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Investigating the Linkage between Precipitation and Temperature Changes in Iraq and Greenhouse Gas Variability

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Abstract
In this study, the homogeneity of annual precipitation and temperature in Iraq were examined for the periods 1981-2010 and 1971-2010, respectively in terms of Greenhouse Gases (GHGs) and their link to climate change. Observational data of precipitation and temperature were provided by Iraqi meteorological stations along with information on GHG concentrations from the Emission Database for Global Atmospheric Research (EDGAR V4.3.2). The homogeneity characterisations of both precipitation and temperature were undertaken, noting that precipitation was homogeneous over the period of study, whereas, temperature, on the other hand, had breakpoints for the meteorological stations investigated. The Mann-Kendall test was performed to determine the trend and magnitude of changes in climate conditions. The time series for precipitation showed a significant decline trend in six stations. However, temperature had a slight trend throughout the period of study. The annual time series of GHG emissions in Iraq and the link with the country's climate was also investigated in this study indicating that the time series of N_2O and CO_2 increased over time, but CH_4 decreased over the same period. The correlation coefficient values of both temperature and GHG were substantial and were found to increase in the southern stations, given the abundance of intense heat and industrial activities, while the relationship between GHG and precipitation were found to be low. Accordingly, GHG emissions have a direct link with the climatic conditions in Iraq due to the development and contribution of various industries, oil refineries, pollutants and population growth that contributed towards climatic change in Iraq.

Keywords: Iraq, Precipitation, Temperature, Homogeneity, Greenhouse, Mann-Kendall, Climate change.

1. Introduction
The study of climate change in Iraq is very important. Decreasing rainfall, increasing temperatures and extreme heat waves, frequent dust storms, and drought are all indexes of climate change contributed by oil factories and refineries, coal energy plants, pollution and population growth causing the rise in GHG emissions. According to the Intergovernmental Panel on Climate Change (IPCC, 2001) of the United Nations (UN), climate change is the phenomenon associated with increasing of the average air temperature, including that of rising temperature in oceans. The greenhouse effect is the phenomenon that is accrued when water vapour (H_2O), carbon dioxide (CO_2) and other atmospheric gases absorb the outgoing infrared radiation causing global temperatures to rise (IPCC, 2007).

The increase in CO_2, CH_4, and N_2O emissions are important factors in GHGs. Many studies have identified the relationship between CO_2 concentrations and air temperature. Florides and Christodoulides (2009) found that concentrations of CO_2 gas were higher compared to normal concentration levels, although temperatures significantly fluctuated. Methane (CH_4), the second most important greenhouse gas has an indirect effect on these concentrations in the Ozone layer and water vapour in the stratosphere (Harvey and Huang, 1995). Whereas, N_2O is one of the trace gases that play an important role in global warming, it is responsible for the degradation of the Ozone layer. Indeed, the concentration of N_2O has been increasing over many decades. N_2O is responsible for Nitrogen (N) found in the soil, which is dissolved by rain and absorbed in the soil. N_2O has afforded greater

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global warming effects compared to CO_2, contributing to climate change (Reay et al., 2012).

Alsarmi and Washington (2011) explored climate change in the Arabian Peninsula, finding that there were many factors attributed to climate change in mid-1997 due to the El-Nino effect. Similarly, climate change in the context of river flow was explored by Adamo et al. (2018) in the Tigris, and Euphrates river basins, given the decreasing rainfall in the areas and increasing temperatures caused drought and frequent sand storms; that are also considered to be climate change indexes. Whereas, Zakaria et al. (2013) predicted significant problems for society in Iraq given rising sea levels in the Arabian Gulf region, causing a steady increase in the salinity of Iraqi rivers. Awadh and Ahmed (2013) examined the trend of three climatological parameters (i.e. temperature, evaporation, and precipitation) of four meteorological stations in Iraq, finding that both temperature and evaporation had increased over time, whereas precipitation had decreased. Also, CO_2 was most dominant in terms of Iraqi climatological parameters. Two time periods 1998-1999 and 2007-2008 pointed significant droughts in Iraq, the more intense of which was on the south-western parts (Hameed et al., 2018). Both drought and salinization of water in Iraq rivers was mainly due to the construction of dams along the Tigris river in Turkey, which was also considered to be an important environmental challenge in the middle-southern parts of Iraq (Ali, 2019).

The homogeneity tests for a time series detects a change along a time series to indicate the change points. Agha et al. (2017) used four tests to assess the homogeneity of annual and seasonal precipitation in northern Iraq where they found that the precipitation was homogeneous based on three tests, and with only two stations having breakpoints in the fourth test. Zhang et al. (2005) studied the homogeneity of the mean daily temperature of 15 countries in the Middle East region between 1950 and 2003, with the results spatially coherent with the trend associated with temperature during this period. Also, Stephenson et al. (2013) examined mean temperature and precipitation extremes for the Caribbean region with the results indicating inhomogeneous temperature and precipitation.

In contrast, the Mann-Kendall test was performed by Tan et al. (2019) to identify the trends of temperature and precipitation extremes in Malaysia. The test indicated a non-significant trend in all annual climate extremes. Ali et al. (2019) studied the flow change in the Zab River in northern Iraq, finding a declining trend in the annual and individual months, which were consistent with decreasing precipitation in the Iraqi region.

Accordingly, this study points to changes in Iraqi climate variables by applying homogeneity and trend tests and indicating the link between the GHG emissions and Iraqi annual precipitation and temperature.

2. Iraqi climatological characteristics

Iraq is located in the south-western region of Asia. Having vast mountainous areas which cover the north and north-eastern areas of Iraq, the plain region extends from the middle to the southern region, while the desert covers the western region (Figure 1). The central and southern regions of Iraq are characterised having low precipitation (100-200 mm/year), intensifying in northern Iraq reaching to about 1000 mm/year. About 90% of the annual rainfall for Iraq is recorded in the winter months between December and March. The other months, especially the most heated months in summer, are extremely dry (Al-Falahi 2008). The minimum temperature during winter is near freezing in the northern and north-eastern parts of the country, while the temperature varies between 4 °C and 5 °C in the alluvial plains of southern Iraq. During summer, minimum temperatures vary between 22.2 °C and 29 °C (Salar, 2013).

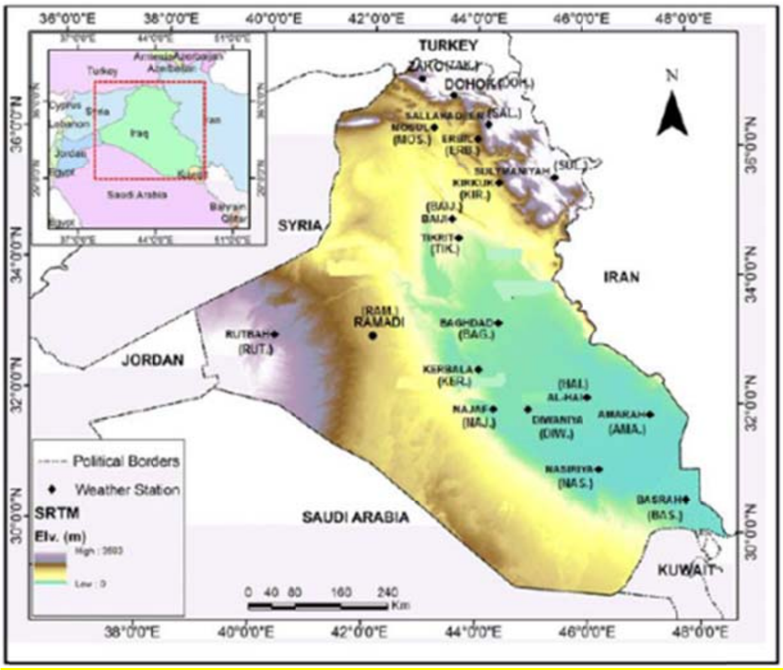


Figure 1. The Iraqi political and geographic map with weather stations (SRTM, 90 m).

3. Data and methodology

The Iraqi meteorological organisation provided observational data of Iraq's annual precipitation and temperature. Precipitation data were used for 18 stations spanning the period between 1981 and 2010, and temperature data were used for 8 out of the 18 stations covering the period between 1971 and 2010. The Pettitt's Test (Pettit, 1979) included in the XLSTAT software (https://www.xlstat.com) added to Microsoft Excel was used to detect the point of change in the time series of both precipitation and temperature to identify the homogeneity of the time series for the two climatological parameters at a 95% confidence level.

Mann-Kendall is a non-parametric test for determining the time series trend, the test compares the data magnitude rather than the values. Mann-Kendall, which is Microsoft Excel add-in, was used to detect trend components in the precipitation and temperature time series (Salmi, 2002). The annual data of GHG and its various sources were provided by the Emission Database for Global Atmospheric Research (EDGAR V4.3.2) (Janssene-Maenhout et al., 2019) representing the period between 1970 and 2012, and plotted using Origin 8.5 software (Figures 6 and 7). A Pearson correlation was used to calculate the linear relationship between the two Iraqi meteorological parameters and GHG concentrations.

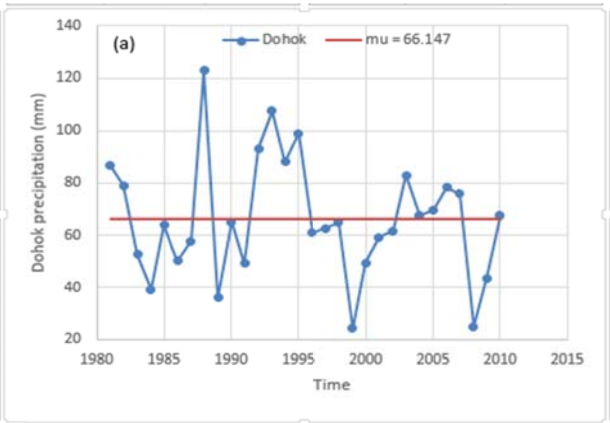
4. Results

4-1 Iraqi precipitation homogeneity

In this research study, annual precipitation homogeneity in Iraq was investigated for a total of 18 stations, covering the period between 1981 and 2010. The precipitation stations were divided into three groups (six stations included in each group) according to their location (i.e. north, middle, and south). The northern mountainous stations (Figure 2) had one mean value along the time series period (homogenous), the Sulaimania in north-eastern area of Iraqi had the maximum value for annual precipitation (150 mm) recorded in 1992, which is considered as the maximum volume of rainfall per year for the northern stations (Figure 2c). The minimum value was recorded at Mosul station (10.9 mm). Most of the northern stations included a three-point period in time for precipitation (1983-1988, 1990-1998, and 2000-2008), referring to the frequency of precipitation of around eight years, but with very few rain showers in 1999 and 2009. The middle stations (Figure 3) were homogenous (having one mean value). Here, the middle three stations located above the Baghdad station (Kirkuk, Baiji, Tikrit) (Figure 3(a-b, e)) had a similar characterisation regarding the minimum precipitation years, with the periodicity of the north stations having less average rainfall.

Kirkuk station had a maximum rainfall value of (85.8 mm), while the other three middle stations had a different structure and frequency from the other three stations. The minimum precipitation values were recorded in 1997 and 2008, with the minimum value recorded at the Alhai station (2.3 mm) (Figure 3f). The southern stations (Figure 4) were also homogenous having less precipitation compared to the previous stations. The minimum precipitation was recorded at Najaf station (0.27 mm) in 1991 (Figure 4d), while Amara station had a value of (40.1 mm) recorded in 1998, considered as one of the highest recorded years in the south stations (Figure 4b).

In summary, precipitation in Iraq is homogenous, with the characterisations varying due to the orography within the period of study.



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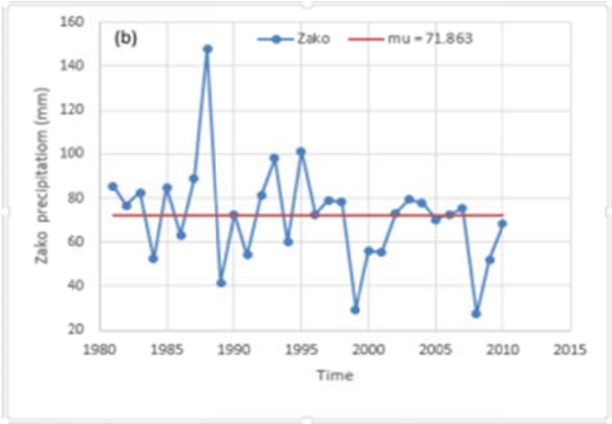

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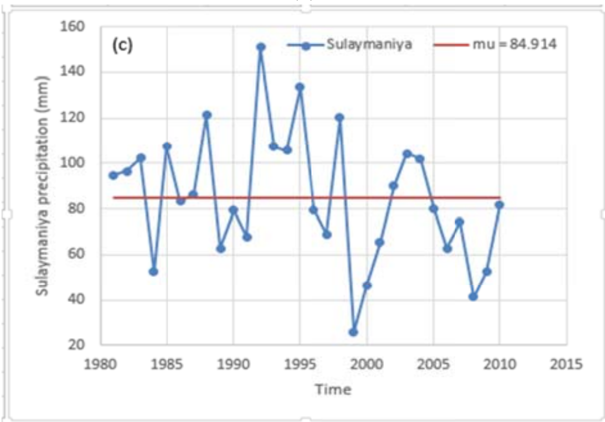

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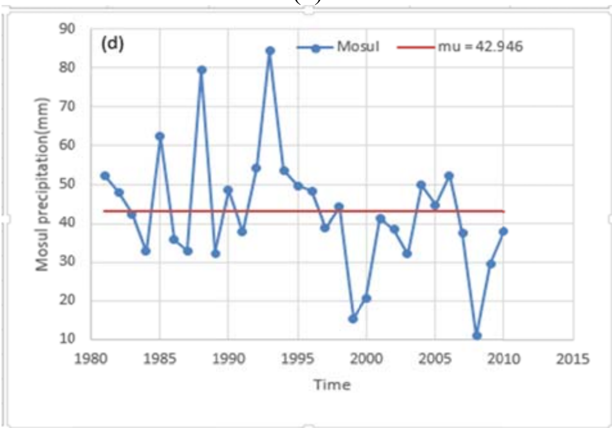

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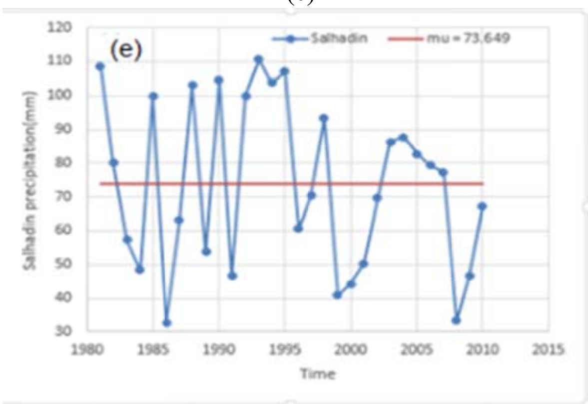

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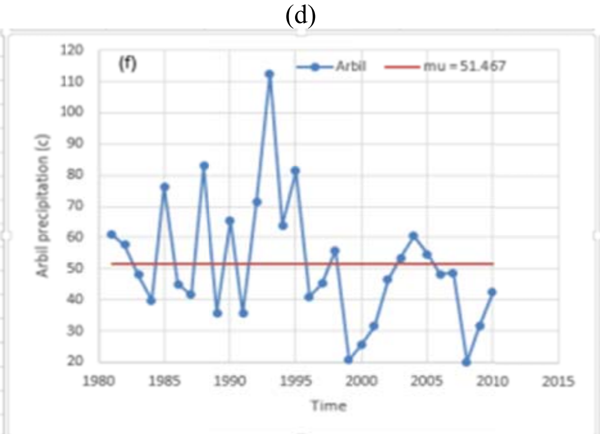

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Figure2. The homogeneity of the Iraqi precipitation (north stations) for the 1981-2010 period, the (mu) refer to the mean of the precipitation.

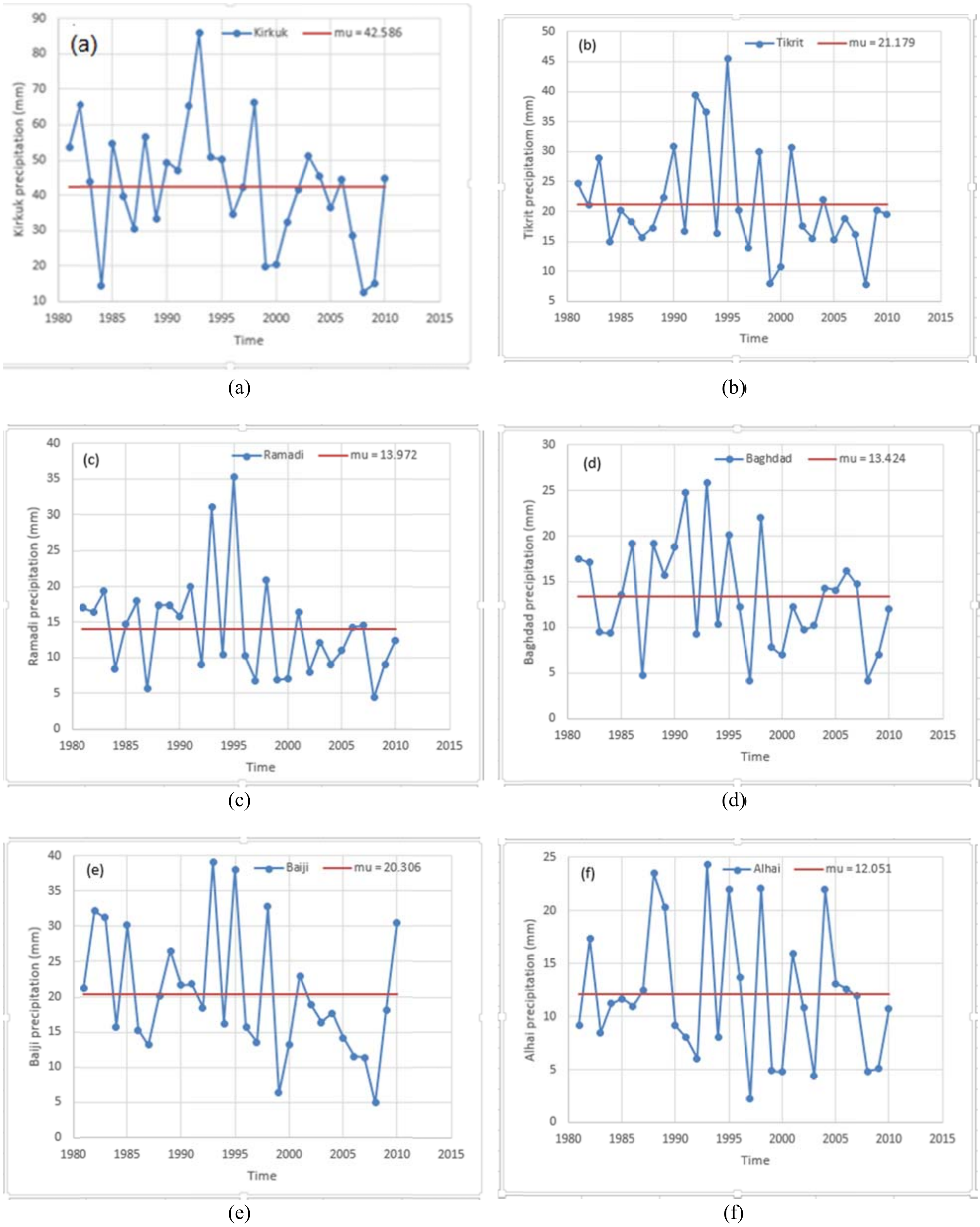
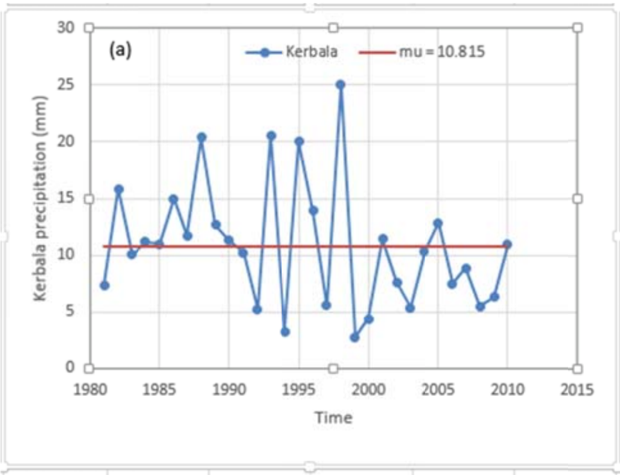


Figure 3. The homogeneity of Iraqi precipitation (middle stations) for the 1981 – 2010 period, the (mu) refers to the mean of the precipitation.



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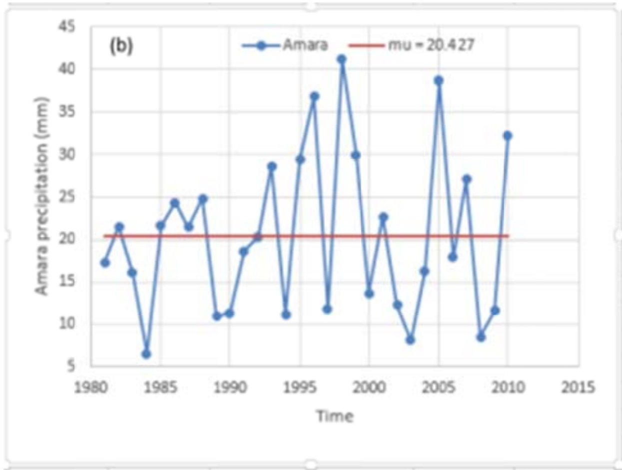

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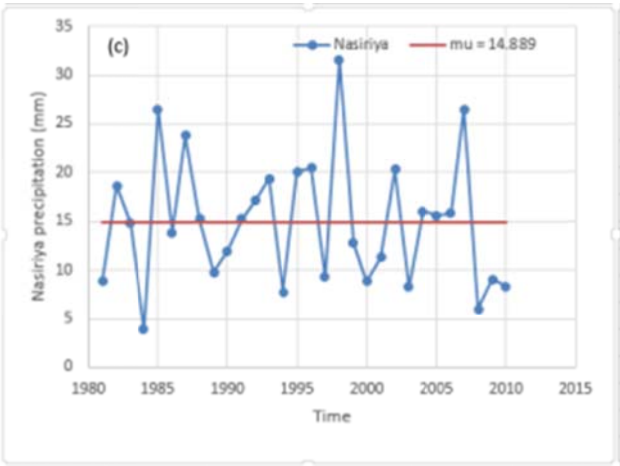

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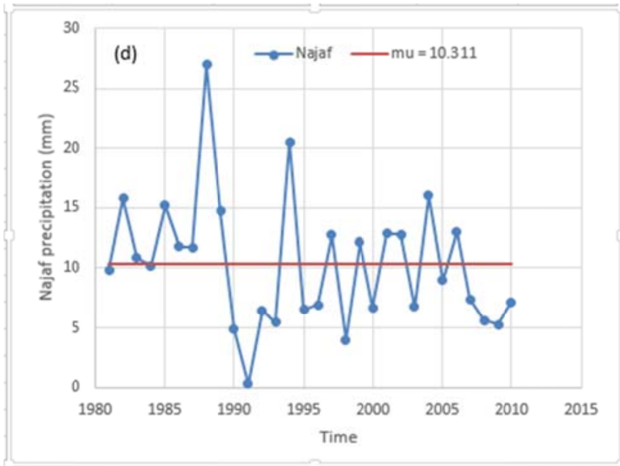

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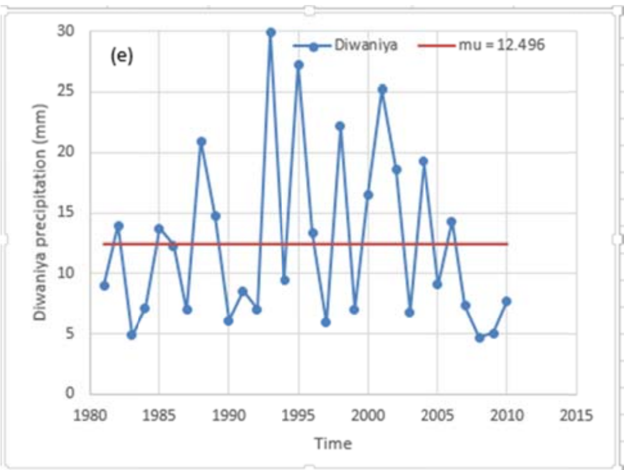

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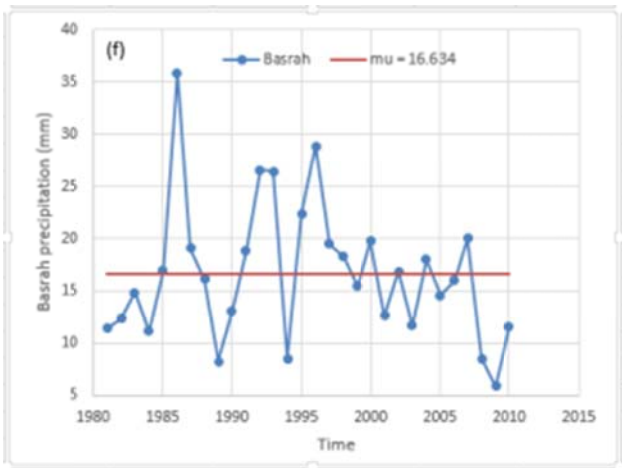


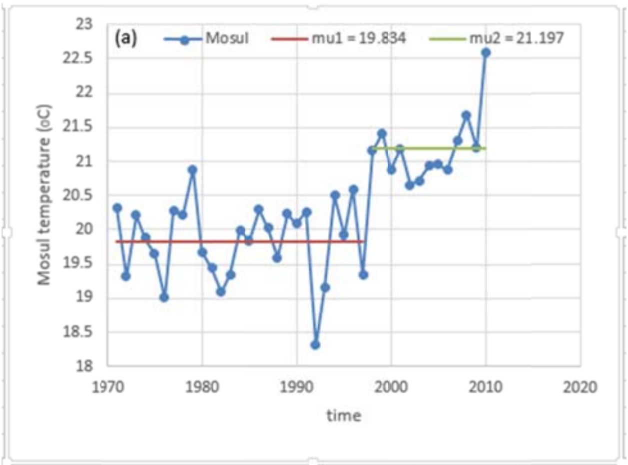
(f)

Figure 4. The homogeneity of the Iraqi precipitation (south stations) for the 1981 – 2010 period, the (mu) refers to the mean of the precipitation.

4-2. Iraqi temperature homogeneity

Annual temperature homogeneity was examined in this study in the context of Iraq. Temperature characterisation was identified at eight stations for the period between 1971 and 2010. During this period, the temperature was inhomogeneous (Figure 5), with two regimes of construction, and two means (mu) over this period. The annual temperature varied between the maximum value recorded for the Basrah station (28.2 ^{0}C) to the minimum value recorded at the Mosul station (18.30 ^{0}C) (Figure 5(f and a)) respectively. Mosul and Kirkuk stations (Figure 5 (a, b)) had the same change point of variation, in which the shift period of the second mean (mu2) began between 1997 and 2010 (Table 1) since GHG could influence it.

In addition, the second trend regime for stations, Rutbah, Nasryia, and Basrah, (Figure 5(d, f and h)) began after the period between 1993 and 2010 (Table 1), while the Baghdad and Alhai stations had a different time period from the other stations; the shift time beginning between 1984 and 2010 and between 1995 and 2010, respectively (Table 1). The minimum temperature was recorded for the years 1982 and 1992, which also reported significant precipitation. The changes in the temperature values could be attributed to the increase in GHGs.



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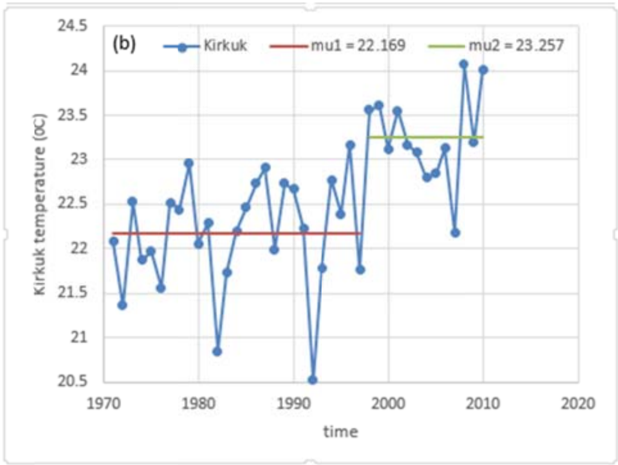

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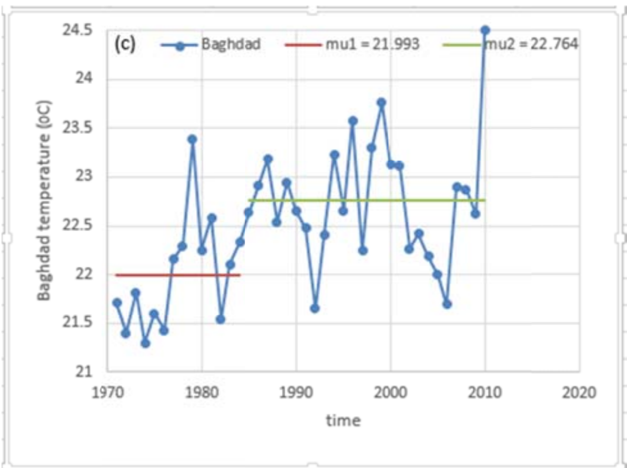

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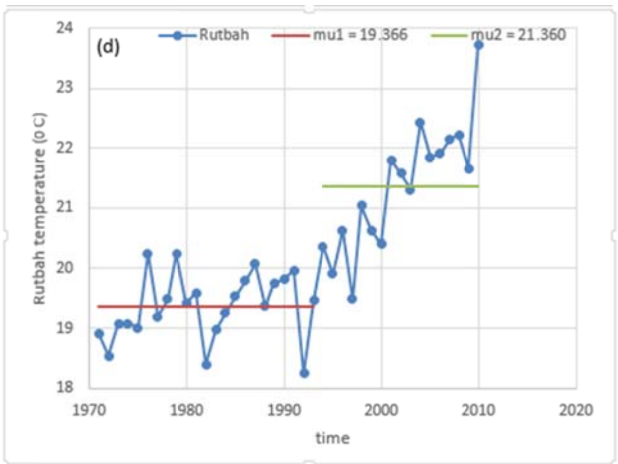

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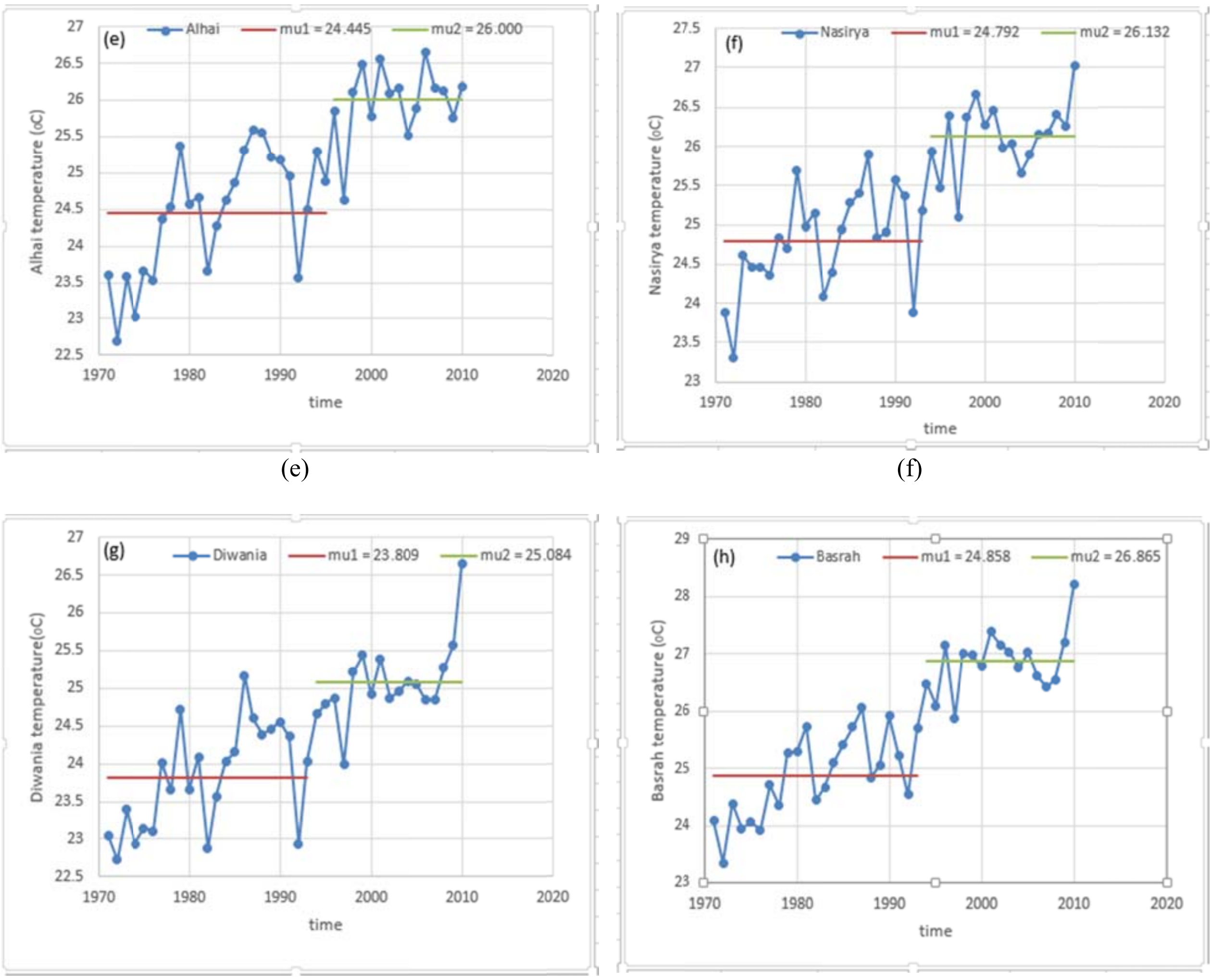


(e) (f)

(g) (h)

Figure 5. The homogeneity of the Iraqi temperature (eight stations) for the 1971 – 2010 period, the (mu1) refers to the temperature mean for the first period, and (mu2) refers to the temperature mean for the second period.

Table 1. The change periods of Iraqi temperature mean (Mu1) and (Mu2) for eight temperature stations.

Stations	**(Mu1) period**	**Shift of data (Mu2)**
Kirkuk	1971-1996	1997- 2010
Mosul	1971-1996	1997- 2010
Rutbah	1971-1992	1993-2010
Baghdad	1971-1983	1984-2010
Alhai	1971-1994	1995-2010
Nasryia	1971-1992	1993-2010
Basrah	1971-1992	1993-2010

4-3. Trend component of Iraqi precipitation and temperature

To emphasis the trend of the two climatological parameters, the Mann-Kendall trend test was undertaken for the stations. Between 1981 and 2010, the annual precipitation for all 18 meteorological stations decreased. However, at a non-significant confidence level (Sig.) for 12 stations, the trend showed a significant value of 90% for Salahalden, Baiji, Diwaniya, Najaf, and Karbala stations. Whereas, in the middle of Iraq, the Tikrit station had a significant negative trend of -0.31 at a 95% confidence level (Table 2). The minimum trend (-0.198) presented at the Baghdad station refers to the precipitation stability at this station, while the maximum trend of -0.464 at the Alhai station.

The trend for annual temperature between 1971 and 2010 was also investigated. Here, the temperature trend for eight stations was shown to be positive, with small slope values but with a significant confidence level, as shown in Table 3. The Basra station had a maximum value for the trend 0.09 due to its location in the south of Iraq, influenced by a heat wave moving downwards. The GHG absorbs the long wave of Infrared (IR) radiation that reflected from the surface of the earth and increasing the temperature.

In summary, the precipitation and temperature in Iraq display a trend that could be influenced by GHGs. GHG emissions and their influence on the climate in Iraq is discussed in the following section.

Table 2. Trend of Iraq annual precipitation between 1981 and 2010, *, + refer to 95%, 90% confidence respectively, the blank cells (Sig.) refer to the confidence level less than 90%.

Stations	Test Z	Sig.	Q
Dohok	-0.21		-0.199
Zako	-1.53		-0.408
Sulaimania	-1.43		-0.337
Arbil	-1.03		-0.460
Salahalden	-1.78	+	-0.321
Mosul	-1.53		-0.376
Kirkuk	-1.57		-0.371
Baghdad	-1.21		-0.198
Baiji	-1.68	+	-0.306
Tikrit	-2.09	*	-0.311
Alhai	-1.07		-0.464
Ramadi	-1.53		-0.364
Diwanyia	-1.86	+	-0.320
Omara	-1.53		-0.370
Najaf	-1.82	+	-0.318
Basra	-1.50		-0.362
Karbala	-1.68	+	-0.301
Nasria	-1.61		-0.370

Table 3. Trend of Iraq annual temperature between 1971 and 2010, *** refers to 99% confidence.

Stations	Test Z	Sig.	Q
Mosul	4.39	***	0.048
Kirkuk	4.05	***	0.040
Baghdad	3.01	**	0.031
Rutba	5.76	***	0.088
Naseryia	5.74	***	0.060
Diwaniya	5.85	***	0.062
Alhai	5.86	***	0.073
Basra	6.23	***	0.092

4-4. Greenhouse Gases over Iraq

Carbon dioxide (CO_2) Methane (CH_4), and Nitrous oxide (N_2O) GHG emissions and their sources were investigated for the period between 1970 and 2012 (Figures 6 and 7). It was found that the N_2O concentrations had a low value compared with the other two gases, in which the concentration increased for the same period (Figure 6). The rising N_2O was mainly due to the increase of human and agricultural activities; direct soil emission and indirect N_2O emissions from agriculture (Figure 7a).

On the other hand, CH_4 gas was found to decrease over the same period due to fewer sources of Methane like in natural wetlands, organic waste, forest burning, and fossil fuels (Figure 6). The main source of CH_4 in Iraq is via fugitive emission compared with other sources (Figure 7b). Further, the concentration of CO_2 has increased given the growth and development of industries and transportation modes, considered as the main contributing sources of CO_2 in Iraq (Figure 7c). The positive trend of CO_2 is evident over time which has an adverse influence on climatic conditions in Iraq. In Figure 7b, some sources do not appear given their small values compared with the other sources. The correlation between the two climatological parameters (temperature and precipitation) and the three GHG concentrations are investigated in the following section.

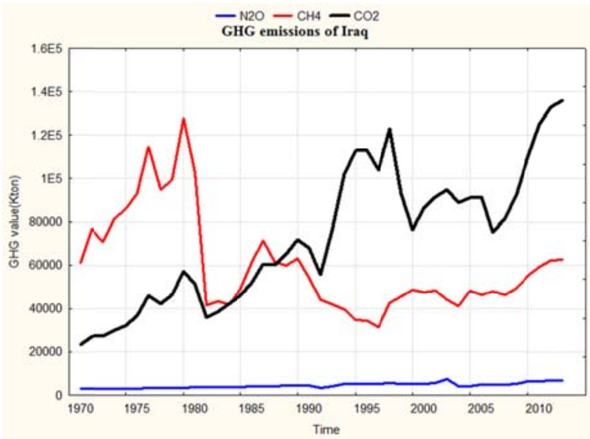
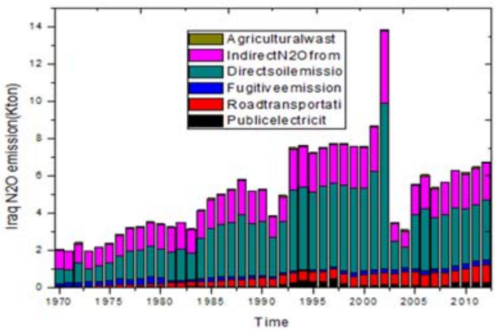


Figure 6. GHG emission (Kton) in Iraq for the period between 1970 and 2012.



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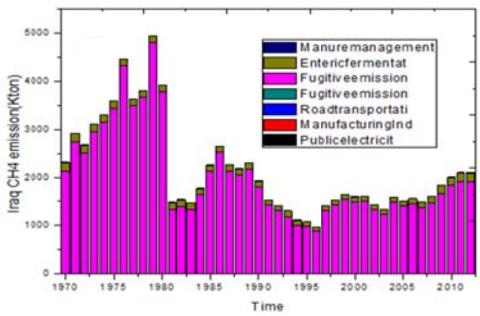

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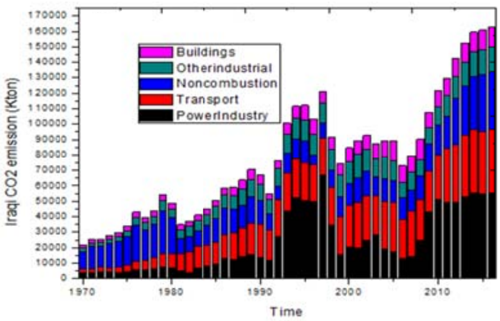

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Figure 7. GHG emissions (Kton) (a) N_2O, (b) CH_4, and (c) CO_2 and its sources of Iraq for (1970 – 2012) period.

4-5. The link between temperature and precipitation with GHG in Iraq

The link between temperature and precipitation and N_2O, CH_4, and CO_2 are investigated by applying Pearson's correlation method (Figure8). The temperature in Iraq between 1971 and 2010 had a significant correlation with GHGs and a positive correlation between temperature and N_2O concentrations. The correlation values increased southward given the abundance of N_2O sources (Figure 8a). In contrast, the temperature had a negative correlation with CH_4 emissions but was significant in the southern region of Iraq given fewer sources such as wetlands and agricultural crops given the period of drought in this period (Figure 8b). CO_2 concentrations had a significant positive correlation with all eight stations, especially in the southern stations given industrial growth within the region and human activities (Figure 8c). As such, the significant correlation values point towards the influence of GHG on climatic conditions and rising temperatures in Iraq.

The relationship between precipitation and GHG between 1981 and 2010 was examined for the 18 stations (Figure 9(a-c)), in which the correlation coefficient between precipitation and the three GHG concentration was found to be negative but non-significant. However, the relation between precipitation and GHG was consistent with the homogeneity test for precipitation, which was found to have greater stability compared to temperature. In summary, GHG impacted climatic conditions in Iraq, contributing to climate change.

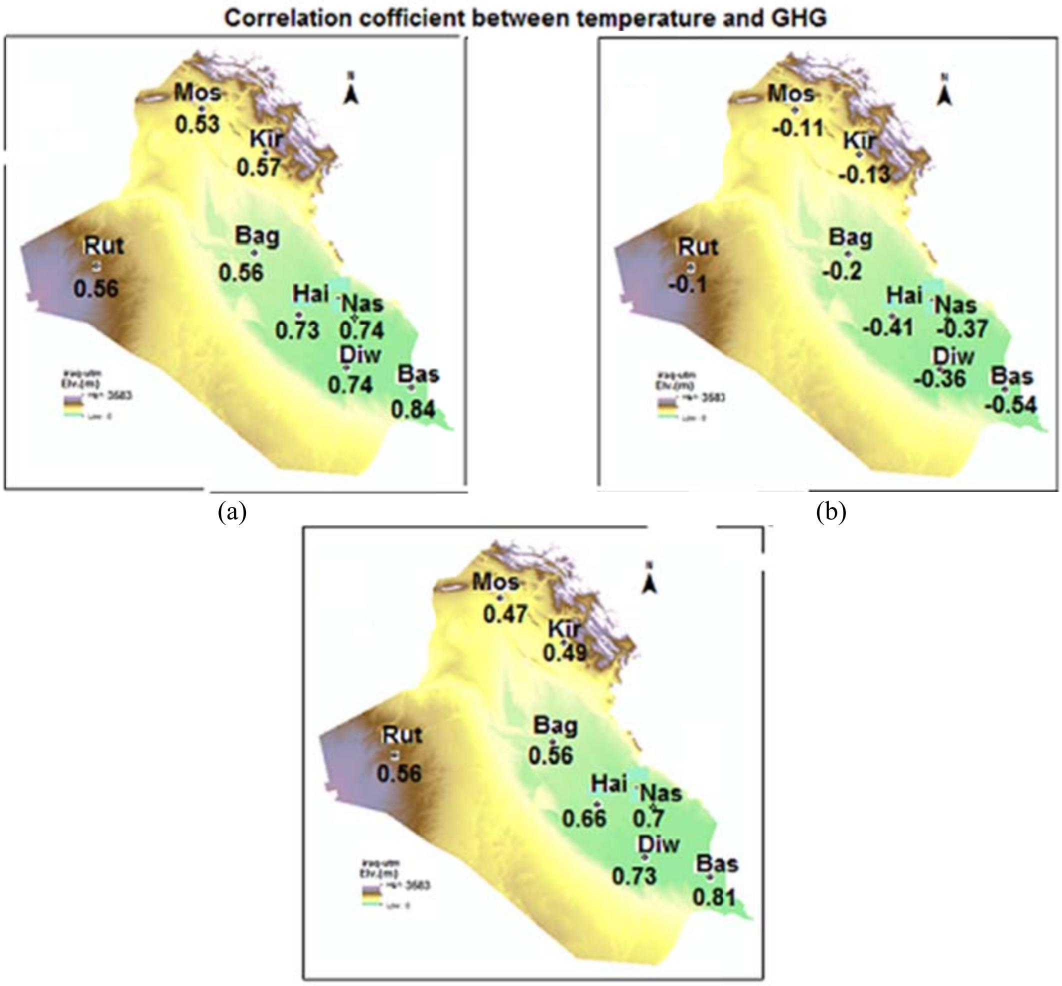

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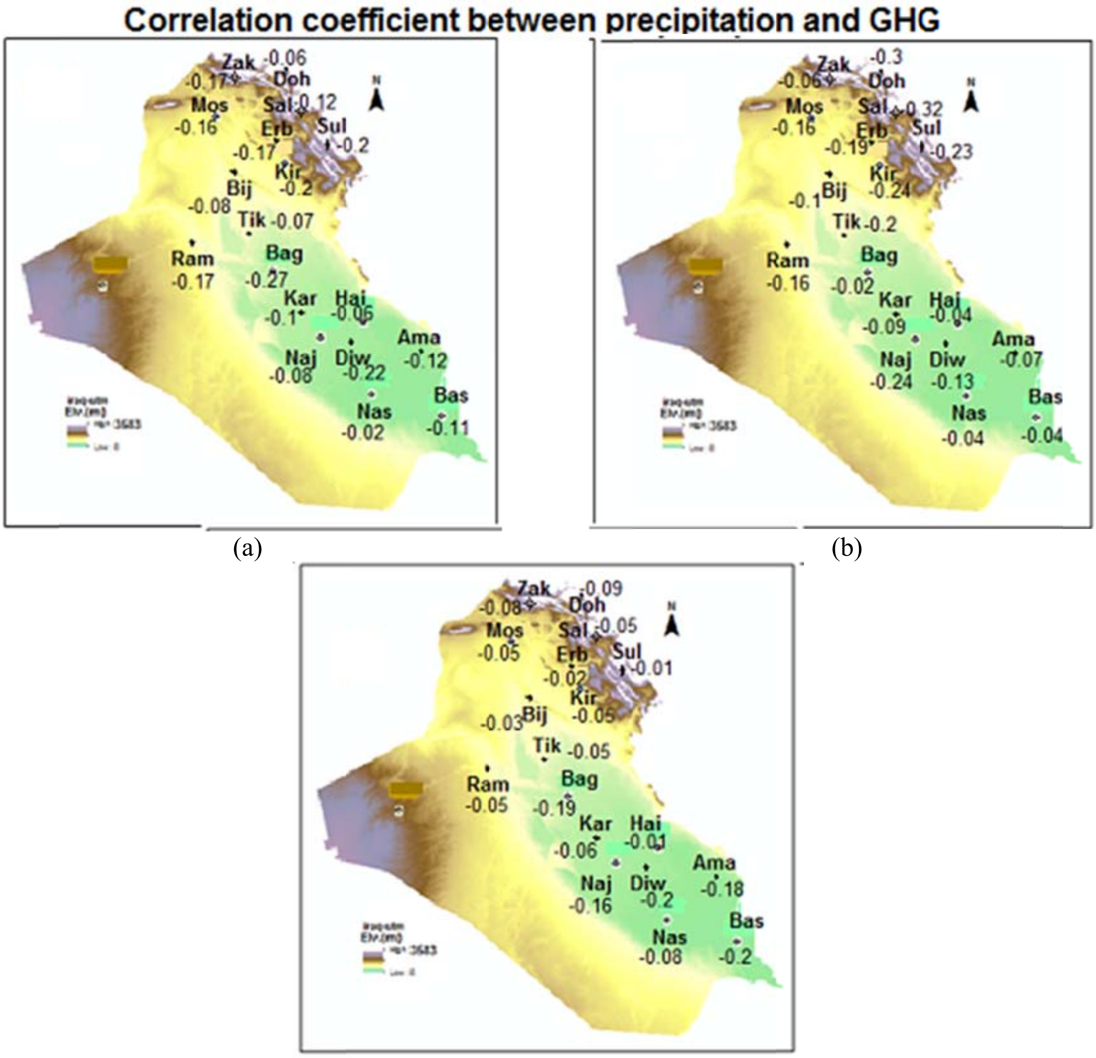
Figure 8. Geographical map of Iraq. The value inside the map represents the correlation value of the temperature and (a) N_2O, (b) CH_4 and (c) CO_2.



(c)

Figure 9. Geographical map of Iraq. The value inside the map represents the correlation value of precipitation, and (a) N_2O, (b) CH_4 and (c) CO_2.

5. Conclusion and Discussion

The results presented and discussed in this study have contributed to gaining a better understanding and appreciation of climate change in Iraq, and the influence of GHGs brought about through climate variations. The main results of this study are presented as follows:

- The time series related to precipitation in Iraq had homogeneous data spanning the period under study, but the temperature shifted for eight stations after 1993 and 1997.
- Precipitation had a non-significant negative pattern, while temperature had a significant but slight upward trend.
- GHGs have been shown to have a significant correlation with temperature, but with a considerably less relationship with precipitation.

As such, it can be concluded that climatic conditions in Iraq are influenced by GHGs, thus causing climate change over the period of study.

Furthermore, it was found that precipitation was homogenous having one mean throughout the period, whereas temperature had breakpoints in all eight stations (i.e. inhomogeneous). The annual temperature had a small but significant positive trend, while precipitation decreased over the period of study. A similar study conducted in China by Shen, et al. (2018) found that precipitation and temperature had breakpoints over the period of study and that the maximum temperature increased over time, while the minimum temperature and precipitation tended to decrease.

The temperature in Iraq also showed a point change after 1993 and 1997, which could have been influenced by GHGs or other climatic conditions such as the El-Nino effect. Similar results by Alsarmi and Washington (2011) in the Arabian Peninsula on climate change found that there were many points of change after the middle of 1997 due to the El-Nino pattern effect.

Altitude and mountainous regions in Iraq also influence both precipitation and temperature and different climate patterns. The study by Al-Khalidi et al. (2017) found that the EOFs of both temperature and precipitation in Iraq are influenced by the orography of the area. A similar study by Ali et al. (2019) found that decreasing water levels in the Dukan Dam situated on the Zab River were due to the decline in precipitation in the Iraqi region.

The GHG absorb the infrared radiation causing the greenhouse phenomenon that is responsible for the increase of the temperature. The precipitation correlated negatively with the GHG emissions in Iraq. A similar study of Meehl et al. (2007) identifies that the temperature increases with rising of GHG, while the precipitation decreases with the increases of the GHG emissions in the subtropical region.

In conclusion, there is no doubt that climatic conditions in Iraq are influenced by an increase in GHG concentrations. The rise in temperatures and a decrease in precipitation are noticeable signals of climate change.

Acknowledgments

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