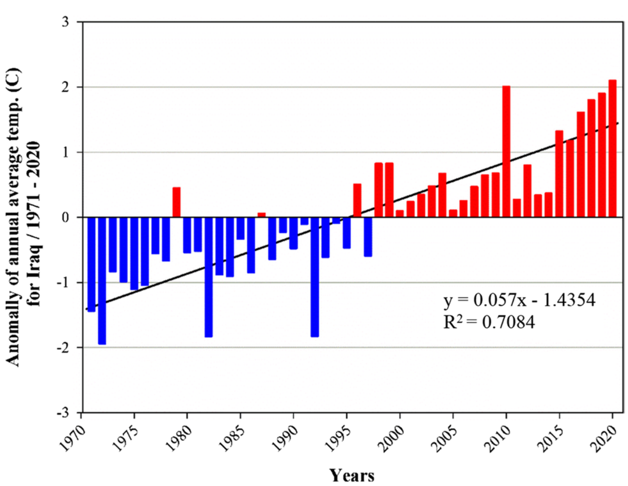

Fig. 5 Anomaly of annual average temperature during 1971–2020

in the western and northwestern regions of Iraq, especially in Anbar and Ninewa, whereas the highest average of temperature was recorded in south and southeastern Iraq, e.g., Basra, Missan and Thi-Qar. The moderate averaged temperature was recorded in the central and northeastern parts of Iraq, ranging between 22.1 and 24.3 °C.

July average temperature recorded over the period 1971–2020 was studied. Figure 4 showed that the highest average temperature from 1971 to 2020 was recorded in the southern parts of Iraq, especially in Barsa and Missan, as it ranged between 37.2 and 37.7 °C. The lowest average recorded was observed within the western and northern Iraq, in Anbar, Ninawa, Erbil, and Dhuk, ranging between 31.4 and 35.5 °C. Figure 4 presented that the moderate average temperature for July month was recorded in the central region of Iraq, especially in Baghdad, Diyala, and Salah Al-Din, and it was ranged between 34 and 35.5 °C. Figure 5 showed the anomaly of annual average temperature in Iraq from 1971 to 2020. Iraq Region demonstrated an increasing temperature by +2.1°C during observed 50 years in 2020. Also it can be noted from Figure 5 that the temperature began to rise continuously from 1998 until 2020, compared to the cooling period from 1971 to 1995, with a linear regression of $R^2 = 0.7084$.

The results of applying the Mann-Kendall test and Sen's slope estimator for annual and July, during 1971–2020, were presented in Figure 6a and b and Table 3. The significant trends at the 5% significance levels were increasing in both annual and July time scale. Also, Sen's slope results were 0.067 and 0.09 for annual and July average temperature, respectively. The test results indicated an increasing trend.

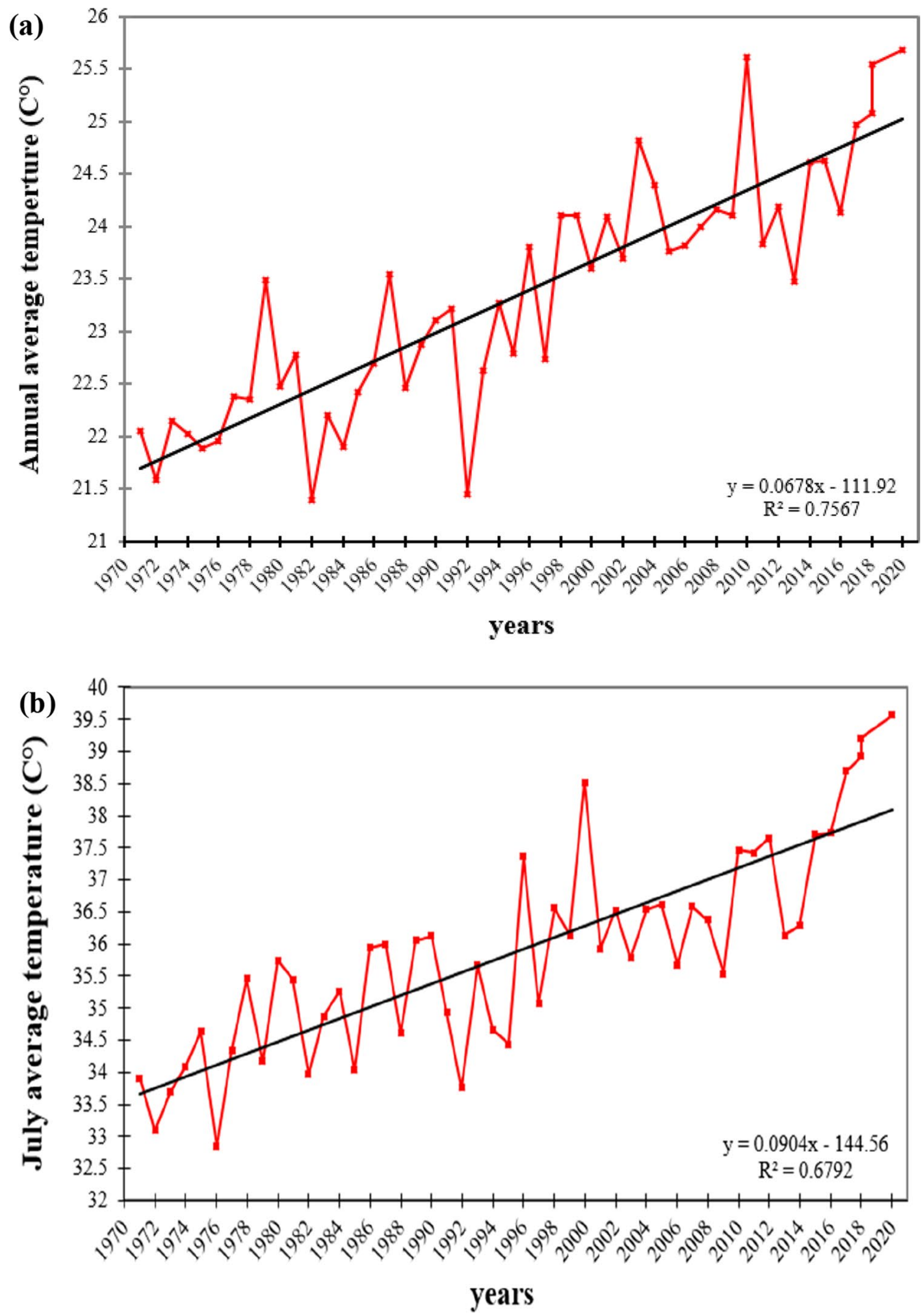

Fig. 6 Mann-Kendall test on temperature data. **a** The annual average temperature, 1971–2020; **b** July average temperature, 1971–2020

Table 3 Mann-Kendall's statistic for temperature parameter in 10 meteorological stations in Iraq during 1971–2020

Temperature data	Kendall's tau	S statistics	Var (S)	*p* value (two-tailed)	Alpha	Sen's slope	Tests results
Annual average	0.714	875	14291.667	< 0.0001	0.05	0.067	Increasing
July average	0.660	808	14290.667	< 0.0001	0.05	0.09	Increasing

3.1.1 Future air temperature in Iraq 2000–2099 based on emission scenarios

For studying the future climatic characteristics of the Iraq Region temperature, according to emission scenarios until 2099, the values of the annual and July averages temperature were extracted based on three emission scenarios. Also, the annual average temperatures were extracted for two periods: near future (2020–2039) and medium future (2040–2059).

Low B1 scenario Appendix A1 provided the future annual and July averages temperature in Iraq during 2000–2099, according to the B1 scenario. The highest average was recorded in the southern and central provinces, especially in Basra, Muthanna, and Dewaniya, ranging between 22.9 and 25.2 °C. The lowest temperature ranged between 13.7 and 15.7 °C in the northern governorates. Appendix A2 illustrated that the highest temperature of July recorded 39.4–40.2 °C at Muthanna and Dewaniya, during 2000–2099. Appendix A3 showed the annual average of the near future during 2020–2039; southern and central parts of Iraq record the highest temperature, ranging 22–26 °C. High values of temperature are still recorded in southern Iraq in the medium future 2040–2059, as shown in Appendix A4.

Medium A1B scenario The annual and July average temperature during 2000–2099 under A1B is reported in Appendix B. The highest temperature reached 25.2–26 °C at Dewaniya, Muthanna, and Basra (Appendix B1). Then average temperature begins to decrease, recorded in Baghdad 22.5–23.4 °C. The lowest annual average temperature was recorded in Dahuk and Sulaymaniyah in northern Iraq, as it reached 14.5–16.3 °C. Appendix B2 showed that the highest average in July was recorded in southwest Iraq, especially at Dewaniya and Muthanna, ranging between 40.3 and 41.2 °C. The high temperature values continue in the Najaf, Karbala, Babylon, Thi-Qar, Basra, and Missan, ranging from 39.02 to 40.3 °C. The lowest temperatures were recorded in northern and western Iraq, which reached between 30.9 and 35.8 °C. Appendix B3 reported the annual average temperature during 2020–2039 based on the A1B scenario. The high temperature was recorded in the southern and southwestern of the region, ranging between 24.5 and 26.3 °C. It showed low temperature values in northern Iraq which varied between 8 and 10.8 °C. During the medium future 2040–2059, the temperature values continue to rise in the southern and southwestern parts of Iraq, ranging between 25.3 and 27.2 °C (Appendix B4).

High A2 Scenario Appendix C displayed the annual and July average temperature under A2 during 2000–2099. The results showed that the highest annual average temperature under the A2 scenario during 2000–2099, ranging between 28.2 and 28.6°C, was recorded in the Dewaniya and Muthanna (Appendix C1). Also, other southern provinces e.g., Basra, Missan, Thi-Qar, and Najaf, recorded high temperature values, between 27 and 28.2 °C. The central provinces, e.g., Wassit, Baghdad, Karbala, and parts of Diyala and Anbar, were recorded a medium average of temperature between 24.1 and 26.3 °C. The lowest annual average temperature has been recorded in the Dahuk, Erbil, and Sulaymaniyah, as it ranged between 17.4 and 20.3 °C.

July average temperature, according to A2 (2000–2099), is presented in Appendix C2. The highest average was recorded in southwestern Iraq, especially in Dewaniya, Muthanna, and Najaf, as it reached 39.8–41.5 °C. It can be noted, the wide range of high temperature spans from Basra in the south to Kirkuk and Ninewa in the north. That is confirming that large areas of Iraq are affected by the repercussions of the A2 scenario, which is more pessimistic in terms of high temperature. The lowest July average temperature is recorded in northeast Iraq, especially in Dahuk and Erbil, ranging between 24.6 and 27.1 °C. Based on Appendixes C3 and C4, the southern and southwestern parts of the region are still witnessing the highest temperatures according to the A2, for the near and medium future periods, respectively. The temperature rises in these parts from 24.4–26.3 °C to 25.3–27.1 °C.

Figure 7a exhibited the comparison between the annual average temperature among B1, A1B, and A2 scenarios for the period 2000–2099. The average temperature according to B1 arisen from 20.5 °C in 2000 to reach 21.8 °C in 2050 and continues with a slow rise until it reaches 22.1 °C in 2099. According to the A1B scenario, the average temperature rises from 20.5 °C in 2000 to 22.6 °C in 2050 and then rises faster in the 2nd half of the current century to reach 23.8 °C in 2099. The A2 represented a significant rise in the annual average temperature in Iraq, which rises from 20.5 °C in 2000 to 22.5 °C in 2050, and then it continues to rise continuously until it reaches 25.3 °C in 2099.

The forgoing results emphasized that Iraq will face an increase in the annual temperature during the current century at least, according to A1B and A2 scenarios, unless the world countries take measures to reduce greenhouse gas emissions. When studying the anomaly of the annual average temperature for 2000–2099 under the three scenarios, Figure 7b exhibited a positive increase in these averages over 2099 that reached 0.4 °C, 1.2 °C, and 2.4 °C for B1, A1B, and A2, respectively. According to these results, the temperature behavior in Iraq during the twenty-first century is upward behavior, regardless of the scenario used in modeling according to its multiple assumptions.

The projection of annual temperature changes (%) for the four future periods (2020–2039, 2040–2059, 2060–2079, and 2080–2099), in relation to the observed period (1981–2000) under B1, A1B, and A2 scenarios, is presented in Table 4. The results showed a substantial decrease for the two periods (2020–2039 and 2040–2059) recorded under the B1 scenario at (−1.4% and −0.9%), respectively. After the 2nd half of the current century in the last periods (2060–2079 and 2080–2099), A2 recorded the highest increase in temperature (0.8% and 2.2%), respectively.

3.2 Recorded precipitation in Iraq 1971–2020

In the current study, precipitation patterns were studied for the period (1971–2020). Figure 8 proved that the annual

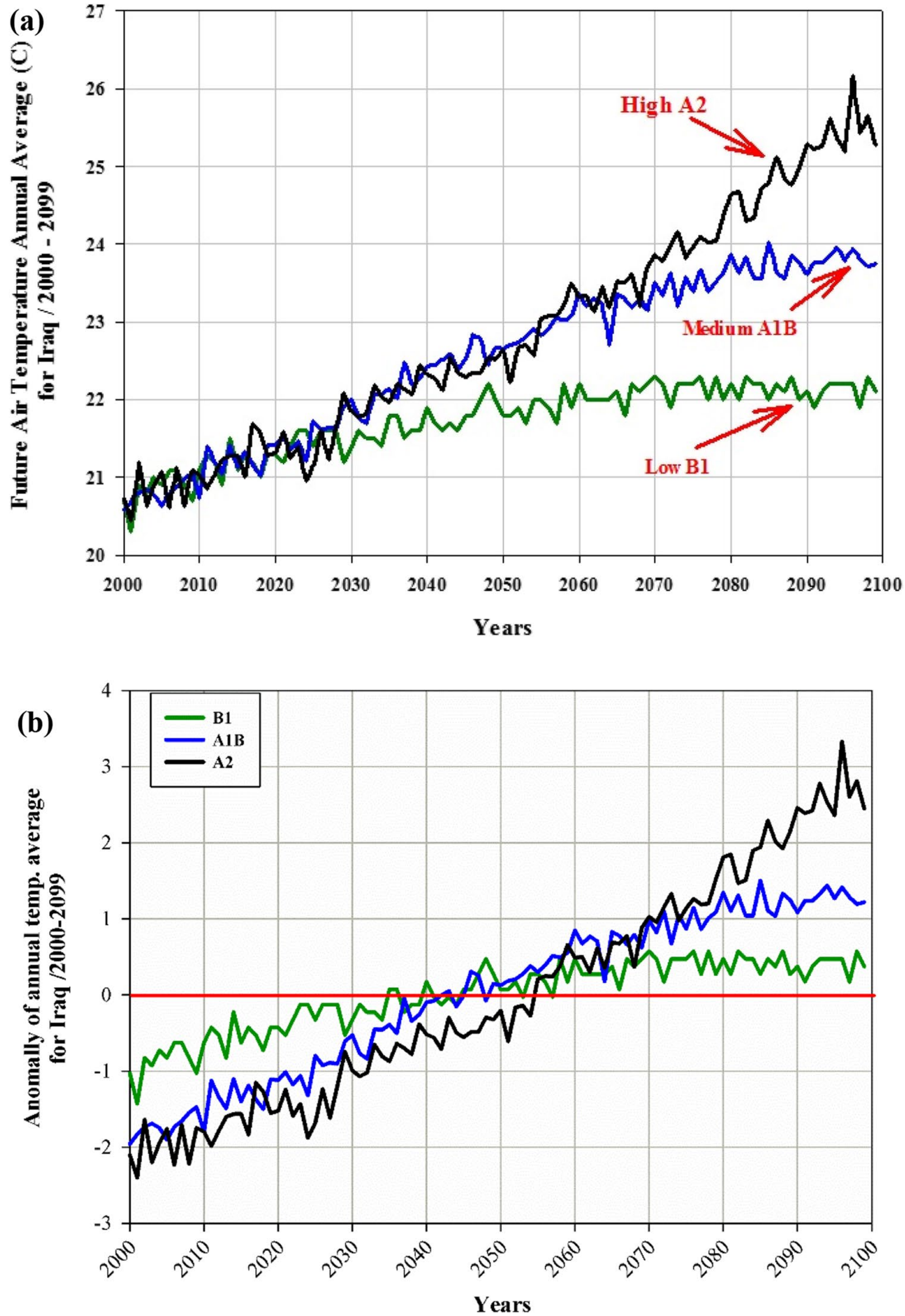

Fig. 7 **a** Comparison among B1, A1B, and A2 for the annual average temperature in Iraq during 2000–2099; **b** anomaly of the annual average temperature in Iraq during 2000–2099 according to B1, A1B, and A2

Table 4 The projection of annual temperature changes (%) for the future periods (2020–2039, 2040–2059, 2060–2079, and 2080–2099), in relation to the observed period (1981–2000)

Simulated periods	B1	A1B	A2
2020–2039	−1.4	−1.1	−1.2
2040–2059	−0.9	−0.2	−0.3
2060–2079	−0.8	0.5	0.8
2080–2099	−0.7	0.9	2.2

average of the total precipitation recorded at the 12 Iraqi meteorological stations ranged between 85 and 339 mm. It was the highest average recorded in the northern region of Iraq, especially in Ninewa, Dahuk, Erbil, and Kirkuk, while the lowest precipitation average was recorded in southwestern and western parts of Iraq (i.e., Muthanna, Najaf, and Karbala). The moderately averaged precipitation was recorded in the middle and northern parts of Iraq, ranging between 109 and 202 mm.

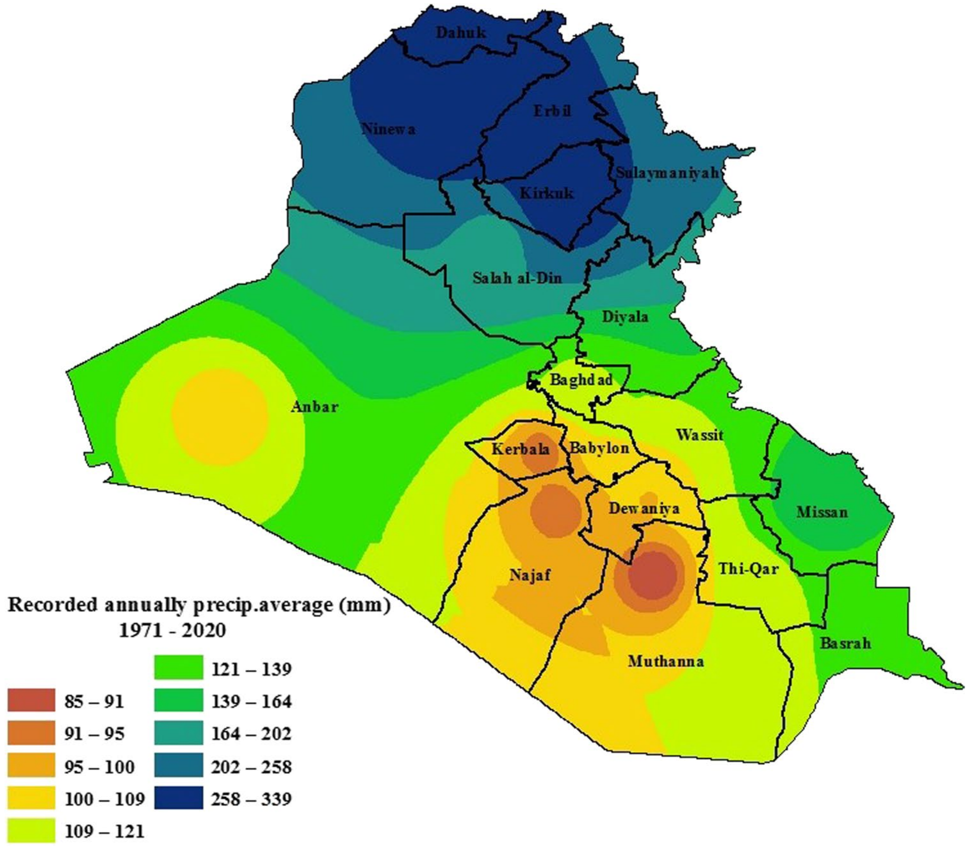

Fig. 8 Annually average of total precipitation in Iraqi meteorological stations from 1971 to 2020

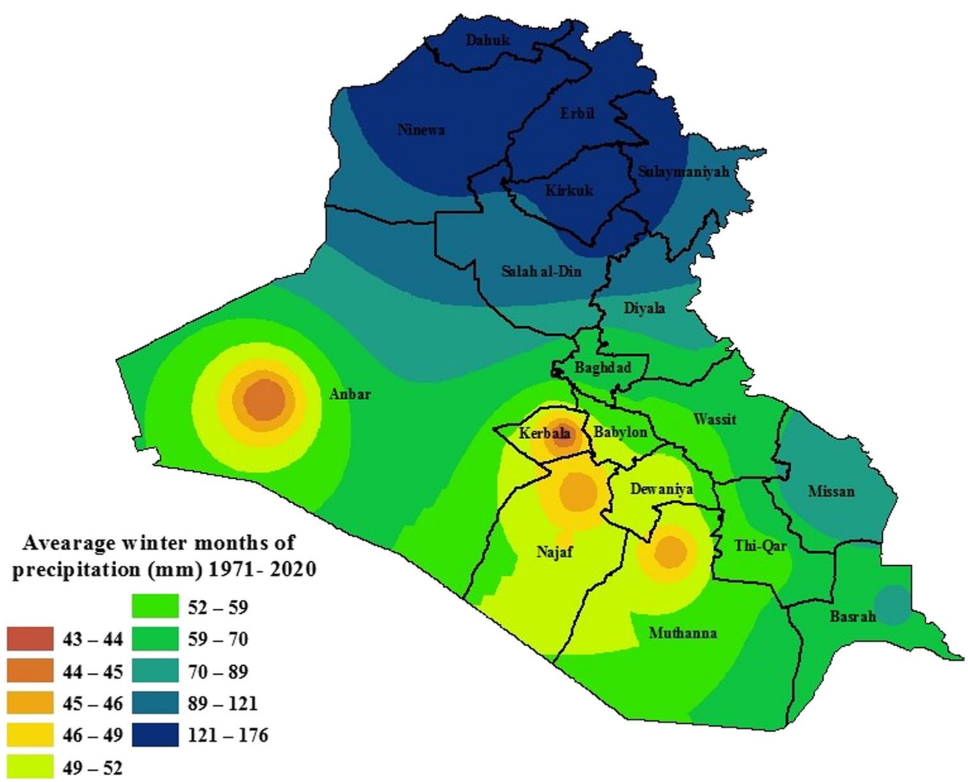

Fig. 9 The average winter months (December, January, and February) of precipitation in Iraq from 1971 to 2020

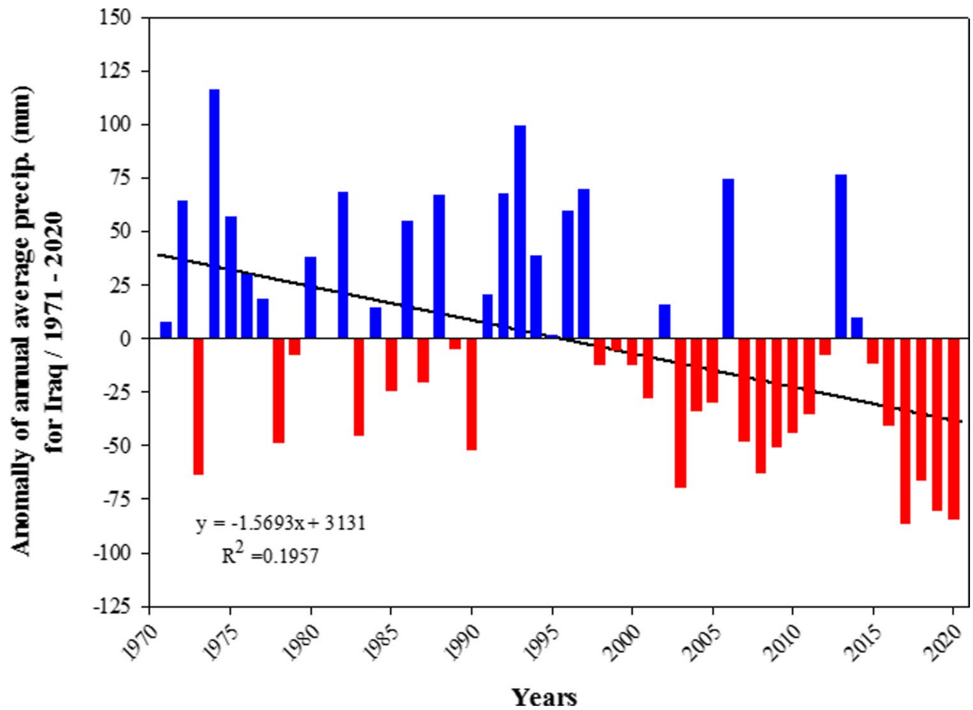

Fig. 10 Anomaly of annual average precipitation during 1971–2020

Figure 9 displayed the average winter months (i.e., December, January, and February) of precipitation over 1971–2020. The results confirmed that the highest precipitation values were focused on northern Iraq, ranging between 121 and 176 mm. In addition, the lowest values were recorded in the southwest and western parts of Iraq around 43 mm. Figure 10 showed the anomaly of annual average precipitation for the period 1971–2020. The results showed precipitation decreasing by −84 mm during the observed 50 years in 2020. Further, it was noted from Figure 10 that precipitation began to downward continuously from 1998 until 2020, compared to the wet period (1971–1997), with linear regression $R^2 = 0.1957$.

The annual trend and winter month time series of precipitation were analyzed using the Mann-Kendall test and Sen's Slope during 1971–2020 (Figure 11a and b and Table 5). The trends were significant at 5% confidence level for both annual and winter month scales. The results showed a decreasing trend in annual and winter month precipitation during the current study. According to these results, Sen's slope results were −1.802 and −1.095 for annual and winter months, respectively, and the test results are decreasing.

3.2.1 Future precipitation in Iraq 2000–2099 based on emission scenarios

For studying the future climatic characteristics of precipitation in Iraq, according to the SRES scenarios until 2099, the values of the annual averages were extracted, as well as the averages of winter months (i.e., December, January, and February) for the two periods (2020–2039 and 2040–2059), based on three emission scenarios as follows.

Low B1 scenario Appendix D reported the future precipitation of the annual and winter month averages during 2000–2099, according to the B1 scenario. Appendix D1 showed the future annual average precipitation for 2000–2099, according to scenario B1. The highest averages were recorded in northern Iraq (i.e., Dahuk, ranging between 248 and 320 mm), while the lowest averages were recorded in the western and southwestern regions of Iraq, which are characterized by a dry desert climate (i.e., Anbar, Najaf, and Muthanna), where the precipitation ranges between 62 and 85 mm. Appendixes D2 and D3 revealed the average winter months of precipitation for the two periods 2020–2039 and 2040–2059, according to scenario B1, respectively. Appendix D2 indicated that the lowest average precipitation was recorded in southern and southwestern Iraq, 160–193 mm, particularly at Muthanna and Najaf. The highest average was recorded in the northern region, as it ranged between 851 and 1145 mm. Appendix D3 indicated the lowest average precipitation was recorded in southern Iraq (i.e., Muthanna and Najaf, ranging between 155 and 188 mm). The highest average was recorded in Dahuk, which reached around 1100 mm. From Appendixes D2 and D3, there is a slight difference in the amount of expected precipitation, according to B1 during the above two time periods. Although the precipitation average for the current century based on B1 is higher than the average precipitation of the twentieth century of the studied region.

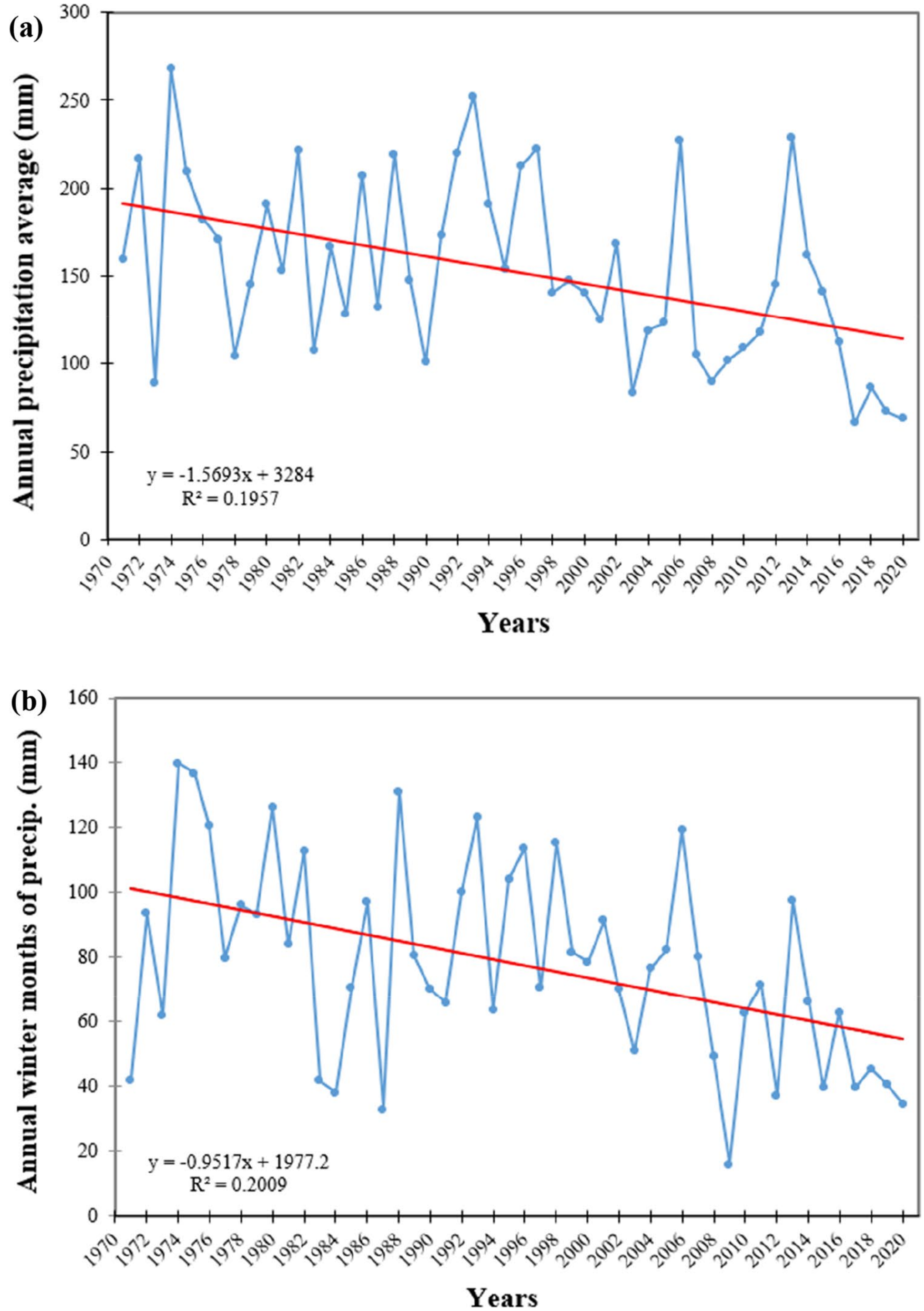

Fig. 11 Mann-Kendall test on precipitation data. **a** The annual average precipitation from 1971 to 2020; **b** precipitation winter months from 1971 to 2020

Table 5 Mann-Kendall's statistic for precipitation parameter in 12 meteorological stations in Iraq during 1971–2020

Precipitation data	Kendall's tau	S Statistics	Var (S)	*p* value (two-tailed)	Alpha	Sen's slope	Tests results
Annual average	−0.313	−383	12036.447	0.000	0.05	−1.802	Decreasing
Winter months average	−0.322	−395	20847.410	0.006	0.05	−1.095	Decreasing

Medium A1B scenario Appendix E presented the annual and winter months average of the future precipitation under A1B during 2000–2099. Appendix E1 showed the highest annual average precipitation for the period 2000–2099, based on A1B which reached 243–308 mm, in Duhok, while the lowest annual was recorded at Anbar and Najaf, ranging between 64 and 86 mm.

Appendix E2 stated the amount of precipitation for the winter months according to the A1B during 2020–2039. Appendix E2 revealed that the southern and southwestern region have the least precipitation, ranging between 150 and 188 mm. The governorates of the northern region recorded the highest precipitation average ranging between 861 and 1145 mm. Appendix E3 disclosed the highest amount of precipitation for the second period 2040–2059 in Iraq; according to the A1B, 802–1075 mm was recorded in northern Iraq (i.e., Dahuk). The lowest precipitation values for the same period were recorded in the southwest of the region, ranging between 159 and 190 mm. The precipitation values for the second period of the A1B were lower than their values for the first period. This confirms the decrease in the precipitation amount during the current century, due to the consequences of climate change and Iraq falling within the arid and semiarid region within the midlatitudes.

High A2 scenario The annual and winter month averages of the future precipitation under A1B during 2000–2099 are presented in Appendix F. The results showed that the highest annual average precipitation according to A2 for the period 2000–2099 was recorded within the northern part of the region (i.e., Dahuk, ranging between 251 and 299 mm). Approach values were also recorded at Basra and ranged between 182 and 251 mm. This indicates a change in the pattern of precipitation based on A2. The lowest annual precipitation average was recorded in the western and southwestern regions of Iraq at Anbar and Najaf, which reached 69–98 mm. While the other central and southern governorates recorded similar precipitation values, ranging between 98 and 157 mm. Appendix F2 explained the amount of future precipitation for the winter months according to A2 for the first period 2020–2039. The southwestern region of Iraq (e.g., Najaf, Muthanna, Basra, and parts of Anbar) has the least precipitation during the above period, ranging between 158 and 215 mm. The governorates of the northern Iraq recorded the highest precipitation average, between 611 and 1082 mm. Appendix F3 indicated the highest amount of precipitation for the winter months for the second period 2040–2059, based on A2 in which more than 1000 mm was recorded in northern Iraq (i.e., Dahuk). The lowest precipitation value was recorded in the south and southwest parts of the region (i.e., Muthanna, Najaf, and Anbar, between 150 and 193 mm). The precipitation values for the second period of the A1B were lower than their values for the first period. This confirms the decrease in the average of precipitation of Iraq during the current century.

To compare the annual precipitation averages in Iraq among the three scenarios B1, A1B, and A2, during 2000–2099, Figure 12a showed that the average precipitation according to B1 declines from 125 mm in 2000 to 111 mm in 2050 and continues with a fluctuation until it reaches 133 mm in 2099. The annual precipitation average according to the assumptions of the A1B decreases from 161 mm in 2000 to 121 mm in 2050 and then declines at the end of the current century to 104 mm in 2099. The A2 confirmed a significant rise in the annual precipitation average, as it rises from 129 mm in 2000 to 163 mm in 2050, and then it maintains to rise continuously until it reaches 193 mm in 2099. When studying the anomaly of the annual precipitation average for the period 2000–2099 under the three scenarios (Figure 12b), it can be noted that there is a positive increase in these averages over 2099 that reached 5.1 mm and 56.2 mm for B1and A2, respectively. There is a negative value for A1B reaching −25.5 mm in 2099. According to the obtained results, the precipitation trend in Iraq during the twenty-first century is upward, especially based on the evaluation of the A2 scenario.

The projection of annual precipitation changes (%) for the four future periods (2020–2039, 2040–2059, 2060–2079, and 2080–2099), in relation to the observed period (1981–2000) under B1, A1B, and A2, is displayed in Table 6. The results showed a noticeable decrease for the near period (2020–2039) recorded under A2 (−28%). In the middle of the century, A1B recorded decreased percentage (−30%). After the 2nd half of the current century, B1 recorded the highest decrease on (−24% and −22%) to the end of the century. These results confirm that precipitation values will clearly decrease under SRES conditions related to the observed period along the twenty-first century.

4 Discussion

In this study, we analyzed the annual, monthly, and seasonal temperature and precipitation averages as observed data in many meteorological stations in Iraq for 1971–2020. NCAR-CCSM3 is categorized as modeled data to evaluate the future of temperature and precipitation situation in Iraq under B1, A1B, and A2 scenarios for 2000–2099, 2020–2039, and 2040–2059. The results showed that the highest annual and July temperature averages recorded for 1971–2020 in the southern part of Iraq (Basra and Missan) reached 26 °C and 37 °C, respectively. Several studies found that the southern part of Iraq is the most affected by a warming trend in temperature over the periods 1941–2013 and 1972–2010, respectively

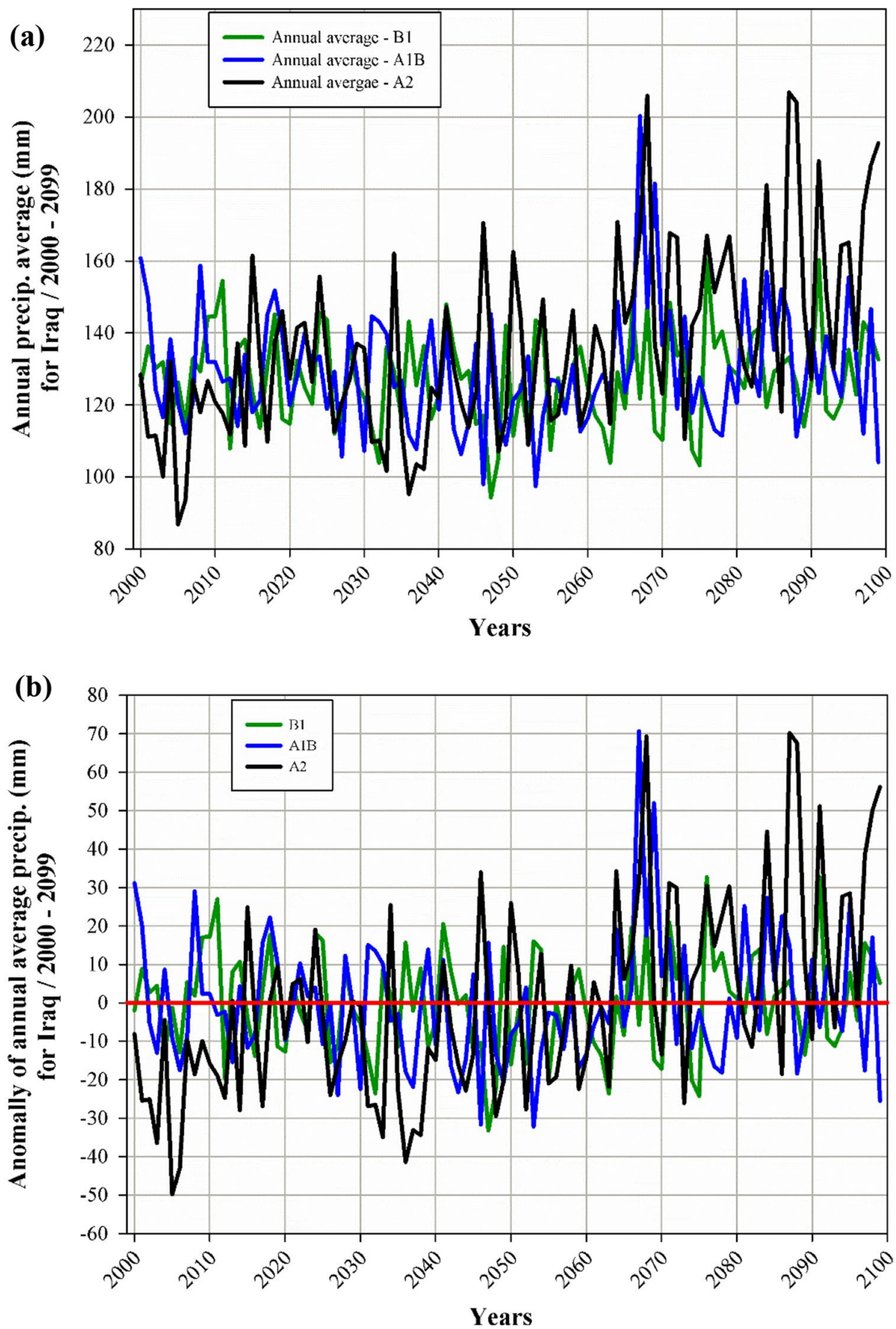

Fig. 12 **a** Comparison among B1, A1B, and A2 for the annual average precipitation in Iraq during 2000–2099. **b** Anomaly of annual precipitation average in Iraq during 2000–2099 according to B1, A1B, and A2

(Robaa and Al-Barazanji 2015; Muslih and Błażejczyk 2017). The lowest annual and winter months precipitation averages were recorded in the middle and southwestern parts of Iraq (i.e., Mothanna, Najaf, Dewaniya, and Karbala) about 88 mm and 43 mm, respectively. Robaa and Al-Barazanji (2015) found similar results dealing with annual precipitation in Iraq. Hameed et al. (2018) discovered a significant drought exacerbation over Iraq during the period of 1998–2009. Their results also showed that drought has become more intense in the central and southwestern parts of Iraq, compared to that in the northern and southeastern parts. The temperature anomaly increased to +2.1 °C, during the observed period 1971–2020. Further, precipitation anomaly clearly decreased during the studied period about −84 mm, as shown in Figures 5 and 10, respectively, especially from the year 1998, due to

Table 6 The projection of annual precipitation changes (%) for the future periods (2020–2039, 2040–2059, 2060–2079, and 2080–2099), in relation to the observed period (1981–2000)

Simulated periods	B1	A1B	A2
2020–2039	−26	−25	−28
2040–2059	−27	−30	−24
2060–2079	−26	−21	−13
2080–2099	−24	−22	−8

drought and increase temperature. Temperature increases under B1, A1B, and A2 scenarios in the future, which reached 2.4 °C in 2099 under the A2 scenario. All the climate models projected a higher increase in temperature of the Middle East compared to those of other parts of the globe. Sharif (2015) projected the temperature of Saudi Arabia using four GCMs under three scenarios and reported a temperature rise in the range of 2.24–5.5 °C at the end of century. Lelieveld et al. (2016) projected a temperature increase by 6 °C relative to 1986–2005 in the Middle Eastern region. The projection of annual temperature changes (%) for 2080–2099 related to 1981–2000 under A1B and A2 showed the highest increase about 0.9 °C and 2.2°C, respectively, as shown in Table 4.

Table 6 pointed a clear decrease in the projection of the annual precipitation changes (%) for all future periods related to the observed period (1981–2020) under B1, A1B, and A2 scenarios. The results explained that the greatest decrease for the near future period (2020–2039) was recorded under A2 (−28%). After the 2nd half of the current century, B1 recorded the highest decrease on (−24% and −22%) till the end of the century.

The results of Mann-Kendall's statistic for temperature and precipitation based on observed data during 1971–2020 showed upward trends in annual and July temperature averages. On the contrary, it demonstrated a downward trend in the annual and seasonal precipitation averages. It is worth to mention the results of the present study correspond to the finding of previous studies (He and Zhang 2005; Elnesr et al. 2010).

5 Conclusions

According to the UN Environment Program, Iraq is classified as the fifth most vulnerable country in the world to decreased water and food availability and extreme temperatures. That will negatively affect food security, water security, social security, and health security in Iraq (UNEP 2017). That is also confirmed by the results of the current study. The results showed that the annual temperature average recorded in Iraq for 1971–2020 was characterized by fluctuation during the second half of the twentieth century and was lower than the general average. From the mid-1990s up to now, the temperature average began to rise the general average in Iraq, which explains the continuous high temperature in recent years, as a result of the implications of global climate change. On the other hand, the amount of precipitation in Iraq decreased, and this was evident from 1998, as it appears in Figure 10.

Under B1, A1B, and A2 scenarios and during the twenty-first century, the temperature behavior was upward and above general averages. The current study is the first step to a better understanding of the future evaluation of temperature and precipitation projections in the Iraq Region for the twenty-first century under SRES scenarios NCAR-CCSM3. It is useful in terms of its association with many aspects such as drought, hydrology, and health. Furthermore, the plans for adaptation and mitigation to be implemented in Iraq under the Paris Agreement are prepared. The study results can help out the decision-makers, policy-makers, administrative, and others stakeholders in implementing the quantitative and qualitative approaches of the future trends, contexts, risks, and opportunities. Scenario-based temperature and precipitation projections have been used as an important methodology for policy-making, management, monitoring, and planning in the context of uncertain future conditions.

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Author contribution Bassim Mohammed Hashim: data curation; formal analysis; methodology; investigation; visualization, writing—original draft, review and editing draft preparation; resources; software.

Ali Al Maliki: investigation; visualization; writing—original draft, review and editing draft preparation; resources.

Esam Abd Alraheem: data curation; formal analysis; visualization; writing—original draft, review and editing draft preparation; resources.

Ahmed Mohammed Sami Al-Janabi: formal analysis; investigation; writing—original draft, review and editing draft preparation.

Bijay Halder: investigation; visualization; writing—original draft, review and editing draft preparation.

Zaher Mundher Yaseen: supervision; conceptualization; project leader; writing—original draft, review and editing draft preparation.

Availability of data and files Data will be provided upon request from the corresponding author.

Declarations

Ethics approval The manuscript is conducted within the ethical manner advised by the TAAC.

Consent to participate Not applicable

Consent for publication The research is scientifically consented to be published.

Competing interests The authors declare no competing interests.

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