Predicting long-term climate changes in Iraq

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Abstract. Changes in air temperature have a significant impact in Iraq due to global climate change. The objective of this study is to project future trends of air temperature in Iraq. In this study, the future air temperature was projected for 2025, 2050, 2075 and 2100 from the CCSM4 climate model belong to CMIP5 under RCP2.6, RCP4.5, RCP6.0 and RCP8.5 scenario for Iraq. The historical observed air temperature data (1950 – 2014) acted as referenced as the mean air temperature data obtained from 18 meteorological stations. Statistical downscaling has implemented. The model outputs were calibrated by using around 80% of the observed historical and model historical data. After that, it proved a significant performance of a statistical downscaling process for simulation air temperature for future periods. The results revealed that the mean air temperature would increase under the four RCPs scenarios with different levels. The lower increase rate belongs to the RCP2.6 scenario, the increase rate is expected to be (0.5-0.8 °C) above the observed historical level. However, the RCP8.5 has the highest rate at (4.1 -6 °C) while, the RCP4.5 and RCP6.5 have (1-2 °C) and (2-4 °C) respectively. On the other hand, the temperature expands direction is from the south toward central, west and north of Iraq.

Keywords: Climate change, Air temperature, CCSM4, RCPs, Trend analysis, Iraq.

1. Introduction
Climate change and its consequences become global concerns [1]. According to [2], that the earth’s temperature has increased by 0.74 °C in the last century Increase of Greenhouse Gases (GHGs) concentration in the atmosphere as a result of anthropogenic activities has led to the rising global temperature around 1°C since the pre-industrial period [3]. Climate change is an unequivocal phenomenon that attracts researchers to address the future effects [4]. Climate change is a global phenomenon where the air temperatures are increasing gradually [5]. Change in climatic refers to a state within a certain period that expresses changeable in the statistical distribution of weather patterns due to Radiative Forcing (RF) variation [6]. Because of changes in the composition of the earth’s atmospheric system that impacts on earth’s energy balance exchange which is causing global climatic change ([7, 8]) Climate change is recognized as a future threat to the ecosystem [9]. Environment and public health [10]. High temperature and change in climatic conditions dramatically adversely impact agriculture and crop yields as they highly depend on climate elements [11].

General Climate Models (GCMs) are mainly used for future climate projection [12]. Global climate models (GCMs) are the most powerful tool used widely to investigate climate scenarios for both present and future horizons [3]. Also, to understand the world climate system sensitivity and project future climate change [13]. High-resolution climate change projections can provide important information for decision-makers to set up mitigation and adaptation policies [14]. Climate models that predict future changes in climate conditions still exhibit a spread in display long-term of climate variable change [15]. The IPCC, fifth assessment report (AR5) set a climate model, known as Coupled Model Intercomparison Project phase 5 (CMIP5) [16]. CMIP5 designed to promote the understanding of the climate system and depict future events of climate change [8, 13]. CMIP5 is widely used for analysis and project future climate, as it has significant improvements compared to previous models [12]. The CMIP5 used emission scenarios of Representative Concentration Pathways (RCPs) [17]. The RCPs refers to the concentration of GHGs that are responsible for climate change. IPCC adopted four RCPs according to
RF level at 2.6, 4.5, 6.0 and 8.5 W/m² extending up to 2100 to be RCP2.6, RCP4.5, RCP6.0 and RCP8.5 respectively [13, 18]

Air temperature is an essential climate variable in research aiming to tackle climate change issues [19]. Changes in mean air temperature (Tas) is a crucial climate parameter to illustrate climate change of a particular area by using GCMs outputs for future anticipate [20]. An increase in Tas can trigger many extremes weather events such as heatwaves, spread diseases, drought, soil erosion and habitats shift [21]. Changes in air temperature can modify many natural elements in an environment such as soil moisture leading to the inconstancy of energy exchange between the atmosphere and land surface. The anomaly in air temperature trend has substantial impacts not only on environmental aspects, but also on socioeconomic development [19]. According to Doulabian, Golian [3] the arid and semiarid areas will experience a significant increase of Tas based on RCPs scenarios. Hence, it’s very important to investigate Tas variability over Iraq and its future fluctuation.

Iraq is an arid country and considers vulnerable to climate change in the Arab region and most sensitive to climate variability [7]. Iraq might have increased in air temperature and decreased in precipitation in the future [22]. The arid and semi-arid climate are predominantly in Iraq, mainly in central to south, thus it has a frequent extreme temperature. Some areas in the Persian Gulf and south of Iraq will exceed the threshold for human adaptability within the scenario of RCP8.5 of CMIP5 [23]. In recent years Iraq has experienced more heat waves in summer. The temperature in Basra city located in the Southern has reached 54°C as the hottest recorded in the eastern hemisphere [7]. Many studies have revealed that air temperature and precipitation patterns in the middle east will significantly affect climate change. Rahimi, Khalili [23] indicated that the temperature would increase in the middle east between 1.4°C to 4°C by the end of 2100, according to the A2 scenario from AR4. A limited number of studies have been done on Iraq’s climate variables [24]. The study aims to present and analyse historical trends by projecting annual mean air temperature across Iraq for the period 1950 to 2100 by using the CCSM4 output climate model under RCP2.6, RCP4.5, RCP6.0 and RCP8.5.

2. Iraq geography and climate
Iraq is located in the southwest of Asia in the northeast of the Arab homeland (lat 29° 15 N to 38° 15N and lon 38° 45 to 48° 45 E). It has a total area of around 437,072 Km² [25]. The topography is like a basin of the Mesopotamian alluvial plain. 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 [26] as in Figure 1.

Figure 1: Study area and climatic zones.
Iraq’s weather is strongly affected by its geography [26]. According to [27] Iraq has 4 climatic regions. Zone I: The Mediterranean climate of the mountain chains in the north and northeast that covers around 21%; Zone II: Steppe climate of the undulating area that in south and west of the first zone cover about 9.6%; Zone III: the subtropical semi-arid climate in the central and the south (the Mesopotamian plain) covers around 30.2%. The last climatic Zone IV: the continental desert climate in the west covers about 39.2%. Iraq has four climatic seasons, (1) summer (July – October) a hot and dry; (2) Autumn (October – November); (3) Winter (December – February) cool and wet; finally, Spring (March-May). The mean temperature in summer ranges from a minimum of 27-31°C to a maximum of 41-45°C. However, in winter it varies from near freezing in northern to 4-5°C in central and southern [7][28].

3. Data sources
The observed data of annual air temperature over Iraq has obtained from the Iraqi Meteorological Organization and Seismology organization http://www.meteoseism.gov.iq/index.php. The data from 1950 to 2014 has been used to illustrate historical trends of temperature patterns and to calibrate projected model outputs for the study area.

The Community Climate System Model (CCSM) version 4 has been used in the study. It’s one of the climate models participating in CMIP5 [29]. And it is maintained by the National Centre for Atmospheric Research (NCAR). Its available at a spatial resolution of (0.942⁰ * 1.25⁰) were downloaded from www.dkrz.de as NetCDF files for 2006 to 2100 of the RCPs (2.6, 4.5, 6.0 and 8.5) for air temperature daily data. On the other hand, the historical output for the same model outputs has been obtained from the same source for calibrating.

4. Calibration
The GCMs can’t be used at the local scale directly on a particular area to project future climate change patterns for tempospatial distribution because of their coarse spatial resolution [12]. The errors of global climate model output to study climate variables are large, for instance, in relation to anticipated future air temperature. Hence, it’s important to calibrate and make corrections for climate model outputs’ raw data to produce more accurate climate projection [5]. To address this, point a downscaling technique has been used for bridging the gap between GCMs coarse and local scale [12][30]. Also, comparing climate models’ outputs with observation data is crucial to prove their reliability and demonstrate predictive capacities [15]. They reduce uncertainties [30]. There are two main sorts of downscaling techniques: dynamical and statistical. Statistical downscaling is more preferred compare to dynamical [12]. Statistical downscaling has been applied in the study to determine future changes in surface air temperature according to scenarios of AR5 of IPCC [14].

The process of statistical downscaling went through two main steps. 1: developed a statistical relationship between observed air temperature data with large-scale data of the CCSM4 daily air temperature outputs data. 2: applied the statistical relationship that figures out previously on model outputs to simulate local climate properties and projected accurate future climate change [31]. The ArcMap 10.5 used to extract historical and projection model outputs of daily air temperature. The observed data and historical model outputs of 55 years from 1950 to 2005 have been used to figure out the statistical relationship. The linear regression (Person Correlation Coefficient) has applied. Figure 3. Illustrated the trend of observed and model historical data where the correlation was 0.624 that before the calibration process. However, after the calibration process, some extreme data points were ignored to improve the correlation where it jumped to 0.910 as in Figure 3.
5. Results

5.1. Historical Air temperature

The results of the historical annual mean air temperature over Iraq from 1950 to 2005 are demonstrated in Figure 4. The air temperature trend for the first 28 years (from 1950 to 1978) has a stable tendency with low fluctuation and frequentation with no rise or decline in temperature trend. However, the trend from 1979 to 2006 had more peaks and frequentation. It took a raised line in mean air temperature. The historical annual mean of air temperature maps in figure 5. Provides a clear view on temperature change consequences over historical air temperature, the average was found to increase the rate of (0.674 °C) from 1979 to 2006. The map of the years 1950 and 1975 had very slight changes in the four of Iraq’s climate zones. On the other hand, looking at the mean air temperature of the map of the year 2000, the changes become more significant in central, west, and south of Iraq while the northern zone had little changes.
5.2. Prediction Air temperature

The prediction of annual mean air temperature for up to 2100 over Iraq was based on four scenarios RCP2.6, RCP4.5, RCP6.0, and RCP8.5 of the CCSM4 model as part of CMIP5. The period 2020 to 2100 with the historical data have been demonstrated in Figure 6. and Figure 7. Four sequencing years have been chosen 2025, 2050, 2075 and 2100 that each of them addressed and represented through the 4 RCPs. Moreover, each map in Figure 7. represented a mean of 12 months in °C for the targeted year, which was obtained through using the CCSM4 model outputs by using www.knmi.nl.

5.2.1. RCP 2.6. The annual mean air temperature of the period 2020 under the scenario RCP2.6 of the CCSM4 model is shown in Figure 8. The mean air temperature, according to this scenario, is expected to increase up to 2100. The mean air temperature will increase from around 22.7 °C to 23.2°C in mid of the 21 century. The mean is expected to increase slightly to be about 23.5 °C in 2100 where the mean air temperature shows the state of stability from mid to end of the 21 century. According to the maps in Figure 7. of RCP2.6, indicated that the southern climate zones might affect by insensible changes compare to the other three climatic zones.
Figure 6: Historical and projected (4 RCPs) air temperature over Iraq 1950 to 2100

Figure 7: Projection of RCP2.6, RCP4.5, RCP6.0 and RCP8.5 air temperature in Iraq (2025, 2050, 2075 and 2100)
5.2.2. **RCP4.5.** The RCP4.5 scenario trend line is illustrated in Figure 9. The annual mean air temperature is expected to increase more than in RCP2.6. Despite the fact that RCP2.6 and RCP4.5 have almost similar simulation values to the year 2055, the RCP4.5 records higher mean temperature values by around 1-2 °C with an upward trend line up to 2100. The maps in Figure 7. of the RCP4.5 scenario clearly match the mean air temperature shown in Figure 6. The years 2050, 2075 and 2100 showed an increase in temperature mainly in central and southern zones with slightly affected in the west and less than that in northern climatic zones.

![RCP4.5](image)

**Figure 9:** RCP4.5 of CCSM4 model for Iraq

5.2.3. **RCP6.0.** The annual mean air temperature is based on the RCP6.0 in Figure 10. has suggested an increasing trend as in previous scenarios. From 2020 to 2055, the temperature will increase by around 2 °C compare to the historical mean temperature. The rate will accelerate and increase by about 4 °C according to this scenario at the end of the 21 century. The maps of RCP6.0 in figure 7. Demonstrates crawling of semiarid climate zone from south and central with shrinkage of northern zones. This trend depicts in the years 2025, 2050, 2075 and 2100, respectively.
5.2.4. RCP8.5. It’s the higher and the worst emission scenario in CMIP5 models. The outputs of annual mean air temperature under this scenario are recorded as the highest air temperatures. In the first 35 years (2020-2055), the air temperature is expected to increase by around 4.1 °C above Iraq’s historical mean temperature. It keeps this sharp rise to reach the annual mean of about 28-29 °C in the 10-last year of 2100. The maps of this scenario, as in figure 11, support the hypothesis of the Tas trend in figure 6 and figure 7. The temperature increases dramatically in the first 35 years of this study, then a sharp increase takes place. Those maps proposed that the climatic zones of southern and central will occupy and displace other climatic zones, where the western and northern climate zones will almost disappear after 2055.

6. Discussion
The statistical downscaling between observed historical air temperature and CCSM4 outputs shows superior performance in simulating air temperature in Iraq, where the correlation coefficient R=0.910 consider to be significant. The implemented procedure of statistical downscaling is agreed with [6].

The results of the historical trend of annual mean air temperatures for Iraq are matched with IPCC AR5, in the state of that since the industrial era the surface air temperature increase in most regions in the particular northern hemisphere. The increasing and fluctuating recognized in early 1980 and more on as a result of increasing concentration of GHGs. The study found that the observed air temperature in Iraq increase by (0.674 °C) from 1979 to 2006 which is matched with [22] who indicate an increase in air temperature over Iraq for the period of 1961 – 2010 by (0.42-0.64°C). In addition, Salman, Shahid
reported that the air temperature increases during the 21 century 2-7 times faster after 1970 across Iraq. However, a very close rate has been found in Saudi Arabia, according to [32].

The annual mean air temperature in the future compares to historical in all climatic zones across the country is expected to increase based on simulation under the four scenarios of the CCSM4 model with different rates from low of RCP2.6 to high under RCP8.5. The air temperature prediction of the four scenarios showed an increase in annual mean air temperature in the four climatic zones up to the end of 21 century over Iraq. The maps in figure 7 are translating the figure 6. where to look vertical at figure 7. for instance, in 2050, according to the four scenarios RCP2.6, RCP4.5, RCP6.0 and RCP8.5 all of them indicate an increase in annual mean air temperature. On the other hand, looking horizontal at the same figure for RCP4.5 will get the same result. The prediction direction of thermal expansion is from the south of Iraq to the west (desert climatic zone) based on the amplification mechanism in summer which involves the rise of downward longwave radiation fluxes in the absence of evapotranspiration and limit capacity of heat storage in dry soil [8]. Rahimi, Khalili [23] projected future shifts of climate zones. Because of global warming, some areas in the south of Iraq will severely affect, particularly under the RCP8.5 scenario, where some of these areas will exceed a human threshold in the reference period and the temperature will increase much faster compared to the global average [7]. The annual mean air temperature under RCP4.5 and RCP8.5 are expected to increase by 2.4°C and 3.8°C up to 2100 respectively over Iraq and the surrounding area [23]. Lelieveld, Proestos [8] Proposed that the middle east air temperature projected to increase around (6°C) relative to 1986-2005.

Undoubtedly that positive changes in annual mean air temperature will be remarked in arid regions. The findings of the study are consistent with many studies in Iraq, such as [6, 7, 22] and studies of neighbouring countries such as Iran [3] and the Middle East [8, 33] in Syria [34]. Were all of them are reported an increase in mean air temperature with different levels increasing. The study’s simulation is associated with a high degree of uncertainty in all RCPs scenarios mainly from mid to the end of the 21 century. The concentration of GHGs can’t exactly be predicted as it depends on several factors, including technological development, economic and environmental aspects [35].

7. Conclusion
To investigate the change of air temperature in Iraq up to 2100, the CCSM4 model has been used based on RCP2.6, RCP4.5, RCP6.0 and RCP8.5 scenarios, where the model results contrasted with the referencing period (1950 – 2014) data. The statistical downscaling procedure has been performed to evaluate and check the robustness relationship between historical and model data, which has proven a significant correlation. The air temperature will continue to increase in the future time in Iraq and dry areas will become drier according to all RCPs scenarios at different degrees of changes. The RCP2.6 showed a lower increase rate of air temperature trend. In contrast to RCP8.5, which has a higher increase rate of air temperature among all RCPs scenarios across Iraq. The south climatic zone is the most vulnerable in Iraq. The future direction of thermal expansion is from the south to west climatic zone, which is considered to be less affected by future climate change among all remain climatic zones in Iraq. The study can help planners and policymakers set national strategies for dealing with future climate change in Iraq.

References
[1] Stan K, et al., 2020 Climate change scenarios and projected impacts for forest productivity in Guanacaste Province (Costa Rica): lessons for tropical forest regions. Regional Environmental Change. 20(1): p.14.
[2] IPCC, Synthesis report: summary for policy makers. 2014.
[3] Doulabian S, et al., 2020 Evaluating the effects of climate change on precipitation and temperature for Iran using RCP scenarios. Journal of Water and Climate Change.,
[4] Mumo L and Yu J 2020 Gauging the performance of CMIP5 historical simulation in reproducing observed gauge rainfall over Kenya. Atmospheric Research. 236: p.104808.
[5] Oo H T, Zin W W and Kyi C C T 2019 Assessment of Future Climate Change Projections Using Multiple Global Climate Models. *Civil Engineering Journal*. 5(10):2152-66.

[6] Al-Mukhtar M and Qasim M 2019 Future predictions of precipitation and temperature in Iraq using the statistical downscaling model. *Arabian Journal of Geosciences*, 12(2): p.25.

[7] Salman S A, *et al.*, 2017 Long-term trends in daily temperature extremes in Iraq. *Atmospheric Research*. 198: p. 97-107.

[8] Lelieveld J, *et al.*, 2016 Strongly increasing heat extremes in the Middle East and North Africa (MENA) in the 21st century. *Climatic Change*. 137(1):245-60.

[9] Shiny R, Sreekumar J and Byju G 2020 Coupled multi-model climate and climate suitability change predictions for major cassava growing regions of India under two representative concentration pathways. *Journal of Tropical Agriculture*. 57(2).

[10] Li Z, *et al.*, 2020 Impacts of projected climate change on runoff in upper reach of Heihe River basin using climate elasticity method and GCMs. *J Science of The Total Environment*. 716: p. 137072.

[11] Harkness C, *et al.*, 2020 Adverse weather conditions for UK wheat production under climate change. *J Agricultural Forest Meteorology*. 282: p. 107862.

[12] Noor M, *et al.*, 2019 Selection of CMIP5 multi-model ensemble for the projection of spatial and temporal variability of rainfall in peninsular Malaysia. *J Theoretical Applied Climatology*. 138(1-2):999-1012.

[13] Gorguner M, Kavvas M L and Ishida K 2019 Assessing the impacts of future climate change on the hydroclimatology of the Gediz Basin in Turkey by using dynamically downscaled CMIP5 projections. *Journal of Science of the Total Environment*. 648: p.481-99.

[14] Araya-Osses D, *et al.*, 2020 Climate change projections of temperature and precipitation in Chile based on statistical downscaling. *Climate Dynamics*.; p.1-22.

[15] Jensen L, *et al.*, 2019 Long-term wetting and drying trends in land water storage derived from GRACE and CMIP5 models. *J Journal of Geophysical Research: Atmospheres*. 124 (17-18): 9808-23.

[16] Taylor K E, Stouffer R J and Meehl G A 2012 An overview of CMIP5 and the experiment design. *Bulletin of the American Meteorological Society*. 93(4):485-98.

[17] Singh R and AchutaRao K 2020 Sensitivity of future climate change and uncertainty over India to performance-based model weighting. *Climatic Change*. 160(3):1-22.

[18] Van Vuuren D P, *et al.*, 2011 The representative concentration pathways: an overview. *Climatic change*. 109(1-2): p. 5.

[19] Chen S, *et al.*, 2019 Present-day status and future projection of spring Eurasian surface air temperature in CMIP5 model simulations. *Climate Dynamics*. 52(9):5431-49.

[20] Sreelatha K and Anand Raj P 2019 Ranking of CMIP5-based global climate models using standard performance metrics for Telangana region in the southern part of India. *ISH Journal of Hydraulic Engineering*.; p. 1-10.

[21] Khan N, *et al.*, 2020 Selection of GCMs for the projection of spatial distribution of heat waves in Pakistan. *J Atmospheric Research*. 233: p. 104688.

[22] Salman S A, *et al.*, 2019 Characteristics of Annual and Seasonal Trends of Rainfall and Temperature in Iraq. Asia-Pacific Journal of Atmospheric Sciences 2019. 55(3):429-38.

[23] Rahimi J, Khalili A and Butterbach-Bahl K Projected changes in modified Thornthwaite climate zones over Southwest Asia using a CMIP5 multi-model ensemble. *J International Journal of Climatology*. 39(12):4575-94.

[24] Agha O M M and Şarlak N 2016 Spatial and temporal patterns of climate variables in Iraq. *Arabian Journal of Geosciences*. 9(4):302.

[25] Al-Khalidi J, Dima M and Stefan S 2018 Large-scale modes impact on Iraq climate variability. *Theoretical and Applied Climatology*. 133(1-2):179-90.
[26] Khayyun T S, Alwan I A and Hayder A M 2020 Selection of suitable precipitation CMIP-5 sets of GCMs for Iraq using a symmetrical uncertainty filter. in IOP Conference Series: Materials Science and Engineering, IOP Publishing.

[27] Bishay F K 2003 Towards sustainable agricultural development in Iraq. The transition from relief, rehabilitation and reconstruction to development. Food and Agriculture Organization of the United Nations.

[28] Alozeer A, et al. 2020 Estimation of mean areal rainfall and missing data by using GIS in Nineveh, northern Iraq. The Iraqi Geological Journal. 53(1E):93-103.

[29] Gent P R, et al., 2011 The community climate system model version 4. Journal of climate. 24(19):4973-91.

[30] Chou S C, et al., 2020 Downscaling projections of climate change in Sao Tome and Principe Islands, Africa. Climate Dynamics: p.1-22.

[31] Laflamme E M, Linder E and Pan Y 2016 Statistical downscaling of regional climate model output to achieve projections of precipitation extremes. Weather and Climate Extremes. 12: p.15-23.

[32] Almazroui M, et al., 2012 Recent climate change in the Arabian Peninsula: seasonal rainfall and temperature climatology of Saudi Arabia for 1979–2009. Atmospheric Research. 111:29-45.

[33] Pal J S and Eltahir E A 2016 Future temperature in southwest Asia projected to exceed a threshold for human adaptability. Nature Climate Change. 6(2):197.

[34] Homsi R, et al., 2020 Precipitation projection using a CMIP5 GCM ensemble model: a regional investigation of Syria. J Engineering Applications of Computational Fluid Mechanics. 14(1): 90-106.

[35] Bhandari R, Kalra A and Kumar S 2020 Analyzing the effect of CMIP5 climate projections on streamflow within the Pajaro River Basin. Open Water. 6(1):p.5.