IMPACTS OF CLIMATE CHANGE ON THERMAL BIOCLIMATIC INDICES OVER IRAQ

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ABSTRACT

This study was aimed to investigate the trends in (11) thermal bioclimatic indicators throughout Iraq's various climates to better understand their spatiotemporal variations in different climates. All bioclimatic indicators have been calculated from daily ERA5 datasets of temperature extracted from 361 grid points covering Iraq. This data set covers global coverage of monthly temperatures from 1980 to 2022, with a spatial resolution of (0.25°x0.25°). Eleven thermal bioclimatic indicators were subjected to the Mann-Kendall (MK) test in order to measure trends in a single direction, without taking into account the influence of natural cycles. The findings showed that the majority of Iraq's thermal bioclimate indicators had changed. implying that rising temperatures have had a significant influence on the country's bioclimate. The annual mean temperature data revealed that Iraq had a considerable increase in Bio1 of (0.28 to 0.48) °C/decade, which is more than the (0.15) °C/decade worldwide average. The rise was found to be significantly greater in Iraq's northern and eastern regions. The analysis suggested that the diurnal temperature range decreased in most regions of Iraq, especially in the southern and northeastern sections. The maximum temperature increased most dramatically in the warmest quarter, whereas the changes in the coldest quarter were less noticeable, showing an increase in climatic extremes in Iraq. The study unequivocally shows that climate change is leading to an increase in the mean temperature, specifically during the warmest months of the year.

Keyword: Temperature; seasonality; isothermally; gridded; Mann–Kendall test

تأثيرات التغيرات المناخية على المؤشرات المناخية الحرارية في العراق

ياسين كاظم التميمي علاء مطر اللامي فراس صبيح بشير عمار ياسين عواد
استاذ استاذ مدرس مدرس
قسم علوم الجو – كلية العلوم – الجامعة المستنصرية , قسم الجغرافية – كلية التربية للعلوم الانسانية – جامعة الانبار

المستخلص

تهدف هذه الدراسة الى دراسة الاتجاهات في 11 مؤشر مناخي حيوي حراري في جميع انحاء العراق من أجل فهم أفضل لتغيراتها الزمانية المكانية في المناخات المختلفة. تم حساب جميع المؤشرات المناخية الحيوية من مجموعات بيانات ERA5 اليومية لدرجة الحرارة المستخرجة من 361 نقطة شبكة تغطي العراق. تغطي مجموعة البيانات هذه التغطية العالمية لدرجات الحرارة الشهرية من عام 1980 إلى عام 2022، بدقة مكانية تبلغ(0.25 درجة × 0.25 درجة). تم إخضاع أحد عشر مؤشراً مناخياً حرارياً لاختبار مان كيندال (MK) من أجل قياس الاتجاهات في اتجاه واحد، دون الأخذ بعين الاعتبار تأثير الدورات الطبيعية. وأظهرت النتائج أن غالبية مؤشرات المناخ الحيوي الحراري في العراق قد تغيرت. مما يعني أن ارتفاع درجات الحرارة كان له تأثير كبير على المناخ الحيوي للبلاد. كشفت بيانات متوسط درجة الحرارة السنوية أن العراق شهد زيادة كبيرة في Bio1 بمقدار(0.28 إلى 0.48) درجة مئوية/عقد، وهو أكثر من المتوسط العالمي البالغ 0.15 درجة مئوية/عقد. وتبين أن الارتفاع كان أكبر بكثير في مناطق شمال وشرق العراق. ورجح التحليل انخفاض المدى الحراري النهاري في معظم مناطق العراق وخاصة في القسمين الجنوبي والشمالي الشرقي. ارتفعت درجة الحرارة العظمى بشكل كبير في الربع الأكثر دفئا، في حين كانت التغيرات في الربع الأبرد أقل وضوحا، مما يدل على زيادة في الظواهر المناخية المتطرفة في العراق. وتظهر الدراسة بشكل لا لبس فيه أن تغير المناخ يؤدي إلى ارتفاع متوسط درجة الحرارة، وتحديدا خلال الأشهر الأكثر دفئا في السنة.

الكلمات المفتاحية: درجة الحرارة؛ الموسمية. متساوي الحرارة. شبكي؛ اختبار مان–كيندال

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INTRODUCTION

It is considered that the weather and climate affect everyday activities and lifestyles. One of the most significant variables that have impacted our lives since the beginning is the climate. Bioclimatology is a field of study that seeks to comprehend the long-term interactions between climate and living things (2). Thermal bioclimatic indicators are variables and indices that result from primary observed or modeled climate fields, such as temperature and precipitation. These indicators can offer useful insights into the potential impacts of climate change caused by global warming on humans, ecosystems, and the environment (16). Bioclimatic indicators are characterized by intra-annual patterns of temperature and precipitation (28). Thermal bioclimatic indicators vary widely for different climatic regions. When planning for climate change adaptation and mitigation, it is important to evaluate regional trends in thermal bioclimatic indicators to identify any changes in bioclimatic features (18). The spread of human comfort zones may be mapped using bioclimatic indicators. It has also been utilized to ascertain whether a certain area is suitable for cultivating a specific crop (16). Researchers use these indicators to estimate changes in regional climates under different scenarios and develop adaptation strategies. Bioclimatic indicators are crucial for many environmental applications, including forestry, biodiversity conservation, and plant ecology (24, 28). Changes in bioclimatic indicators can affect both humans and ecology. Climate change impacts ecosystems' functions and can undermine the ecological equilibrium of ecosystems. Climate change is affecting the habitats of several species, which must either adapt or migrate to areas with more favorable conditions (31). In addition to changes in average temperature and precipitation, climate change has altered seasonality, intra-annual variability, and many other climatic features. Also, they have altered a region's favorable bioclimate for human health and biological niche. Bioclimatic indicators have recently seen an increase in adoption as a means to assess ecological reactions to and impacts of climate change on bio-environments (15,30). Examining climatic trend is used to quantify climate change by common tool for this is the Mann-Kendall (MK) trend test. Despite its many advantages, this non-parametric approach is limited by data autocorrelation, which reduces test significance (3,34). The MK test has undergone a variety of adjustments, including pre-whitening of the data, to eliminate the impact of autocorrelation. However, recent studies indicate that the impacts of data series reliance on MK trend significance have not been adequately mitigated (21,26,28.29).The Intergovernmental Panel on Climate Change (IPCC) added that certain global climate trends might not be reliable because of the data's long-term self-similarity (14). Several studies have been carried out to evaluate the change of trend in thermal bioclimatic indicators. Hadi et.al assessed the trends in thermal bioclimatic indicators over the diverse climate of Iran, the results show that there is a significant increase in temperature across most parts of Iran, with some areas experiencing a decrease in temperature (16). Hamed et.al assessment thermal bioclimate in Egypt, the result showed the mean temperature rose and its diurnal temperature range fell as a result of the Paris Agreement. There is substantial evidence linking bioclimate to public health, according to a number of studies. (8,27,31,33). Researchers have discovered a strong correlation between certain bioclimatic conditions and the outbreak of a variety of illnesses as well as death. In their study, Hamed et.al., 2022 utilized 23 global climate models from the Coupled Model Intercomparison Project Phase 6 (CMIP6) to assess alterations in 11 thermal bioclimatic indicators across South Asia. The analysis focused on two shared socioeconomic pathways (SSPs), namely 2-4.5 and 5-8.5. The results of the mean multi-model ensemble indicated a range of changes in mean temperature, varying from (-0.71 to 3.23) °C in the near future and from (0.00 to 4.00)°C in the distant future (18,17). The study aimed to calculate the (11)thermal bioclimatic indicators in Iraq and assessment the trends using MK tests. Data from ERA5 with a spatial resolution of (0.25)will be employed to map the trend analyses from the period (1980-

2022).

MATERIAL AND METHODS

Area of study and data sources: Iraq is located in the Middle East and shares a border with six countries: Kuwait, Iran, Turkey, Syria, Jordan, and Saudi Arabia. The country's topography can be divided into four regions: the alluvial plains of the central and southeastern parts of the country; Al-Jazirah, an upland region in the north between the Tigris and Euphrates rivers; mountainous regions along the Iranian and Turkish borders; and a desert region west of the Euphrates River (4,20). Iraq climate is described as a continental, subtropical climate which features four district seasons (5). Because of this location, the climate area may be regarded as being similar to a Mediterranean climate, is hot and dry during the summer, while cold and rainy during winter (9). Iraq has a hot, dry climate characterized by long, hot, dry summers and short, cool winters. The climate is influenced by Iraq's location between the subtropical aridity of the Arabian desert areas and the subtropical humidity of the Persian Gulf. In most areas, summers are warm to hot, with mostly sunshine. January is the coldest month (11,21). Wintertime temperatures are typically around (16)°C during the day and 2 °C at night, with the potential of frost. However, during the summer months, it is extremely hot, with daytime highs of over(45)°C in July and August and nighttime lows around 25°C. The country can be divided into three different climate zones (7,10). The western and southwestern areas have a hot desert climate (BWh). Rainfall in Iraq is seasonal and occurs mostly during the winter season from December through February for most of the country except in the north and northeast, where the rainy season is from November to April. The annual precipitation ranges between (700 and 1,000) millimeters in the northeastern part of Iraq, occupied by the mountains of Iraqi Kurdistan (Zagros and Taurus), while in the rest of Iraq, which is occupied by plains or hills, the climate is arid Mean annual precipitation in the lowlands range from about (100 to 180 mm(6, 10).The value of (192.03) mm/year computed by Thiessen method is considered as a reliable mean annual value of rainfall for the country (12).While the annual average of wind speed in the study area was 3.6 m/s (1). Eleven thermal bioclimatic indicators were computed and their trends evaluated using the temperature information acquired from ERA5 (ECMWF Reanalysis V5). This dataset comprises the mean, maximum, and lowest temperatures recorded throughout Iraq. This atmospheric reanalysis of the world's climate is known as ERA5, and it is the fifth generation of the ECMWF Reanalysis V5. The ECMWF Copernicus Climate Change Service (C3S) is responsible for producing ERA5. These datasets are available from the Copernicus Climate Change Service website, https://cds.climate.copernicus.eu (accessed on 2 January 2023), for the climate period of 1980–2022. The spatial resolution of the data is (0.25°x0.25°), with longitude and latitude values. The daily data on temperature were extracted from 361 grid points during 43 years to cover the entirety of Iraq. Figure 1. Using observed data, extracted temperature data quality was tested. So, long-term temperature records from several Iraqi locations were compared to the nearest grid point. All locations showed a high connection between observed and temperature.

Thermal bioclimatic Indicator

The current study evaluated trends in (11) thermal bioclimatic indicators. Except for Bio3, all of the indicators' units are in ^{o}C. This study used absolute values (^{o}C/decade) to depict the changes in indicators, as opposed to the commonly employed method of expressing changes in rainfall as percentages (25,32). Each thermal bioclimatic indicator's annual time series at each grid point was computed using the daily average of maximum and lowest temperature data from 1980 to 2022. The formulas for thermal indicators and additional details could be shows in Table 1.

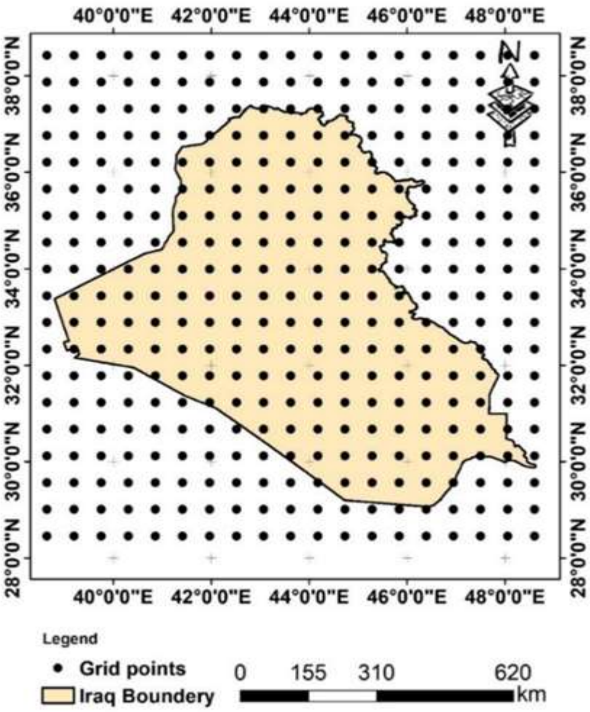

Figure 1. Location of study area

The Mann-Kendall Trend Test

The Mann-Kendall Trend Test (MK test) is a non-parametric, distribution-free statistical test used to analyze data collected over time for consistently increasing or decreasing trends. It is best viewed as an exploratory analysis and is most appropriately used to identify stations where changes are significant or of large magnitude and to quantify these findings. The MK test does not require that the data be normally distributed, and it works for all distributions. The MK test is based on the correlation between the ranks and sequences of a time series, and it can be used to determine whether a time series has a monotonic upward or downward trend. The MK test can also be used to assess if there is no trend or an upward trend in the data. The detailed calculations of the MK test can be found in many studies (13,19,22,29,35).

Table 1. Definitions of the thermal bioclimatic indices for the study area.

Index	Description	Formula	Units
Bio1	Annual Mean Temperature	$\text{Bio1} = \frac{1}{12}\sum_{1}^{12} T(month)$	°C
Bio2	Diurnal Temperature Range	$\text{Bio2} = T_{day\ max.} - T_{day\ Min.}$	°C
Bio3	Isothermally	$\text{Bio3} = (\frac{Bio2}{Bio7}) \times 100$	°C
Bio4	Temperature Seasonality	$\text{Bio4} = std_{1\le month\le 12}\,(T(month)) \times 100$	°C
Bio5	Maximum Temperature in the Warmest Month	$Bio5 = T_{day\ max}(month\ max(T_{day\ max}))$	°C
Bio6	Minimum Temperature in the Coldest Month	$Bio6 = T_{day\ min}(month\ min(T_{day\ min}))$	°C
Bio7	Annual temperature range	$Bio7 = Bio5 - Bio6$	°C
Bio8	Mean Temperature of the Wettest Quarter	$T_q(quarter\ \max(p)) = \frac{1}{3}\sum_{month=quarter\ max(p)-1}^{quarter\ max(p)+1} T(month)$	°C
Bio9	Mean Temperature of the Driest Quarter	$T_q(quarter\ \min(p)) = \frac{1}{3}\sum_{month=quarter\ min(p)-1}^{quarter\ min(p)+1} T(month)$	°C
Bio10	Mean Temperature of the Warmest Quarter	$T_q(quarter\ \max(T)) = \frac{1}{3}\sum_{month=quarter\ max(T)-1}^{quarter\ max(T)+1} T(month)$	°C
Bio11	Mean Temperature of the Coldest Quarter	$T_q(quarter\ \min(T)) = \frac{1}{3}\sum_{month=quarter\ min(T)-1}^{quarter\ min(T)+1} T(month)$	°C

RESULTS AND DISCUSSIONS

1. Annual Mean Temperature (Bio1)

Figure 2 (a and b) illustrate the spatial distribution of Bio1 and its trends obtained at various grid points in Iraq. The Bio1 ranges from 6°C in the northern parts to 26 °C in the southern parts. Topography has a strong impact on the geographical distribution of Bio1. Bio1 increased significantly in Iraq, rising between 0.28 and 0.48 °C every decade, with lower concentrations in mountainous regions and higher concentrations in plain deserts. The northern and eastern parts of Iraq had a much steeper increase. In general, it was found that Iraq's temperature increases after 1970 was substantially more than the 0.15 °C/decade global average. It was found using the MK test that the increases were large in most locations of the study at the 95% confidence level. overall, the MK test showed that temperature increases brought on by global warming are already apparent in most parts of the count

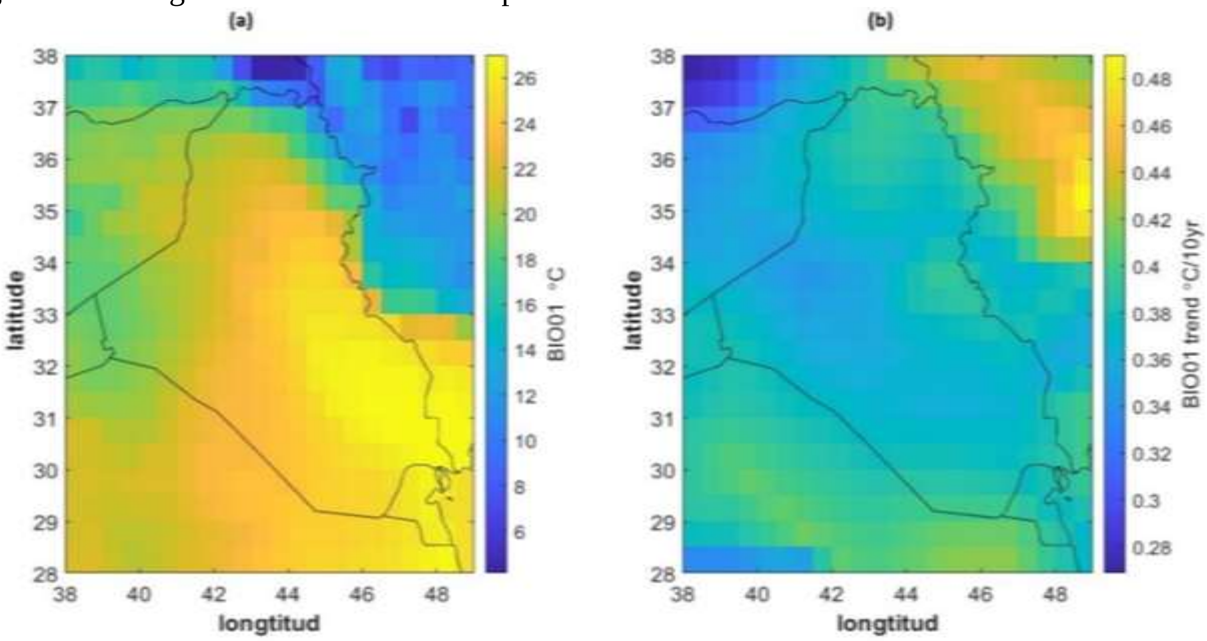

Figure 2. (a) Map of the spatial distribution of (Bio1), (b) map of Bio1 trends (°C/decade) presents the rate of change for the MK tests in Iraq

2. Diurnal temperature range (Bio2)

Since it is independent of internal climatic fluctuation, Bio2 is frequently used as an indicator of a region's impact on climate change. Figures 3(a and b) show geographical distribution of Bio1 and its corresponding patterns obtained at different grid sites in Iraq. There has been a global decline in Bio2, which is compatible with studies of global climate change, in several parts of the world. The current study further shows a decline in Bio2 in Iraq. Bio2 values in Iraq range from 4 °C in the northeastern part s and (14) °C in the southern part. MK test results revealed that most areas of Iraq especially in the southwestern and northeastern parts exhibited a decline in Bio2. The findings showed that Iraq is already experiencing the effects of climate change brought on by global warming.

3. Isothermally (Bio3)

The spatial distribution of Bio3 and its trends over Iraq are depicted in Figures 4 (a and b), Figure 4a shows the range of Iraq's Bio3 from (25 to 55)%. For the most part, it is less than 50%, although, in the southwestern and some areas in the northeastern, it ranges from (50) to 55%. The Bio3 trends showed a decline in various areas of Iraq. It indicates a gradually declining difference between diurnal and annual temperature changes in several regions of the country. The decline in diurnal temperature changes is the major cause of this.

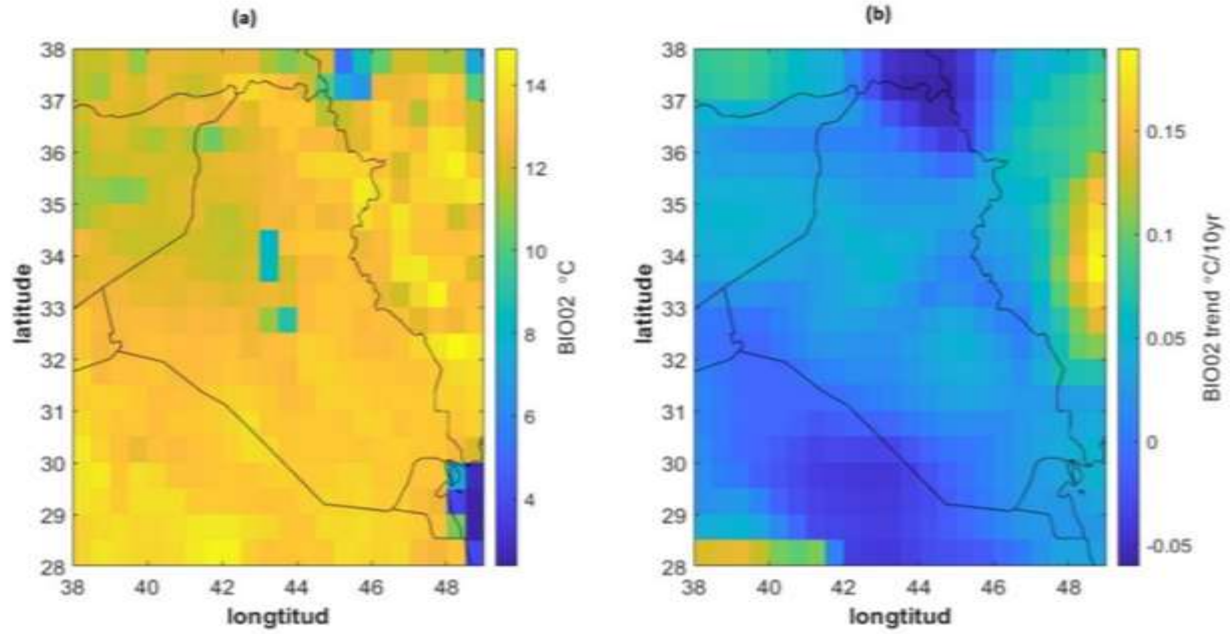

Figure 3. (a) Map of Map of the spatial distribution of (Bio2), (b) map of Bio2 trends (°C/decade) presents the rate of change for the MK tests in Iraq

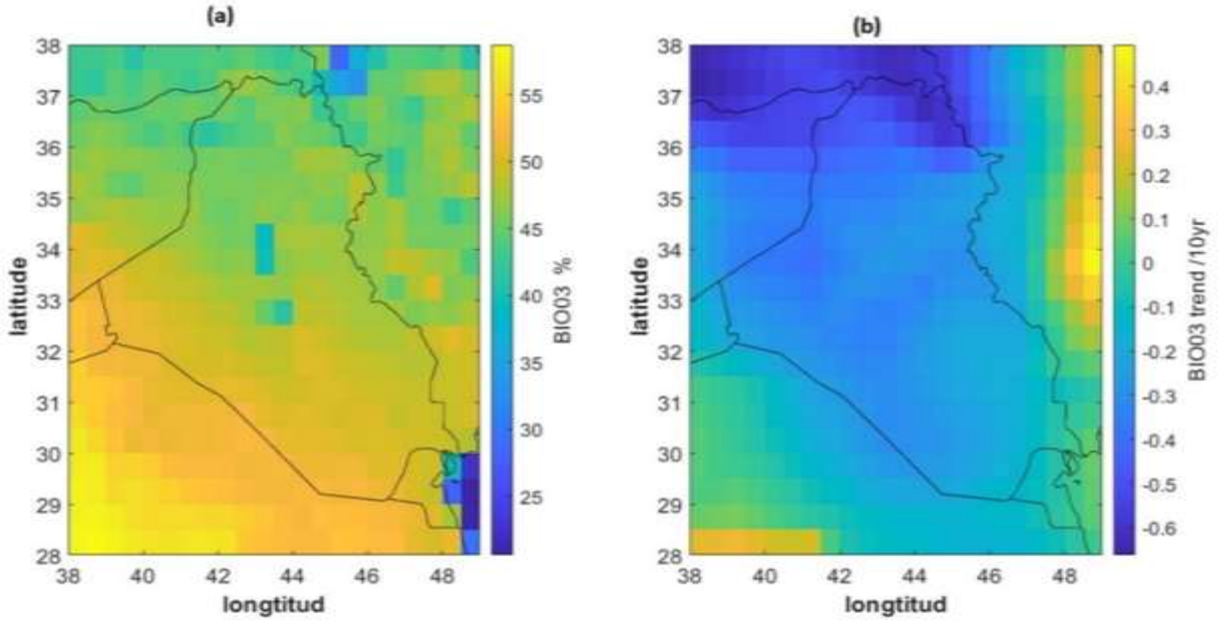

Figure 4. (a) Map of Map of the spatial distribution of (Bio3), (b) map of Bio3 trend (°C/decade) presents the rate of change for the MK tests in Iraq

4. Temperature seasonality (Bio4)

Figures 5(a and b) illustrate the geographical distribution and patterns of Bio4 in Iraq. The variation in temperature throughout the year is referred to as seasonality. It accurately expresses the temperature dispersion in terms of comparison. Temperature fluctuation is indicated by a higher Bio4 score. Iraq's Bio4 ranged from (7 to 10.5) °C. It was found to be higher in the eastern part and less prevalent in the western and southwestern parts, especially along the western parts, where it varied between (7.5 and 8.5) °C. The MK test found that there was an increase in Bio4 mostly in most parts of Iraq, and extremely in the western and southwest areas, and certain areas of central Iraq, where the environment is primarily arid and semi-dry.

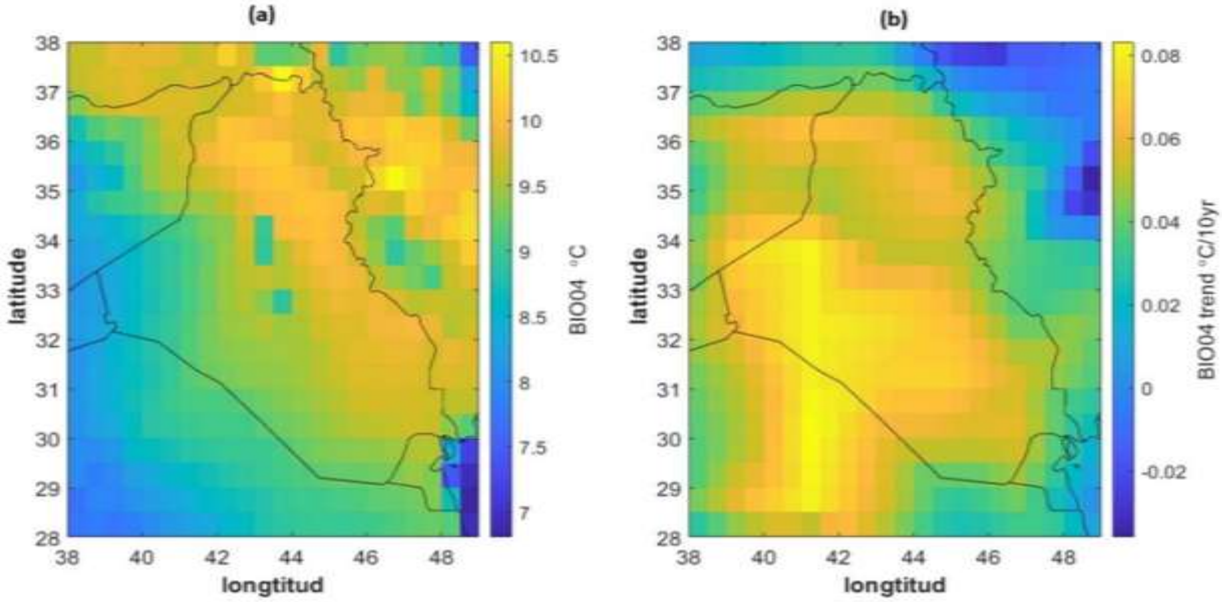

Figure 5. (a) Map of the spatial distribution of (Bio4), (b) map of Bio3 trends (°C/decade) presents the rate of change for the MK tests in Iraq

5. Maximum Temperature in the Warmest Month (Bio5): According to Figure 6(a and b), the Bio5 ranged from 45 to 47.5 °C, which suggests a high temperature in Iraq's hottest region. The southern regions recorded unusually high temperatures of 42.5 to 47.5 °C. The Bio5 also reached temperatures exceeding 35 °C in the northern parts and in mountain areas, where it is typically colder. The MK test indicated a nationwide rise in Bio5, with particularly elevated increments observed in the northern regions of Iraq. All of Iraq's climatic zones showed a unidirectional increase in Bio5, according to the data. Overall, it was discovered that the Bio5 increased where it is typically less.

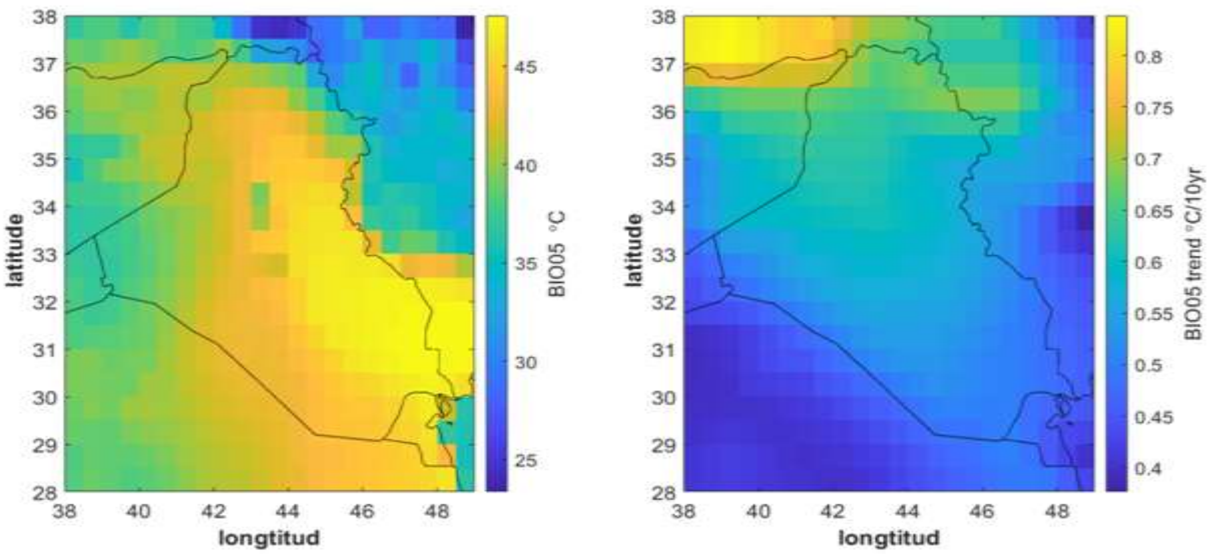

Figure 6. (a) Map of the spatial distribution of (Bio5), (b) map of Bio3 trends (°C/decade) presents the rate of change for the MK tests in Iraq

6. Minimum Temperature in the Coldest Month (Bio6): The geographical variability of Bio6 and Bio5 was roughly comparable (Figure 7). It fluctuated between 0 and 20 °C. The lowest value appeared in the northern parts of the country with the far northern mountainous regions seeing the lowest temperatures. Most regions of the country had an increase in Bio6 according to the MK test with a range of (0.26 to 0.46) °C /decade, and the northern parts indicated the highest trend increase. The alterations in Bio6 were found to be less pronounced in the coldest quarter than those in Bio5 (Figure 7b).

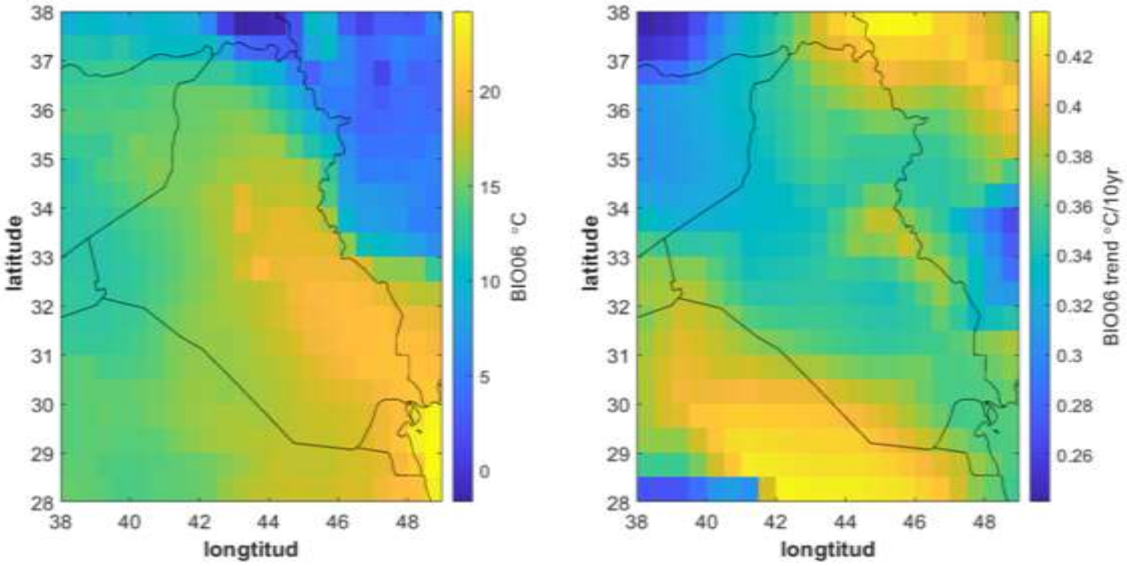

Figure 7. (a) Map of the spatial distribution of (Bio6), (b) map of Bio3 trends (°C/decade) presents the rate of change for the MK tests in Iraq

7. Annual Range of Temperature (Bio7)

In Iraq, the Bio7 varied greatly, from a very high value (>30 °C) in the far north to a low of 12 °C in the south. Figure 8a shows that there are noticeable variations in Bio7 between northern and southern Iraq. .MK test results showed a positive trend for most regions in the country and the highest increase appeared in the northwestern part of Iraq (Figure 8b).

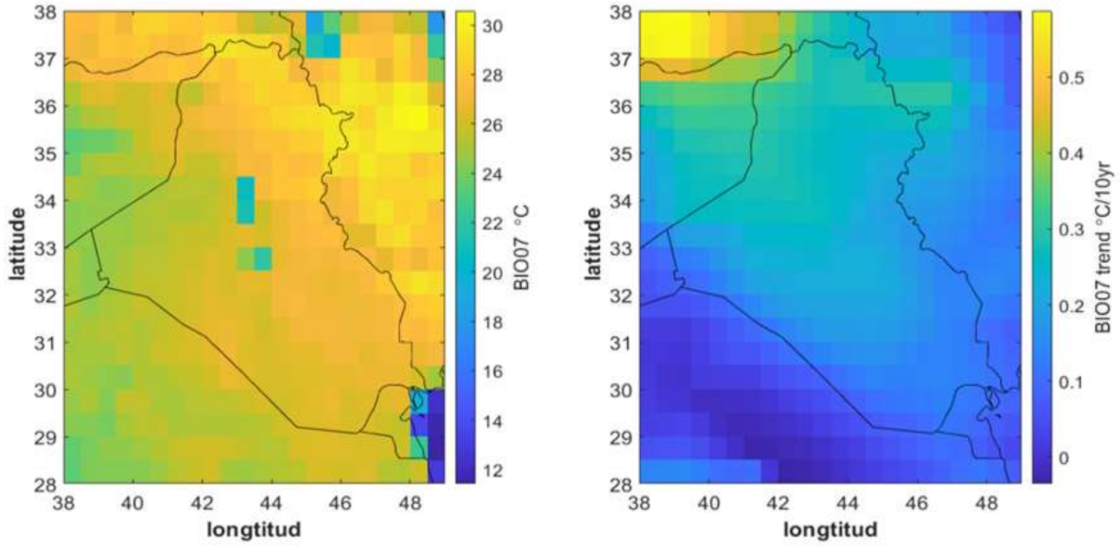

Figure 8. (a) Map of the spatial distribution of (Bio7), (b) map of Bio3 trends (°C/decade) presents the rate of change for the MK tests in Iraq

8. Mean Temperature of the Wettest Quarter (Bio8): The distribution of rainfall in Iraq varies considerably based on the season due to its different climate. As a result, there are large variations in the wettest quarter of the country. Each grid point's wettest quarter was calculated by approximating the rainfall for each of the three subsequent months. To depict their regional distribution (Figure 9a) and trends (Figure 10b), the mean temperature for the wettest quarter was calculated. The distribution of Bio8 values ranges from -2 °C in the northern part of Iraq to 16 °C in the southern part of Iraq. The regional distribution of the Bio8 trend was found to be heterogeneous in Iraq. The MK test revealed notable patterns in Bio8 scattered across the country.

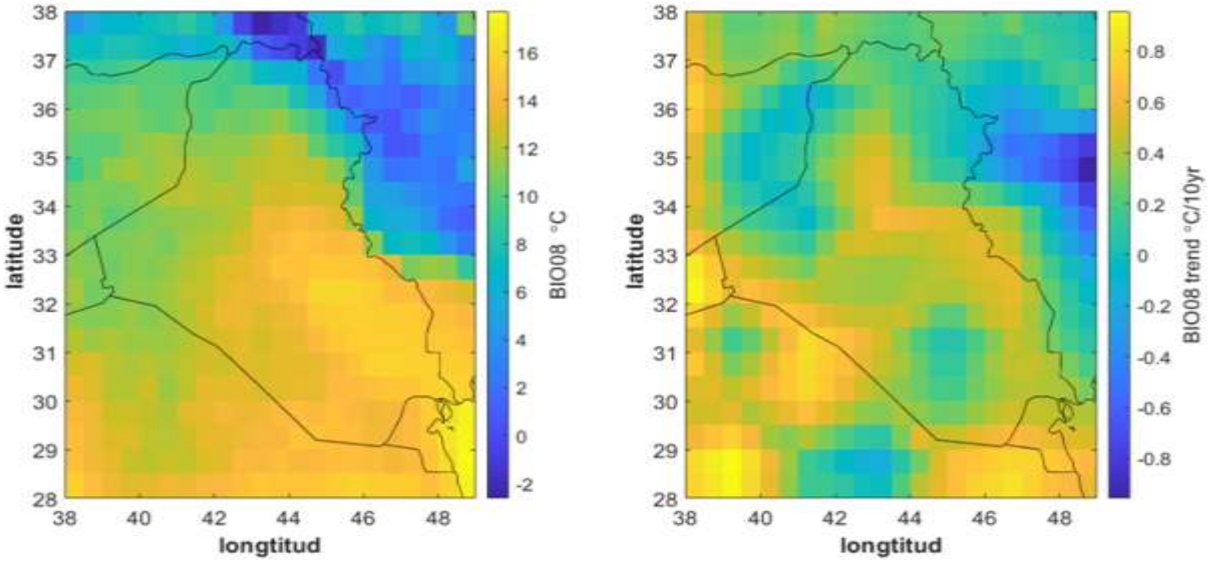

Figure 9. (a) Map of the spatial distribution of (Bio8), (b) map of Bio3 trends (°C/decade) presents the rate of change for the MK tests in Iraq

9. Mean Temperature of the Driest Quarter (Bio9): In order to ascertain the quarter with the least amount of rainfall at each grid point, an approximation was made for the rainfall during three consecutive months at each grid point. Figure 10(a and b) show a map illustrating the geographical distribution and trend analysis of a specific location. The study is based on the average temperature recorded during the driest quarter. The Bio9 in Iraq ranges from 15 °C in the far northern part and 37.5 °C in the most southern part of the country. The results of the MK test showed an appositive increase for most of the country and the central parts revealed the lowest increase.

10. Mean Temperature of the Warmest Quarter (Bio10): Figures 15 (a and b) indicate the geographical distribution and patterns of average temperature during the warmest quarter. It was discovered that Bio10 followed Iraq's topography. The values of Bio10 ranged from 18 °C appeared in the far northern part to 39 °C in the central and southern parts of Iraq. The trend analysis showed an increase for the whole interior country with a range between (0.36 to 0.48) °C /decade, and the highest increase appeared in the northwestern part of Iraq. The results show that the warmest months of the year are experiencing a unidirectional rise in mean temperature due to climate change.

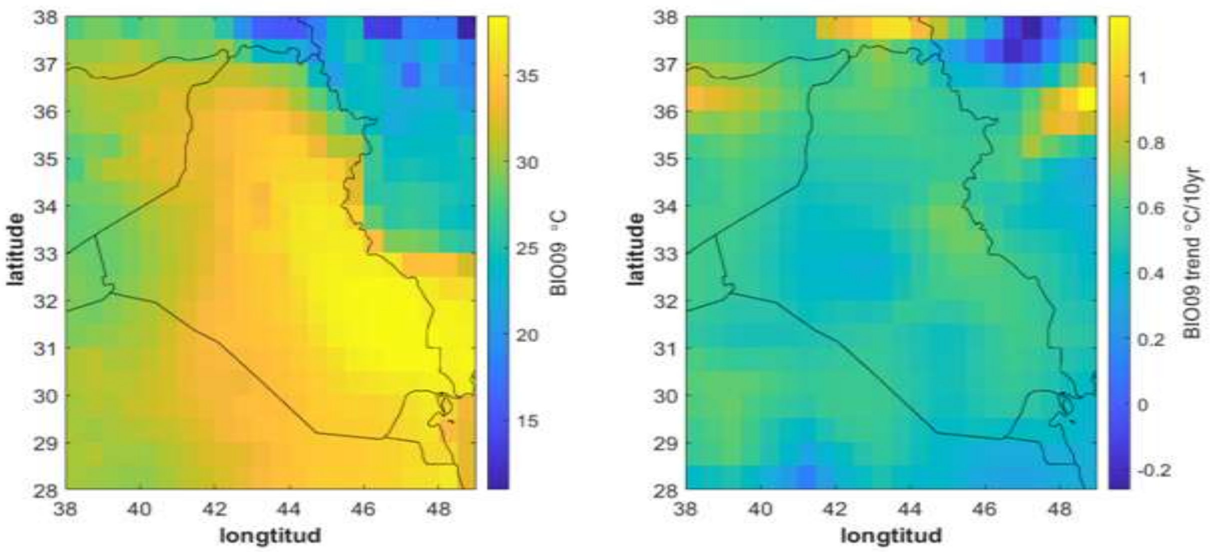

Figure 10. (a) Map of the spatial distribution of (Bio9), (b) map of trends in Bio3 (°C/decade) presents the rate of change for the MK tests in Iraq

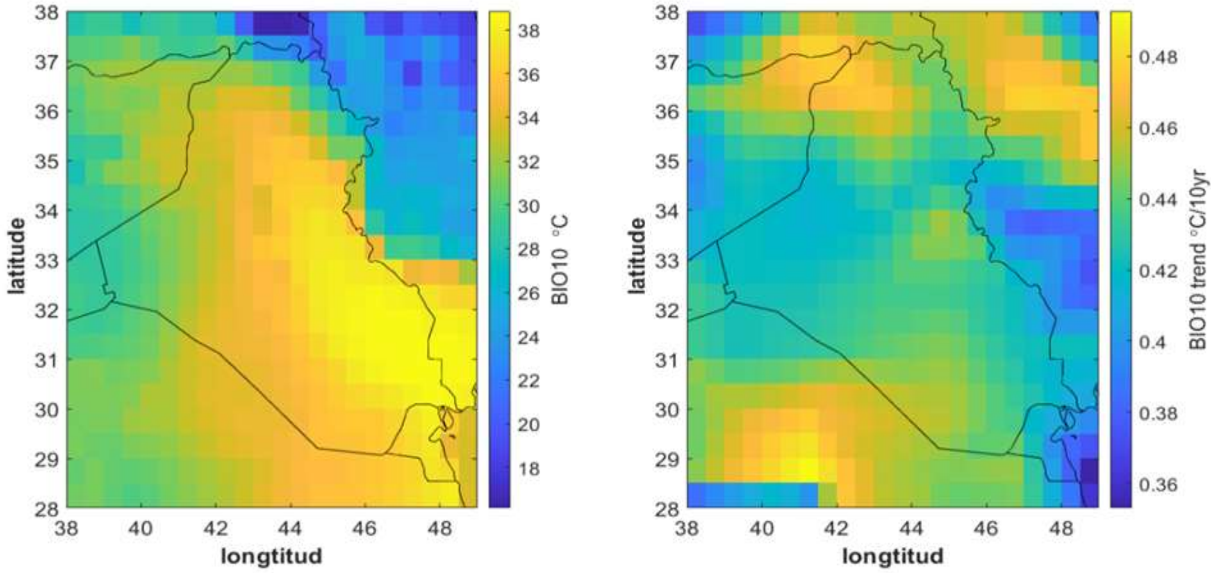

Figure 11. (a) Map of the spatial distribution of (Bio10), (b) map of Bio3 trends (°C/decade) presents the rate of change for the MK tests in Iraq

11. Mean Temperature of the Coldest Quarter (Bio11): The distribution and variations in Bio11 across regions are shown in Figures 12(a and b). It was shown to be lower in mountains and higher in plain regions, following a pattern similar to Bio10The Bio 11 readings are distributed within the range of -5 to 15 °C. The increase in Bio11 ranged from 0.25 to 0.65 °C each decade, which is a substantial growth. The increases were seen in the same regions where Bio10 was increasing, but to a lesser extent.

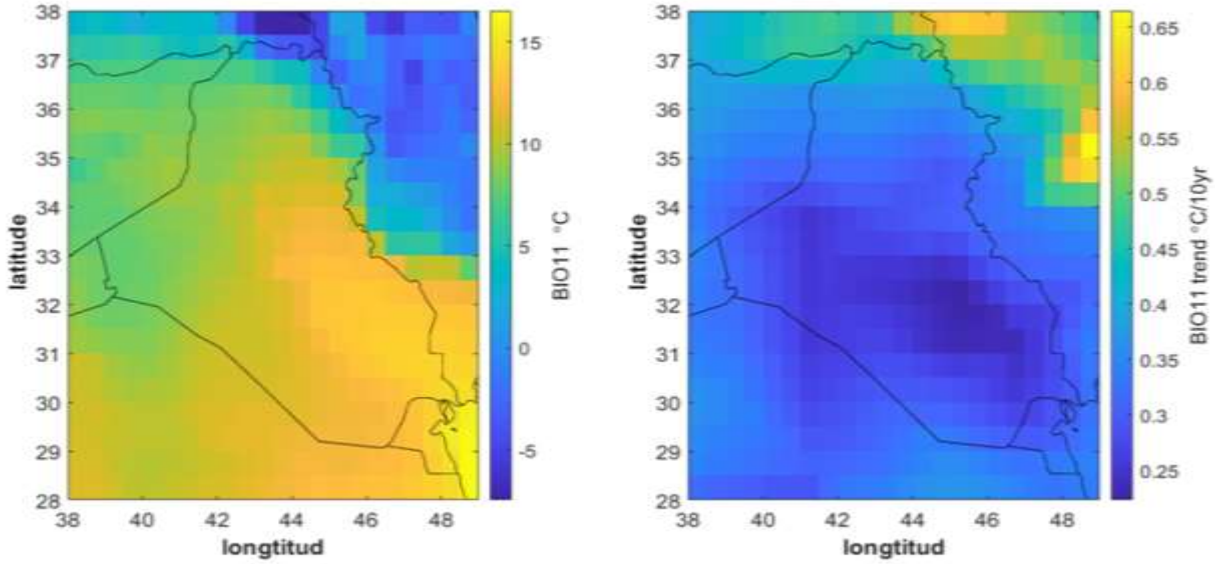

Figure 12. (a) Map of the spatial distribution of (Bio11), (b) map of Bio3 trends (°C/decade) presents the rate of change for the MK tests in Iraq

CONCLUSIONS

The present study was carried out to investigate the changes in thermal bioclimatic indices throughout different climate zones over Iraq, in order to understand their trends from 1980–2022.The trend of 11 bioclimate indices caused by global climate change was evaluated using MK test. The results identified changes in the majority of Iraq's thermal bioclimate indicators, which implies that rising temperatures have had a substantial impact on the bioclimate of the country. The MK test revealed that temperature rises caused by global warming are already seen in most locations of the country. The results of the annual mean temperature reveled that Iraq had a significant increase in Bio1 of (0.28 to 0.48) °C/decade, and this values it is more than the

(0.15) °C/decade global average (two time to three faster). The increase was found to be considerably larger in Iraq's northern and eastern areas. The findings indicated that most regions of Iraq, particularly in the southern and northeastern parts, experienced a decline in diurnal temperature range. The maximum temperature in the warmest quarter increased most drastically, while the changes in the coldest quarter were less apparent, indicating a rise in climatic extremes in Iraq. The analysis clearly shows that climate change is generating a unidirectional increasing in mean temperature during the warmest months of the year. Many of the indicators were shown to rise more in areas with lower mean values, indicating progressive homogeneity in the spatial distribution of particular indicators. Maps and data produced by this study can be used by environmental and conservation specialists to comprehend potential changes or biodiversity changes in relation to climate change. Further investigations may be conducted to examine changes in additional bioclimatic variables that are connected to precipitation and humidity.

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