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Assessing Past and Future Heat and Cold Waves over Iraq Using CMIP6 Model

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Abstract

The United Nations classified Iraq as one of the most vulnerable countries to climate change. Temperatures continue to rise leading to more heat waves, droughts, sandstorms, and desertification. This study aims to investigate the characteristics of heat waves over Iraq from 1982 to 2050 using CMIP6 model at RCP4.5 scenarios. The results clearly showed that the effects of climatic changes were evident in the maximum and minimum temperatures inside Iraq. Average temperature increased of 1.9°C between 1982 and 2020. During 1999, there was a sharp increase in summer days for all stations. The annual number of summer days for the stations (Basra, Nasiriyah, Baghdad, Rutba, Sulaymaniyah, and Mosul) was (195, 193, 177, 108, 106, and 142), while in 2039 the number of summer days was found to be (212, 206, 194, 143, 144, and 149), respectively. The increase in the number of discrete heat wave events began in 2020 and will continue until 2050 for almost the entire territory of Iraq. The warmest day in Basra was in July 2016 with 53.2°C, while the projection of the warmest day was found in July 2046 with 55.7°C. The coldest daily temperature reached -5.03 °C for Baghdad in 1997 and -10.1°C for Sulaymaniyah in 1985, while the projection of the coldest day was -16.2°C over Sulaymaniyah in 2039. The trend of the number of days contributing to cold wave events was decreasing for all stations whereas the coldest year for all stations was 1992 for the entire period (1982 to 2020). Heat waves accelerated from the beginning of the study period in 1982 and continued to increase until the end of the study in 2050 in Iraq.

Keywords: Heat Waves; Daily Maximum and Minimum Temperature; Iraq

تقييم موجات الحرارة والبرودة الماضية والمستقبلية في العراق باستخدام نموذجCMIP6

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الخلاصة

صنفت الأمم المتحدة العراق على أنه أحد أكثر البلدان عرضة للتغيرات المناخية. تستمر درجات الحرارة في الارتفاع وتشهد المزيد من موجات الحر والجفاف والعواصف الرملية والتصحر. تهدف هذه الدراسة إلى التعرف على خصائص موجات الحر في العراق من عام 1982 إلى عام 2050 باستخدام نموذج CMIP6 بتطبيق سيناريو الانبعاث RCP4.5. أظهرت النتائج بما لا يدع مجالا للشك أن تأثير التغيرات المناخية كانت واضحة على درجات الحرارة العظمى والصغرى في المناطق العراقية الست قيد الدراسة. يتسارع الارتفاع في عدد موجات الحر من بداية فترة الدراسة عام 1982 وتستمر في الزيادة حتى نهاية فترة الدراسة عام 2050 في العراق. ارتفاع حاد في عدد أيام الصيف التي تزيد فيها درجة الحرارة العظمي عن 35 درجة مئوية خلال عام 1999 لكل من (البصرة، الناصرية، بغداد، الرطبة، السليمانية، الموصل) حيث سجلت (195، 193، 177، 108، 106، و142 يومًا)، بينما في عام 2039 وصل عدد أيام الصيف الي (212، 206، 194، 143، 144، 149 يوما) على التوالي.

1. Introduction

The distinguished geographical location of Iraq, which places it at the center of the eastern Mediterranean region, bound by Turkey in the north, Iran in the east, Syria and Jordan in the west, while overlooking the Arabian Desert and the Arabian Gulf in the south. Iraq, like the rest of the Middle East, faces the most important challenges posed by climate change, such as extreme heat waves, increased sandstorms, and the resulting environmental disasters**.** The findings of [1] showed a high correlation between climatic data and urban expansion, with urbanization rates rising to (85%) mainly over the 2001–2021 cycle and influencing all climatic aspects. Climatic changes, such as increasing temperatures and increasing salinity and scarcity of water, will likely have serious effects on Iraq in the next few years [2-5]. The influence of global climate change is confirmed by the annual precipitation for the Karbala station-reflect declination, which decreased from 105 mm between 1982 and 1990 to about 71 mm between 2011 and 2015 [6]. In 2019, the United Nations ranked Iraq as the fifth most vulnerable country to climate change in the world. In 2013, the Intergovernmental Program on Climate Change (IPCC) announced that the Middle East would undergo a considerable increase in temperature until the end of this century [7]. The Iraqi government reported in its special report on climate change that the loss of 250 km2 of agricultural area each year due to the expansion of sand dunes represents serious problems in Iraq [8]. The outcomes of [9] indicate that only 73% of Iraq's land area was covered by arid regions at the end of the 1980s, 78% of Iraq's land area was covered by arid regions in the 1990s, and 88% of Iraq's land area was covered by arid regions in the first decade of the 2000s. Research carried out by [10] indicated that, apart from the highland’s regions of the north and northeast, most of the Iraqi land areas witness a climate that is either arid or semi-arid desert. According to [11] analysis, the local climate in Baghdad City suffers as a result of poorly planned land use. NASA reported that, the years 2020 and 2016 were tied as the warmest since temperature records began. Climate projection at different pathway scenarios indicated that arid and semi-arid desert regions are possible to expand in area simultaneously with rising temperatures [12-14]. Recently, more research is needed in order to determine the way climate changes in the Middle East [15]. [16] examines urban expansion using remote sensing data over Baghdad, the study establishes a direct relationship between increasing urbanization, relative humidity rates, the growth of building areas, and rates of temperature rise in such locations. Heat waves

and hot spells are most commonly linked with global climate change [17]. The number of consecutive hot days required to account for a wave may vary in different regions: as an example, [18] that was specialized in Australia, defined a heat wave as an event of a minimum of three successive days above threshold, while [19, 20] defined a European heat wave as an event of a minimum of 6 days duration. The main objective of this research paper is to investigate heat wave indices and characteristics over Iraq. For such purposes, daily maximum and minimum temperatures data was collected from seven main Iraqi cities.

2. Material and Methods

2.1 Study Domain

The Republic of Iraq is a country that lies in southwestern Asia and sited between latitude (29.00°-37.22°N) and longitude (38.45°-48.30°E), approximately 438,317 square kilometers. Iraq has a hot, dry climate characterized by long, hot, dry summers with variations between hot and extremely hot temperatures and short, cool winters, as shown in Table 1 and the illustrative map in Figure 1, which gives the spatial distribution of the selected meteorological stations. In the north-eastern part of Iraq Kurdistan, Sulaymaniyah's (cold and rainy winters, while summers are hot and dry) average temperature ranges from 5.5 ℃ in January to 32 ℃ in July. In Mosul, located in the northernmost part of the country, the average temperature in January is 8 ℃ and can sometimes drop a few degrees below freezing, with daytime temperatures of 43 ℃ in July and August. In Rutba, located in the west of the country, the average is between 9 ℃ in January and 32.5 ℃ in July. In the central part, in the Iraqi capital, Baghdad, the average temperature ranges from 11 ℃ in January to 36.5 ℃ in July. Further south, in Basra and Nasiriyah, the average in January is 13 ℃. Southern Iraq is considered one of the regions with a noticeable rise in summer temperatures worldwide.

Table 1: List of the selected meteorological stations

Station Name	WMO Code	Latitude/Longitude
Basra	406890	30.53°, 47.81°
Nasiriyah	406760	31.23°, 46.41°
Baghdad	406500	33.33°, 44.30°
Rutba	406420	33.33°, 40.08°
Sulaymaniyah	406230	35.44°, 45.00°
Mosul	406080	36.14°, 43.59°

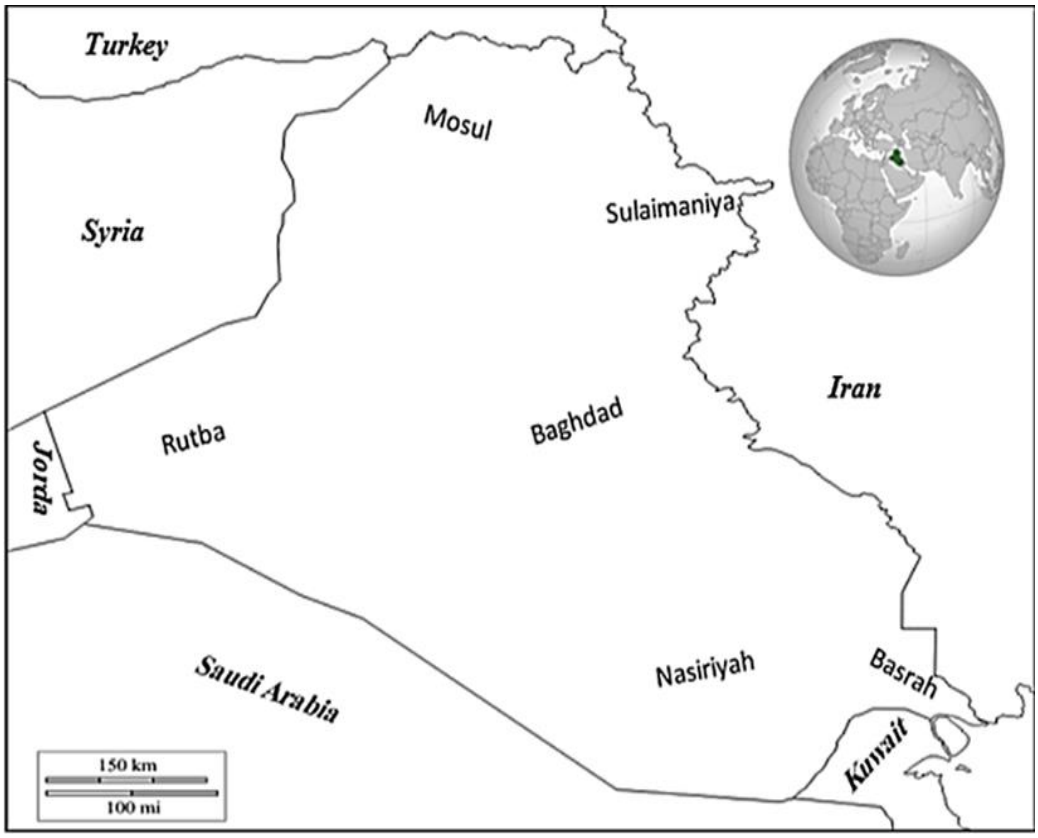

Figure 1: Location of the study areas

2.2 Observational and Model Data

The set of observational climatic meteorological data applied in this study consists of maximum and minimum temperatures for the period 1982-2020, obtained from six stations mainly located in Iraq (Basra, Nasiriyah, Baghdad, Rutba Sulaymaniyah, and Mosul). The climatic data used was obtained from the National Center for Environment Information (NOAA). Projection data of extreme temperature indices (2020-2050) was done by using the EC-Earth3-CC CMIP6 global climate model with scenarios SSP2-4.5. In 1995, under the auspices of the World Climate Research Programme (WCRP), the Coupled Model Intercomparison Project (CMIP) began, which is now in its sixth phase (CMIP6). CMIP6 compares independent models, collects, organizes, and distributes output with high accuracy. The CMIP6 dataset has a spatial resolution of 0.1°x 0.1° (11 km x 11 km), which is considered the highest resolution available for climate change projections based on the Shared Socio-economic Pathway (SSP) scenarios. The results of climate scenarios from CMIP6 were used in the latest Intergovernmental Panel on Climate Change (IPCC) Assessment Report (AR6). Heat waves were drawn and analyzed using ClimPACT2 (R software package), which was made possible by the WMO Commission for Climatology (CCl- OPACE 4).

3. Results and Discussion

3.1 Trend of Temperature

Temperature and precipitation are the main indicators of climate changes on the Earth's surface, so they are subject to many analyses and studies to better and more accurately understand climate change. The climate of Iraq is classified as semi-desert and mountainous. Temperature increases will affect the potential for longer and more intense droughts and dust storms. Generally, the trend is the increase in temperature with the progression of time throughout the study period, which extends from 1982 to 2050. It is noticeable that, as seen in Figure 2, the rise in the southern cities is more than in the northern cities. The climatic

changes in Iraq seem clear from the change in the trend of temperatures towards the continuous and accelerating increase.

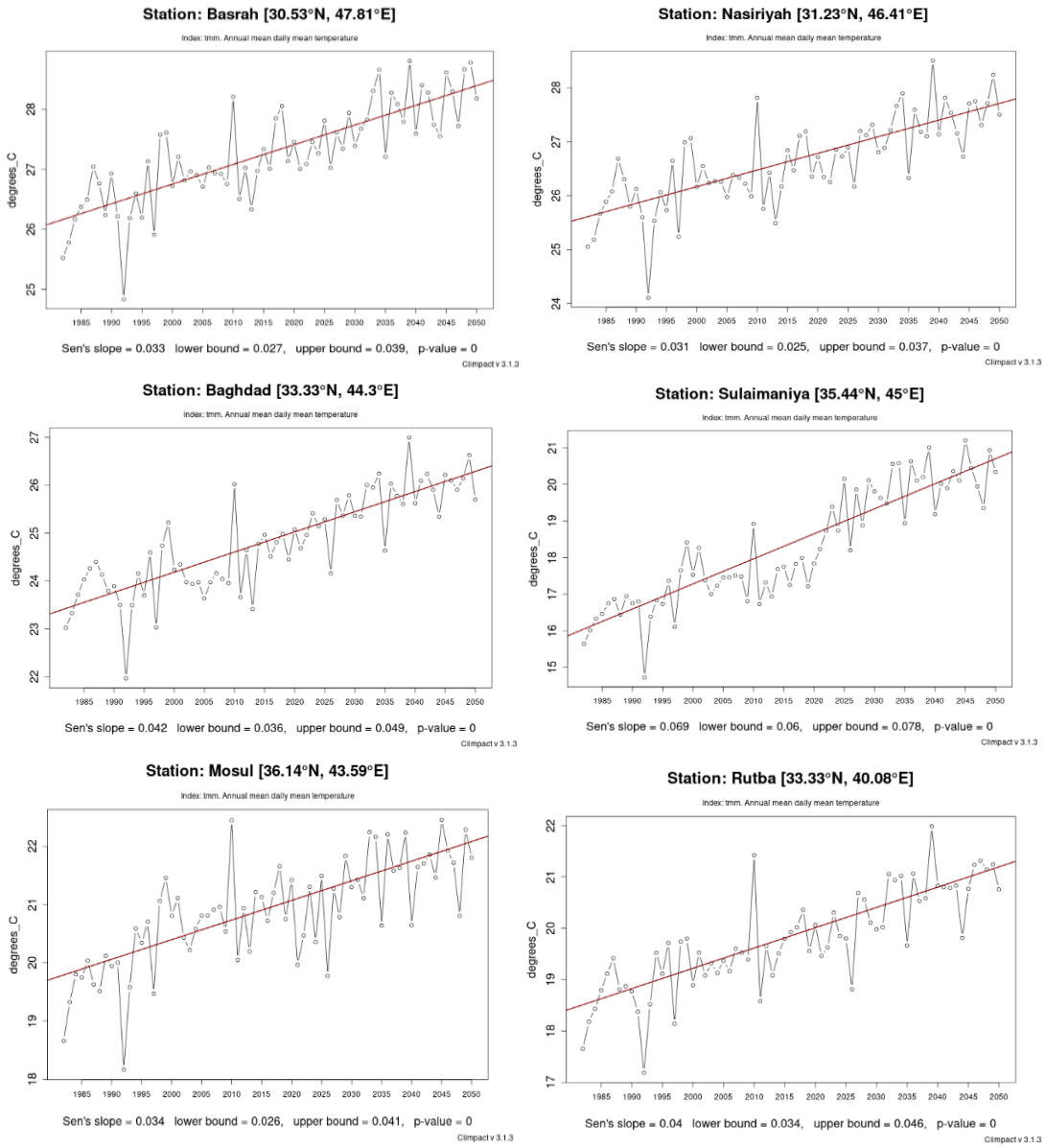

Figure 2: Temperature trends in six selected stations over Iraq during 1982-2050.

3.2. Heat Waves

3.2.1. Heat Wave Aspects

The temperature must be above the annual average in order to be considered a heat wave. The period of at least three consecutive days in which maximum temperatures exceed the heat wave temperature threshold. The World Meteorological Organization had a role in defining heat waves to include all regions of the world [21]. Heat wave indices were applied in this study to investigate the extreme temperatures, which are summer days, Heat Wave number, warmest days, annual coldest days, mean difference between daily maximum temperature and daily minimum temperature, annual percentage of hot days, and cold wave frequency. The definition of heat waves depends on two criteria: (1) the 90th percentile of the minimum daily temperature, and (2) the 90th percentile of the maximum daily temperature. If any of the previous two criteria exceeded three consecutive days, we would consider this time period a

short heat or cold wave, and for 6 or more consecutive days, a long heat or cold wave. This definition was used in our study. A more detailed definition was given by [22, 23]. As a variety of definitions are used for these events, it is difficult to compare heat wave studies [24-26].

3.2.2. Summer Days: Annual number of summer days when TX > 35 °C

There is an increase in the trend of summer days along the period from 1982 to 2050 for all stations, especially in 1999 and 2039, which have a sharp increase in the summer days. During 1999, the annual number of summer days for (Basra, Nasiriyah, Baghdad, Rutba, Sulaymaniyah, and Mosul) was (195, 193, 177, 108, 106, and 142 days), while in 2039, the number of summer days was found to be (212, 206, 194, 143, 144, and 149 days), respectively, as seen in Figure 3.

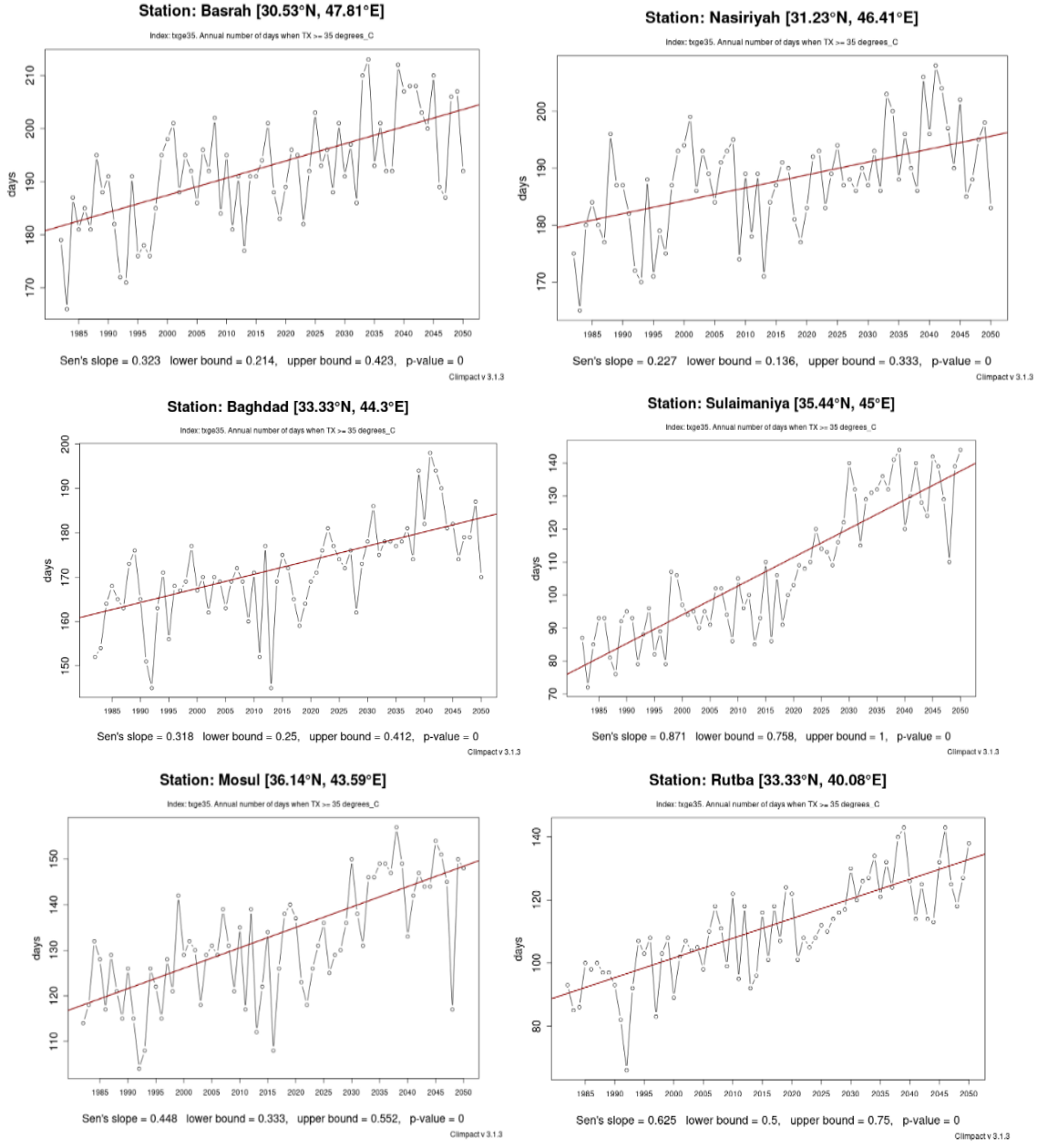

Figure 3: Annual number of summer days when TX > 35 °C over the study areas.

3.2.3. Heat Wave Number (HWN)

It is defined as the number of discrete heat wave events. Figure 4 demonstrates the number of heat waves, which was determined as the 90th percentile of daily highs. The average number of events was less than 3 per year from 1982 to 2020, while after 2020 the number continued to rise between 7 to 12 events. The highest HWN values were found in Sulaymaniyah, which reached 12 events. The increase in the number of discrete heat wave events begins in 2020 and continues until 2050 for almost the entire territory of Iraq. The heat wave amplitude, which is defined as the maximum temperature of the hottest day of the hottest yearly event, for (Basra, Nasiriyah, Baghdad, Rutba, Sulaymaniyah, and Mosul), was found (55.7°C, 55.1°C, 54.7°C, 48.1°C, 49.0°C, and 50.3°C), respectively.

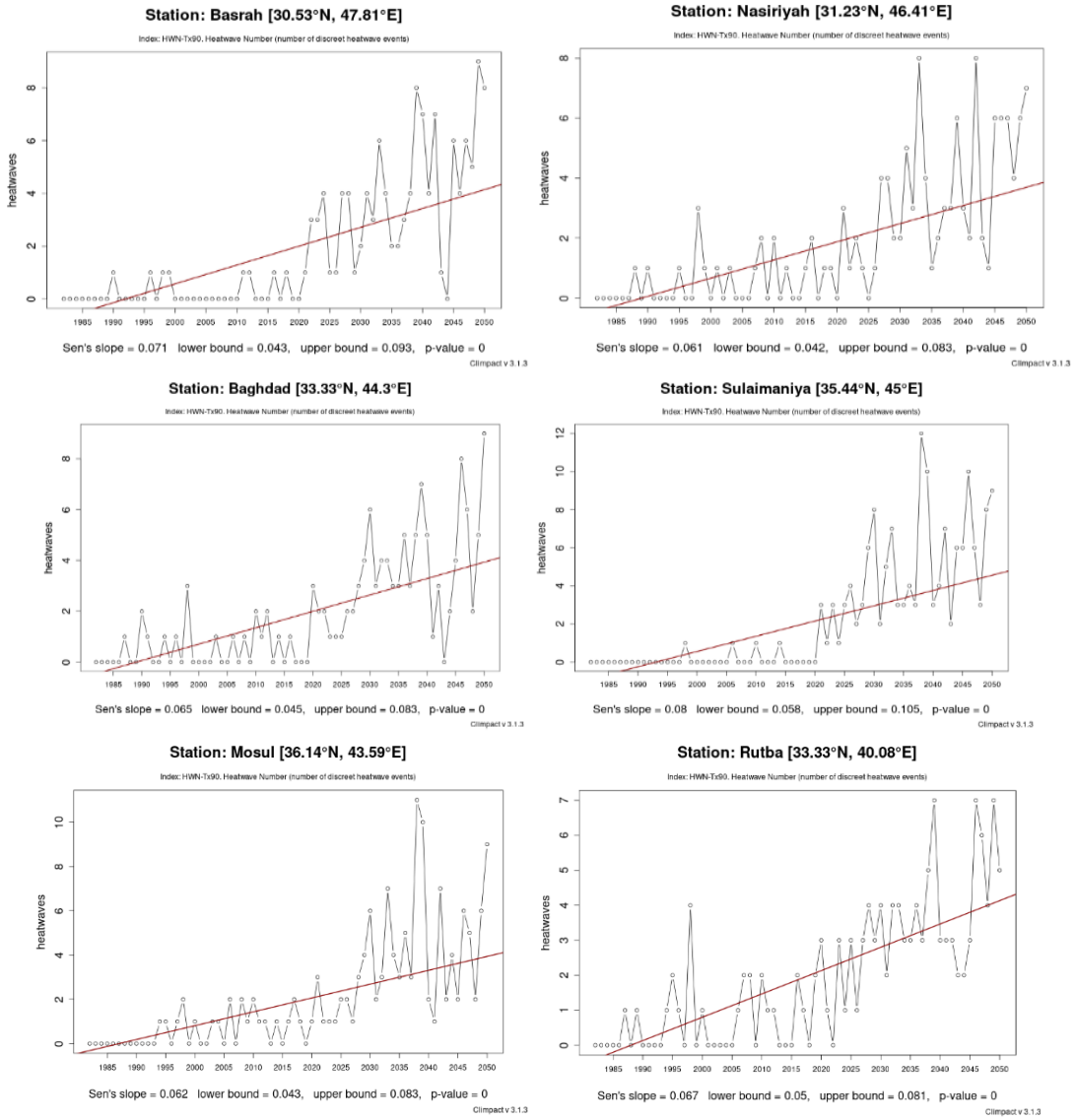

Figure 4: Annual number of heat waves over the study areas.

3.2.4. The Warmest Daily Temperatures

The trend of the warmest day for every year is increasing with the time progress in all stations. The warmest day in Basra was in July 2016 with 53.2°C, while the projection of the warmest day was in July 2046 with 55.7°C, as seen in Figure 5. In the city of Basra, the high temperature meets the high relative humidity, thus reducing the thermal comfort of the residents of that area.

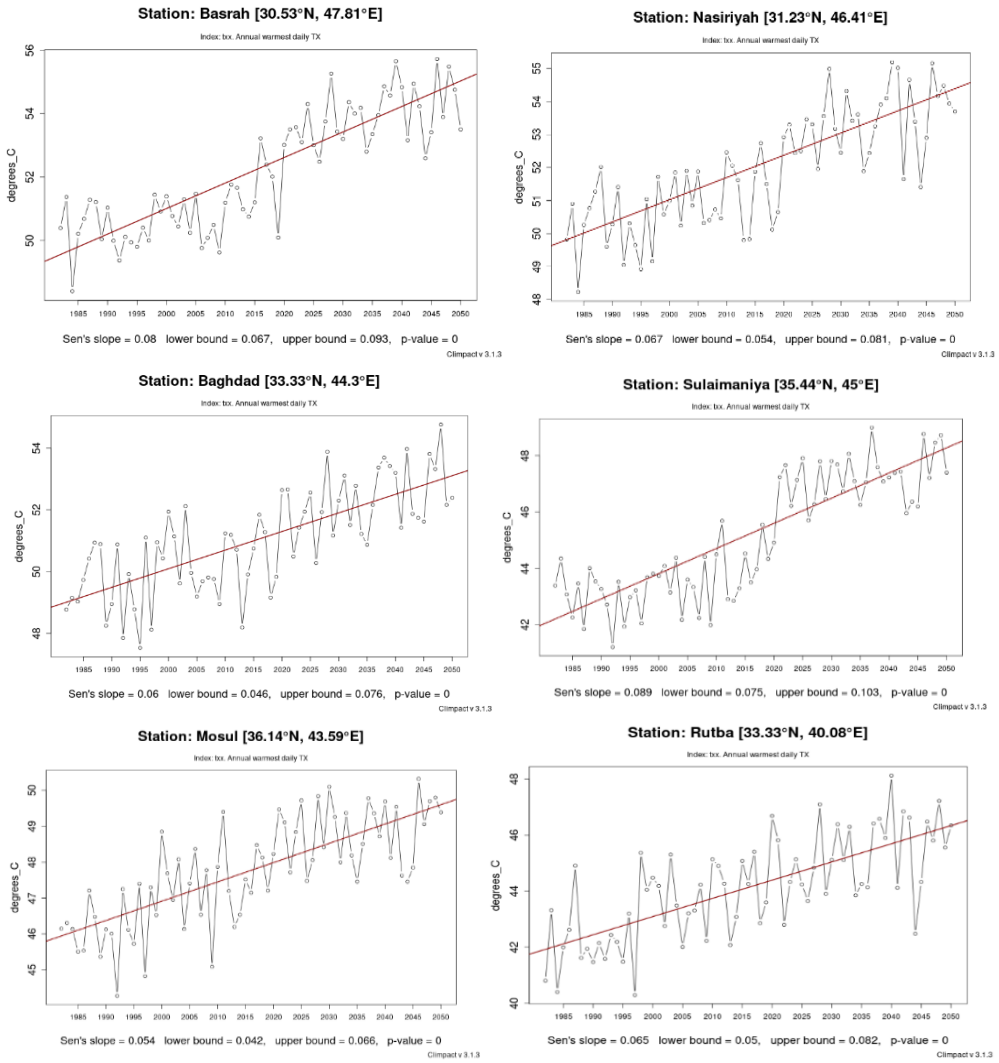

Figure 5: Temperature of the warmest days for every year over six selected cities in Iraq from 1982 to 2050.

3.2.5. Annual Coldest Daily Temperatures

As shown in Figure 6, the general trend of the coldest daily temperatures for every year is a nearly decreasing temperature over Baghdad, Sulaymaniyah, and Rutba, while there is a small increase with stability in the coldest daily temperatures in the rest of the study stations. The coldest daily temperatures reached -5.03 °C over Baghdad in 1997 and -10.1°C over Sulaymaniyah in 1985. The projected coldest day was found -16.2°C over Sulaymaniyah in 2039.

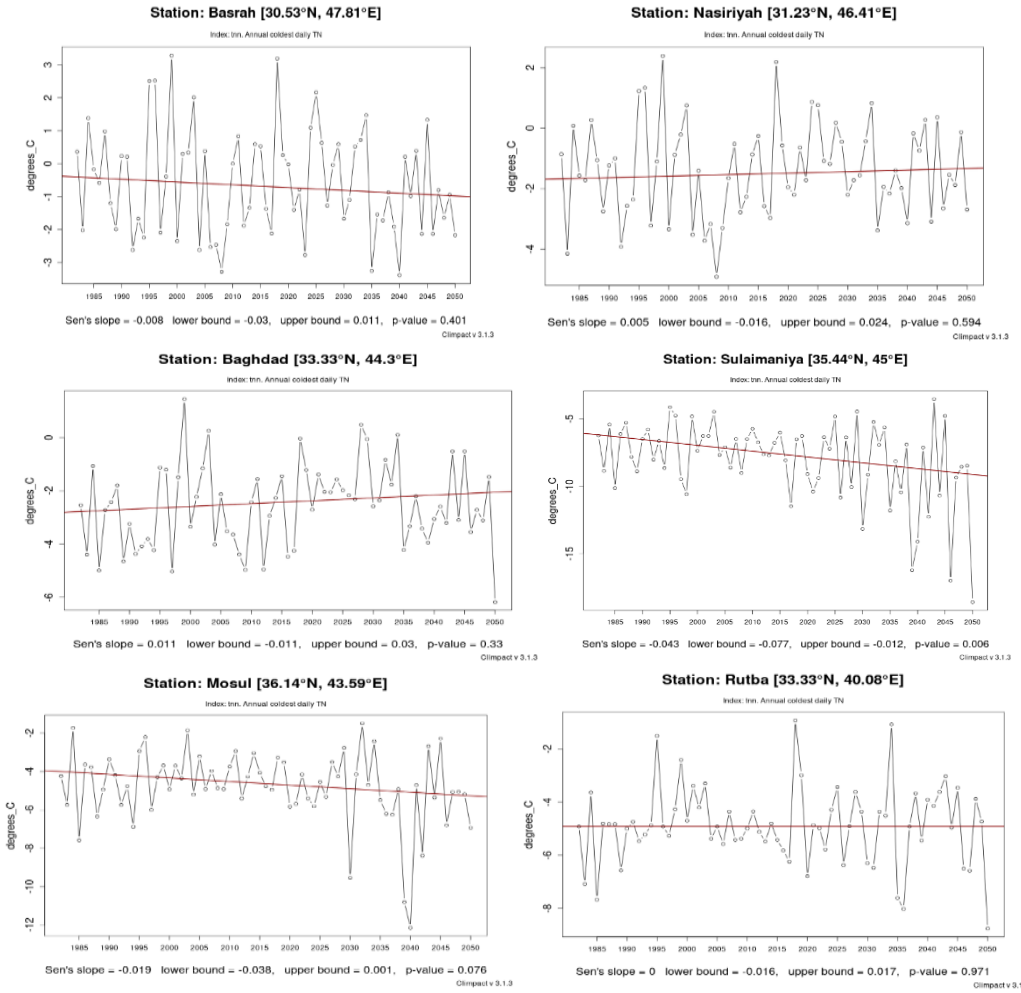

Figure 6: The annual coldest daily temperatures over six selected cities in Iraq from 1982 to 2050.

3.2.6 Mean Difference between Daily TX and Daily TN

The trend of the mean annual difference between daily TX and daily TN is sharply decreasing for Baghdad, Nasiriya, and Rutba stations, as shown in Figure 7. It is a decreasing in Basra and Mosul stations, but it is nearly steady in Sulaymaniyah station. In general, we can conclude that the maximum and minimum temperatures are close to each other in the daily temperature range, which is one of the "fingerprints" of human-caused global warming.

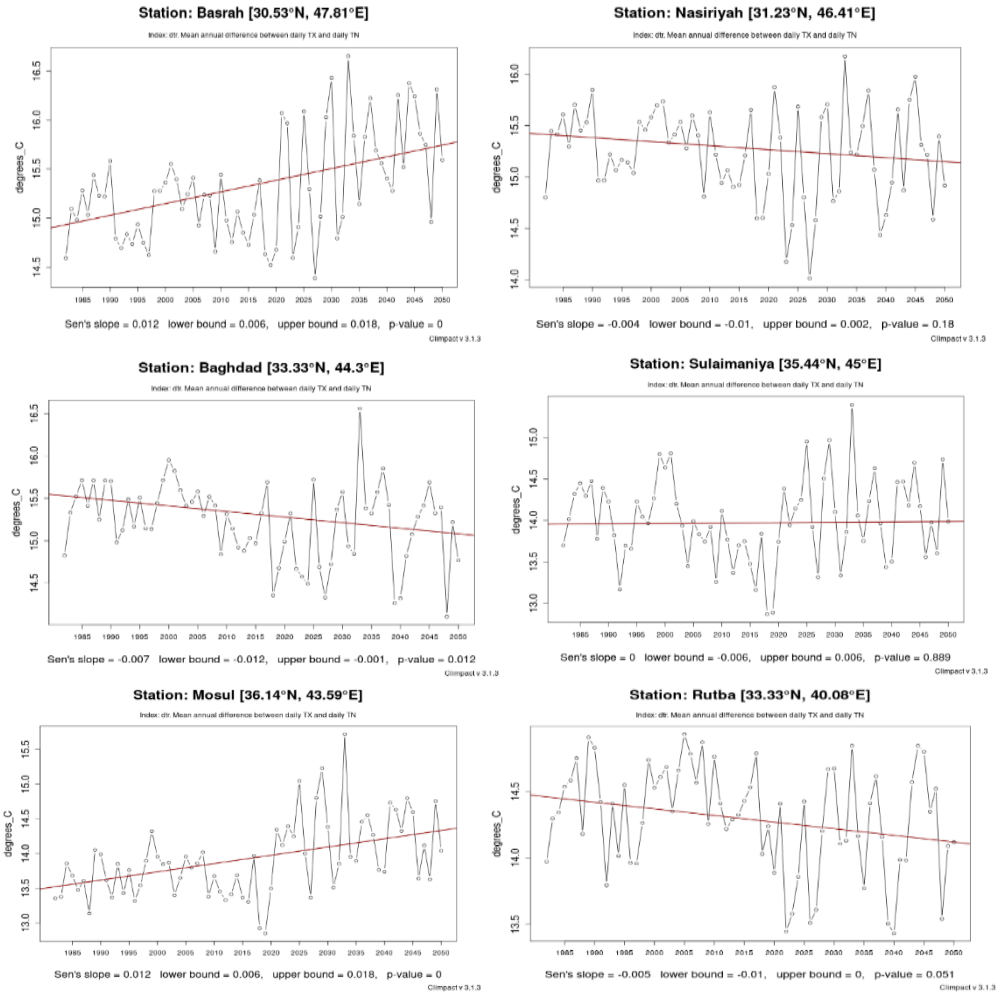

Figure -7 Mean difference between daily TX and daily TN over six selected cities in Iraq from 1982 to 2050.

3.2.7 Annual Percentage of Hot Days when TX > 90th Percentile

There is an increasing trend of annual percentile of hot days for all stations, which represent the base of computing heat wave numbers. The maximum percentile of hot days recorded in 2010 was (17.5, 20.9, 21.5, 28.0, 15.5, and 22.5) percentile for (Basra, Nasiriyah, Baghdad, Rutba, Sulaymaniyah, and Mosul), respectively, as seen in Figure 8.

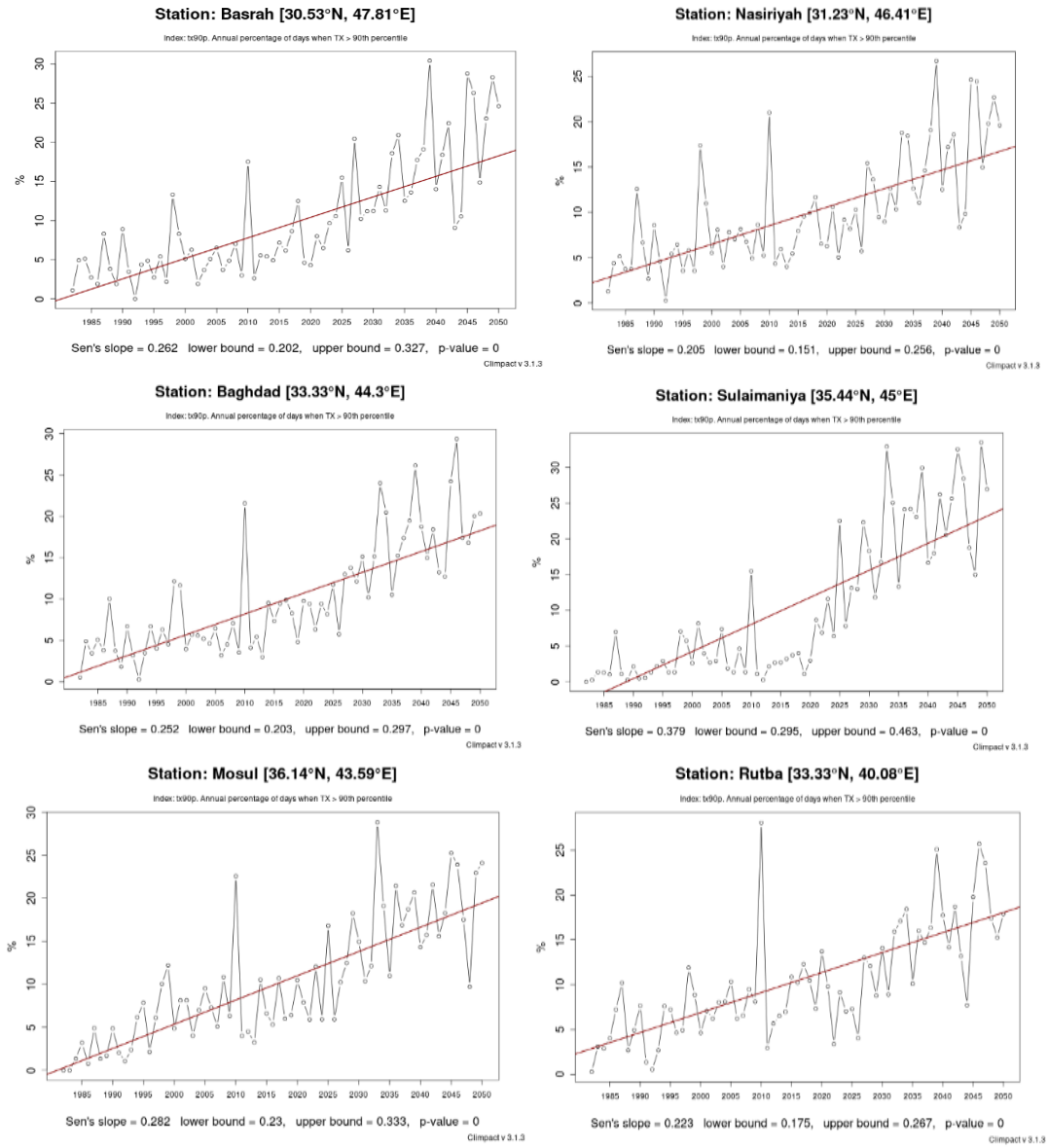

Figure -8 Annual Percentage of hot days when TX > 90th percentile over six selected cities in Iraq from 1982 to 2050.

3.2.8 Cold Wave Frequency

The trend in the number of days contributing to cold wave events is decreasing for all stations. The highest number of cold wave event was recorded in 1992 as (41, 40, 52, 53, 76, and 63) days for (Basra, Nasiriyah, Baghdad, Rutba, Sulaymaniyah, and Mosul), respectively, as illustrated in Figure 9. So, we can conclude that the coldest year for all stations was 1992 for the entire period (1982 to 2020). The projection of cold wave frequency under the SSP2-4.5 scenario found that the highest number of days contributing to cold wave events were in the year 2035 for all stations.

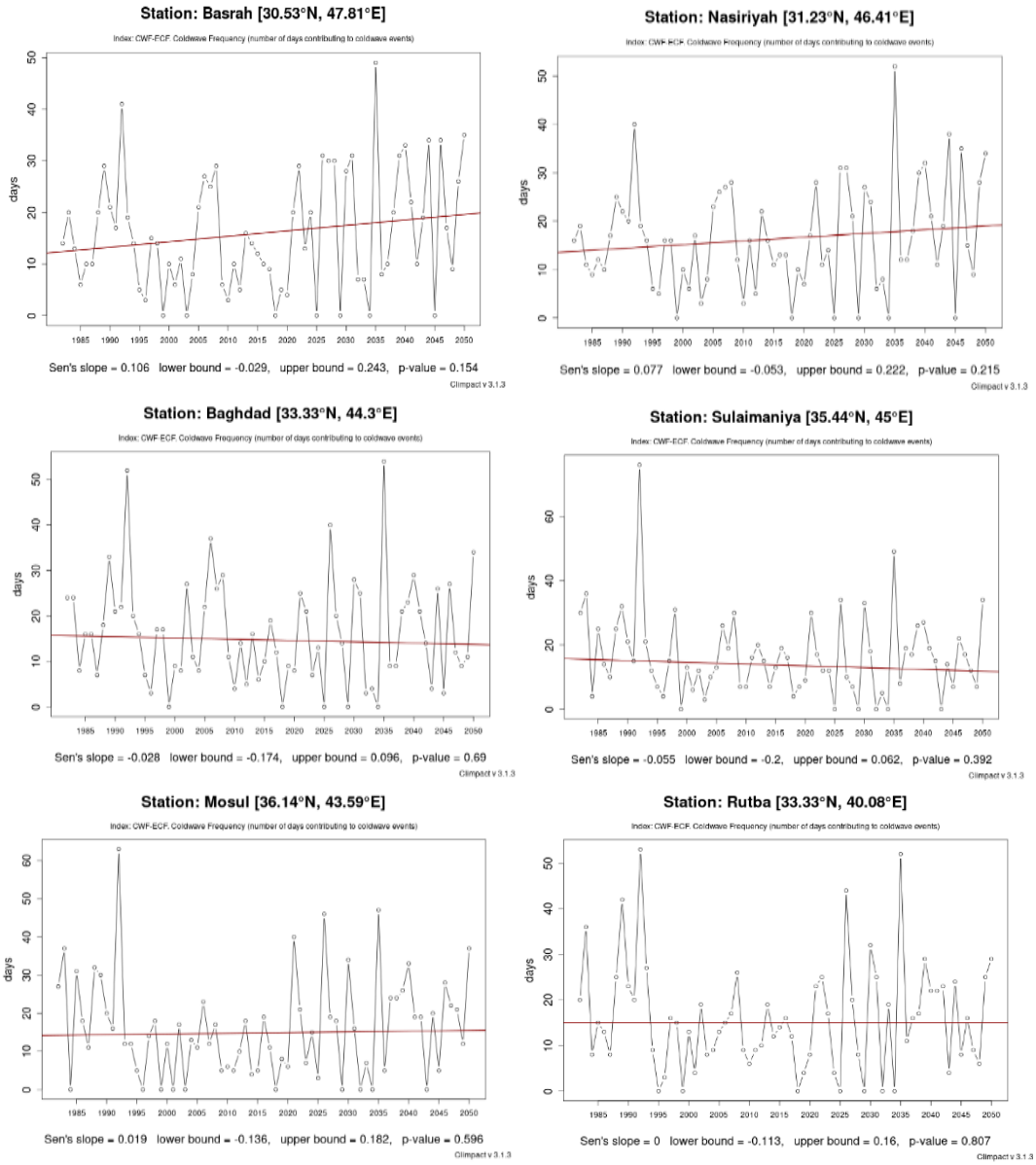

Figure 9: Cold wave frequency over six selected cities in Iraq from 1982 to 2050.

A significant decrease in frequent future cold extremes was observed during the last decades over Europe [27, 28]. The phenomenon of climate change creates real threats to the people of the Middle East and North Africa regions; as the regions are most vulnerable to being affected by the catastrophic results of global warming. Most of their countries are distinguished by a hot desert climate, and increased humidity levels due to their location on the coasts of the Gulf, the Mediterranean and the Arabian Sea.

This study warns that temperatures may exceed 55 degrees Celsius by the middle of this century, which will make life in the region "impossible". As the use of air conditioners is common, residents tend to avoid going out to the streets during the day, and families wait for the evening to go out to public parks during the summer. This forced Qatar to introduce laws prohibiting work in open spaces, starting from the month of June until the end of August, between eleven-thirty in the morning and three in the afternoon.

Studies have confirmed that the Middle East region is among the regions where crime is directly affected by the weather [29]. December is the month of the year in which crimes

against property are committed, while August is the highest rate of violence. The rise in temperature during the summer increases the vitality of the body and its temperament, which makes it more susceptible to excitement, tension and impulsivity, with its weak ability to control its actions, and facilitates its rush to commit violent crimes [30].

4. Conclusions

In recent years, Iraq has been severely affected by climate change, with more and more regular heat waves above 50°C. Iraq was ranked among the eleven most vulnerable countries in the world to the possible impacts of climate change. This will result in higher temperatures, more droughts, less rain, and more sandstorms. The results of the study clearly showed the impact of climate change over Iraq. The hottest day of the hottest yearly event for (Basra, Nasiriyah, Baghdad, Rutba, Sulaymaniyah, and Mosul) was found to be (55.7°C, 55.1°C, 54.7°C, 48.1°C, 49.0°C, and 50.3°C), respectively. The trend of the mean annual difference between daily TX and daily TN is sharply decreasing for Baghdad, Nasiriya, and Rutba stations, which is one of the "fingerprints" of human-induced global warming. The highest number of cold wave events was recorded in 1992 as (41, 40, 52, 53, 76, and 63) days for (Basra, Nasiriyah, Baghdad, Rutba Sulaymaniyah, and Mosul), respectively. So, we can conclude that the coldest year for all stations was 1992 for the entire period (1982 to 2020). Heat waves are more dangerous when combined with high humidity, as is the case in Basra, bordering the Arabian Gulf. It is very difficult to mitigate the previous causes; however, their effects can be reduced with urgent action by the government and raising people's awareness.

Conflict of Interest

The authors declare that they have no conflicts of interest.

References

[1] K. H**.** Moussa and A. Alwehab, "The Urban Expansion Impact on Climate Change for the City of Baghdad," *Iraqi Journal of Science*, vol. 63, No. 11, pp. 5072-5085, 2022.

[2] C. J. Richardson and N. A. Hussain, "Restoring the Garden of Eden: An Ecological Assessment of the Marshes of Iraq," *Biosciences*, vol. 56 (6), pp. 477 – 489, 2006.

[3] V. K. Sissakian, N. Al-Ansari and S. Knutsson, "Sand and Dust Storm events in Iraq", *Natural Science*, vol. 5 (10), pp. 1084-1094, 2013.

[4] N. Abbas, S. Wassimia and N. Al-Ansari, "Assessment of Climate Change Impacts on Water Resources of Khabur River in Kurdistan Iraq using SWAT model", *J Environmental Hydrology*, vol.24, pp. 1-10, 2016a.

[5] USAID 2017, "Climate Risk Profile Iraq". [Online]. Available: https://www.climatelinks.org/resources/climate-change-risk-profile-iraq.

[6] W. H. Kadum and I. A. Al-Ali, "Climate parameters analysis as an indication of climate Changes for diwaniya, Nasiriya, Kut and Karbala meteorological stations - Central and southern Iraq: Karbala climate condition as a case study," *Iraqi Journal of Science*, vol. 63, No. 12, pp: 5295-5308, 2022.

[7] IPCC 2013, "Long-term climate change: projections, commitments and irreversibility Climate Change the Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change" T. Stocker, D. Qin, G. K. Plattner, M. Tignor, S. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. Midgley, *Cambridge University* Press and New York NY USA.

[8] MoE (Iraqi Ministry of Environment) 2010, "Annual Report Internet data last retrieved 20 December 2021", [Online]. Available: https://reliefweb.int/sites/reliefweb.int/files/resources/Climate%20change%20In%20Iraq%20Fact %20sheet%20-%20English.pdf.

[9] L. A. Jawad, "The Climatic Quality Index Determination for Iraq Using Meteorological Stations Data," *Iraqi Journal of Science*, vol. 57, No.4C, pp: 3005-3016, 2016.

[10] M. Al Azhar, M. Temimi, J. Zhao and H. Ghedira, "Modeling of circulation in the Arabian Gulf and the Sea of Oman Skill assessment and seasonal thermohaline structure", *J geophysics Res*

Ocean, vol. 121(3), pp. 1700–1720, 2016.

[11] A. K. Mohammed and F. K. Al-Ramahi," A study of the Effect of Urbanization on Annual Evaporation Rates in Baghdad City Using Remote Sensing," *Iraqi Journal of Science*, vol. 61, No. 8, pp: 2142-2149, 2020.

[12] M. Weston, N. Chaouch, V. Valappil, M. Temimi and W. Zheng, "Assessment of the Sensitivity to the Thermal Roughness Length in Noah and Noah-MP Land Surface Model Using WRF in an Arid Region Pure Appl", *Geophysics*, 2018.

[13] O. Branch, A. Behrendt, Z. Gong, T. Schwitalla and V. Wulfmeyer, "Convection Initiation over the Eastern Arabian Peninsula", *Meteorol Zeitschrift*, pp. 67–77, 2020.

[14] N. Karami, "The Modality of Climate Change in the Middle East: Drought or Drying Up", *The Journal of Interrupted Studies*, vol. 2, pp. 118-140, 2019.

[15] S. M. Ahmed and F. K. Al-Ramahi," Evaluate the Effect of Relative Humidity in the Atmosphere of Baghdad City urban expansion Using Remote Sensing Data," *Iraqi Journal of Science*, vol. 63, No. 4, pp: 1848-1859, 2022.

[16] T. Delworth, J. Mahlman and T. R. Knutson, "Changes in heat index associated with CO2-induced global warming", *Climate Chang*, vol. 43, pp. 369–386, 1999.

[17] S. E. Perkins and L. V. "Alexander, On the Measurement of Heat Waves", *Journal of Climatology*, vol. 26, pp. 4500–4517, 2013.

[18] E. Fischer and C. Schär, "Consistent geographical patterns of changes in high-impact European heatwaves", *Natural Geoscience*, vol. 3, pp. 398–403, 2010.

[19] J. Sillmann, V. V. Kharin, X. Zhang, F. W. Zwiers and D. Bronaugh, "Climate Extremes Indices in the CMIP5 Multimodal Ensemble Part 1 Model Evaluation in the Present Climate", *Journal of Geophysical Research Atmospheres*, vol. 118, pp. 1716-1733, 2013.

[20] A. M. G. Klein Tank, G. P. Konnen, "Trends in Indices of Daily Temperature and Precipitation Extremes in Europe", *Journal of Climate*, vol. 15, pp. 3665-3680, 2003.

[21] World Meteorological Organization and World Health organization, "Heatwaves and Health Guidance on Warming-System Development", *McGregor GR (ed.) WMO* No. 1142 Geneva,2015.

[22] P. J. Robinson, "On the definition of a heat wave", *Journal of Applied Meteorology*, vol. 40, pp. 762-775, 2001

[23] P. Frich, L. V. Alexander, P. Della-Marta, B. Gleason, M. Haylock, A. M. G. Klein Tank and T. Peterson, "Observed coherent changes in climatic extremes during the second half of the twentieth century", *Climate Research*, vol. 19, pp. 193-212, 2002.

[24] C. Souch and C. S. B. Grimmond, "Applied climatology Heat waves", *Progress in Physical Geography*, vol. 28, pp. 599-606, 2004.

[25] G. A. Meehl, C. Tebaldi and D. Nychka, "Changes in frost days in simulations of twenty-first century climate", *Climate Dynamics*, vol. 23, pp. 495–511, 2004.

[26] N. Christidis, P. Stott, S. Brown, G. Hegerl and J. Caesar, "Detection of changes in temperature extremes during the second half of the 20th century", *geophysics Res Lett* 32, 2005.

[27] S. Brown, J. Caesar and A. T. Ferro, "Global changes in daily extreme temperatures since 1950", *J geophysics Res Atmos*, vol. 113, 2008.

[28] O. Loughlin, J. Linke, A.M. Witmer," Effects of temperature and precipitation variability on the risk of violence in sub-Saharan Africa, 1980–2012," *Proc. Natl. Acad. Sci. U. S.* A. 111, 16712–16717, 2014.

[29] C. A. Anderson," Heat and violence," *Current Directions in Psychological Science*, 10, 33–38, 2001.