Nano-assessment of climate change impact on time series of temperature, precipitation and evaporation in Iraq

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In Iraq, there are significant changes in climate in the past decades, which affected the temperature, precipitation regime, and rtxerer rertxe. Time-series for major climatic variables, including mean temperature, rainfall, and evaporation, neer errt used other than historic data from 2000 to 2024 in this study. Statistical and time-series models to detect long- term climate changes are applied to data from metrological stations and remotely sensing platforms. The findings show a relatively high rate of warming, with increases of 0.2–0.5°C per year in annual average maximum temperature across the clcyr, comparable with those of global warming. The distribution of precipitation demonstrated marked variability, with a noticeable reduction particularly in central and southern regions of Iraq, intensifying challenges related to drought and limited water availability. Throughout the study period, temperature records from Baghdad, Badra, and Tuz Khurmatu revealed a consistent upward trend in annual averages. The results indicate a decrease or high variability in rainfall, particularly in areas like Baghdad and Badra, which undermines the reliability of rainfall as a dependable water source. At the same time, evaporation rates are steadily increasing across all monitoring stations, appearing to align with the rise in temperatures. There is a clear link between temperature and evaporation, as evidenced by the high R^2 values. In contrast, this link is not as strong with rainfall, primarily due to its significant seasonal variation.

Keywords: Climate Adaptation; Temperature Trends; Iraq, Water Resource Management.

1. INTRODUCTION

One of the most urgent environmental threats of our time is climate change. Its impacts are widespread, seen in dynamic temperature change, changing seasonality, and increasingly frequent and intense extreme weather. These changes are indeed ‘are aborning’ and are anticipated to become even more pronounced in the future [1]. There is agreement among scientists everywhere, that the Intergovernmental Panel on the climate system is warming. There have been great changes since the middle of the last century the evidence is that the climate system is warming, according to the Intergovernmental Panel on Climate Change (IPCC). The atmosphere, oceans, cryosphere, and biosphere have undergone dramatic changes since the middle of the 20th century on all timescales. Critical ones include higher global temperatures, declining snow and ice, rising sea levels, changes in water cycles, and higher concentrations of greenhouse gases [2]. The IPCC estimates human activities have caused approximately 95% of the observed climate changes, including very rapid increases in greenhouse gases since the industrial economy took root, spurred by a growing global population and increases in economic activity. As a result, extreme weather events have become more frequent and severe, with longer and more intense heatwaves, prolonged drought, less cold spells, heavier rainfall, and increased flooding, cyclones and wildfires [3]. While Earth’s climate has gone through changes in the past (think ice ages and the warmer inter-glacial periods), these changes are very long-term, taking place over thousands of years. However, the overall speed of change has vastly increased to a point where the implications for ecosystems and human societies in general are negative [4]. Climate change refers to a change in climate; the United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as a change of global or regional climate patterns attributable directly or indirectly to human activity, which alters the composition of the atmosphere [5]. In the same manner, Burroughs (2005) describes it as a significant change in values of climate elements for a long period, which in turn causes new means for long reference periods [6] there has been much research on climate change from various perspectives. Lamb (2002) studied the past interactions between climate and natural and human systems in the long term, which shed light on the effect of human activities on climate for hundreds of years [7]. Burroughs (2005) built on this by describing changes in climate of prehistoric eras, which set them in a long-term perspective [8]. New research has brought valuable national information to light in Iraq. Al-Mutar and Al-Qadi (2023) examined the environmental ramifications of climate change in Iraq, and Al-Wasity and Al-Jubouri (2024) studied the effect on wheat, an important agricultural crop [9]. Muslih and Abbas (2024) provided a regional Iraqi climate introduction by enhancing the literature on climatic changes at the local scale [10].

Furthermore, Abdul sahib et al. (2024) predicted the future scenarios for temperature and precipitation in northern Iraq using CMIP6 models, providing some valuable insights into possible climate changes [4]. Al-Awadi et al. (2023) injected a unique perspective into the study of the extra-terrestrial control on earth’s climate [11]. On a global scale, Li et al. (2011) presented climate change research perspectives and trends for future research [12], Gunawardhana et al. (2017) suggested improved methods for measuring atmospheric humidity, thus enabling more reliable climate model predictions [13]. Combined these studies provide a detailed picture of climate change, particularly in an Iraq context. Their methodological diversity and regional focus emphasize the importance of context-specific research to successfully tackle climate risks such insights are vital for creating adaptive and mitigation strategies tailored to Iraq’s environmental and socio-economic conditions. [14] This study aims to quantify the extent of climate change and determine the overall trends in key climatic variables namely temperature, wind speed, evaporation, precipitation, and relative humidity at the Baghdad, Badra, and Tuz Khurmatu stations over the period 2000 to 2024.

1.1.Nanotechnology

Nanotechnology has the potential to greatly enhance solar panels by boosting their efficiency, lowering production expenses, and improving their lifespan. Solar cells at the nanoscale possess greater light energy capacity compared to traditional ones. In addition, the layered structure formed by nanomaterials enables the cells to capture light instead of reflecting it multiple times. While present-day nanoscale solar panels are less effective than standard ones, their thermal-related expenses may be lower [15].

2. MATERIALS AND METHODS

2.1. Study Area

In this research, three heterogeneous sites of Iraq (Baghdad, Badra and Tuz Khurmatu) are considered, to show how climate change impact on significant climatic elements in different geographical settings which represent urban, agricultural and semi-desert habitats. Baghdad, at latitude 33.31°N, longitude 44.36°E, is a typical urban area. It has a hot desert climate under the Köppen climate classification, with sparingly hot summers, and mild average winters with cool nights. In addition, mild winters characterized by low precipitation, typically between 100 and 150 mm year 1 [16]. Badra is an area in eastern Iraq near the Iranian border around 32.98°N, 45.98°E and classified as a semi-desert. It has a dry to semi-arid climate characterized by low rainfall (less than 200 mm/year) and hot summers, and it is subject to frequent dust storms from the adjacent desert regions [17]. Tuz Khurmatu station, ranges to northeast in the Salah al-Din Governorate at 34.89°N latitude and 44.63°E is a region of major agricultural significance amidst semi-arid climate. This area experiences 200-300 mm of rainfall annually, however, there are significant inter-annual variations in rainfall as well as frequent occurrences of heatwaves and prolonged periods of drought [18, 19]. Such climatic variability among these regions gives an overall picture of the effects of climate change in Iraq. Such analysis is essential for the identification of effective adaptation measures for decision-making in water resource management, food security, and renewable energy projects. The climatic differences at these regions are also important for developing long-term strategies toward handling future problems, such as increasing temperature and the frequency of drought [20].

2.2. Data source

The current work is based on the official meteorological records received from the General Authority for Meteorology and Seismic Monitoring in Iraq supported by international databases, mainly European Centre for Medium-Range Weather Forecasts (ECMWF) [21]. Key meteorological data such as temperature, wind speed, evaporation, precipitation and relative humidity are covered in the data set. Monthly and yearly data are extracted from measurements of three meteorological stations within a date range from 2000 to 2024 (Table 1). The field-measured data are the main input for statistical and spatial analyses. ECMWF [22] first-in data are combined to mitigate for possible gaps in spatial and temporal coverage as well as in order to allow for regional comparisons on a wider range. Analyses of ECMWF gridded NetCDF formatted data are also carried out with specialized software (Microsoft Excel and SigmaPlot [23]) and made possible the generation and visualization of long-term climatic trends.

Table 1 Latitude and longitude of study area.

Station	Latitude (°N)	Longitude (°E)
Baghdad	33.31	44.36
Badra	32.98	45.98
Tuz Khurmatu	34.89	44.63

3. METHODOLOGY

To explore long-term trends in the climate time series, ranging from temporal to spatial dimension, Microsoft Excel is employed because of it being user-friendly and easy to apply for complex statistical computations. The package provides many options for statistical analyses and visualization that makes time series construction, analysis, and its detoxed asymmetrical, including temperature, precipitation, and other climate-related variables [24]. To explore long-term trends in climate time series, ranging from temporal to spatial dimensions, Microsoft Excel is used because it is easy to use and easy to apply for complex statistical calculations. The package provides numerous options for statistical analysis and visualization, making it easy to construct, analyze, and diagnose asymmetric time series, including temperature, precipitation, and other climate-related variables [25]. To illustrate the overall directional changes in climate variables over long periods, the linear model represented by simple linear regression is used as in Equation 1 [26,27]:

$$Y = aX + b \tag{1}$$

where Y the mean value of the climatic variable (e.g. temperature, rainfall), X time (in years), a the slope of the line, which represents the change in the variable each year, b: the constant (intercept) that is the value of y when X=0.

This regression model is also valuable in detecting increasing or decreasing trends of climate variables, which provides important information regarding the trends of climate change in the study region. Thanks to this, the fit and importance of the trends are assessed and the determination coefficient (R^2) is calculated and shown in each of the trend lines. Similarly, descriptive statistics like mean (AVERAGE) and standard deviation (STDEV) are also used to express the central tendency and the extent of variation in the data. For selected analyses, regression and analysis of variance (ANOVA) are performed with the Data Analysis Tool Pak in Excel [28, 29]. The strength and direction of linear relationships of climate variables like temperature and evaporation or precipitation and humidity are quantified through the Pearson Correlation Coefficient Eq2 [30]:

$$r = \frac{\sum(X_i - \bar{X}) - (Y_i - \bar{Y})}{\sqrt{\sum(X_i - \bar{X})^2} \cdot \sqrt{\sum(Y_i - \bar{Y})^2}} \tag{2}$$

where r Pearson correlation coefficient (-1 to +1), X_i, Y_i: values of the two variables, respectively, $\bar{X}$, $\bar{Y}$: are the averages of X and Y. Large positive r-values imply strong positive linear relationship and negative values imply inverse linear relationship. Values around zero indicate a weak or no linear association among variables [31].

4. RESULTS AND DISCUSSION

The temperature trends for the years of 2000 to 2023 from all 3 meteorological stations Baghdad, Badra, and Tuz Khurmatu are shown in (Figure 1) and they show an annual increasing trend. The observation of warming is most evident the warming is robust at the Tuz Khurmatu station as shown by the highest R2 and thus a strong temporal linkage to the rising temperatures. These results show that the impact of global warming and other climate changes in the area are increasingly being demonstrated. (Figure 2), on the other hand, demonstrates a decreasing trend in annual rainfall at Baghdad and Badra whereas the amount of rainfall at Tuz Khurmatu exhibited high difference from year to year during the period of study. Low values ofR^2 within the context of rainfall trends demonstrates a weak or irregular temporal association, indicating the presence of irregular seasonal changes or large-scale climatic cycles that affect the precipitation in such areas. This decrease in rainfall may imply a potential decrease in surface and groundwater availability in the future. A continuous upward trend is also noted in evaporation (Figure 3) at all stations from the study period. This increase concurs well with those of temperature trends, except for Tuz Khurmatu, which exhibited the fastest increasing rate. The increased evaporation evades to the increase loss of water from the warmer surface with respect to the cooler. and of a drier troposphere. These findings emphasize the need to adopt effective water-saving and protection measures. In addition to being evidence of an ongoing climatic change, the increase in temperatures across each region has unprecedented implications for public health, the frequency of extreme heat events, and an increased demand for cooling energy. Concomitant reductions in precipitation at Baghdad and Badra, together with erratic records at Tuz Khurmatu, imply growing stress on water resources, particularly in areas relying on rain-fed agriculture. This is a dangerous trend to agricultural sustainability and could culminate in Conceptual framework. The continued rise in evaporation is consistent with warmer temperatures and raises the rate of water being drawn off from human and natural storage areas such as reservoirs, soils and cultivated fields. These changes speed up drought and desertification in ecologically vulnerable and/or thinly vegetated areas. In conclusion, the interpretation of Figures 1, 2 and 3 reveals an alarming trend; rising temperatures and evaporation are accompanied by decreasing or erratic precipitation. This disequilibrium indicates a disturbance of the climatic normality and highlights the necessity of including climatic factors in the planning of the future water resources and in the agricultural sector.

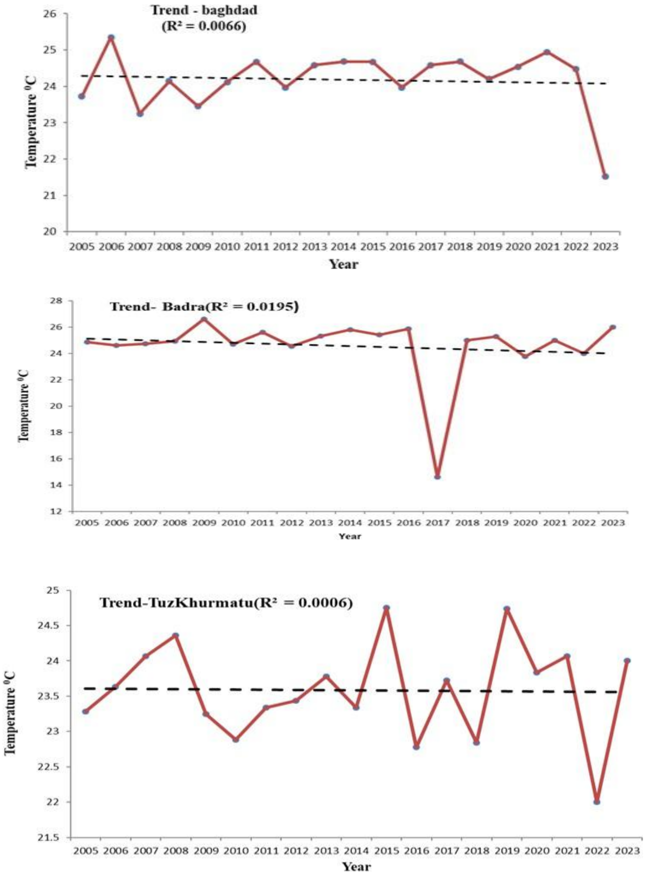

Figure 1 Annual trend of average temperature (°C) for the period 2000–2024.

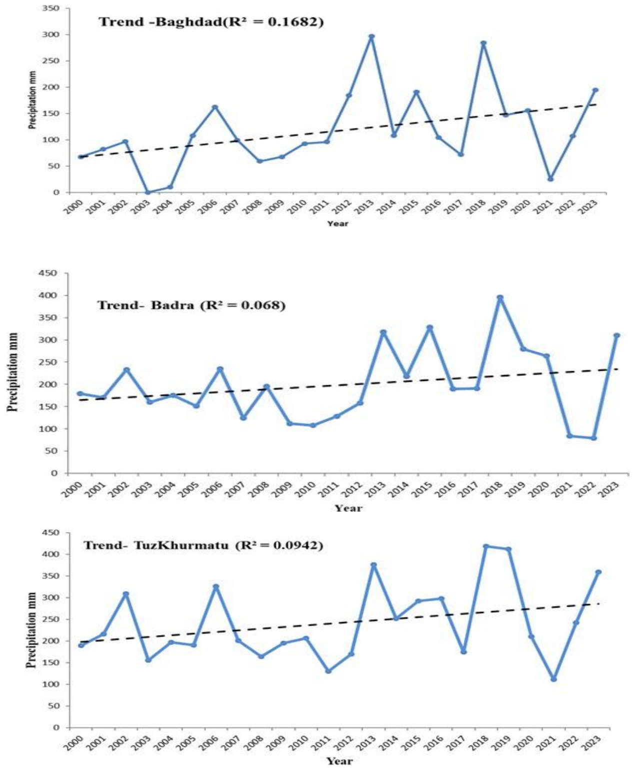

Figure 2 Annual trend of precipitation (mm) for the period 2000–2024.

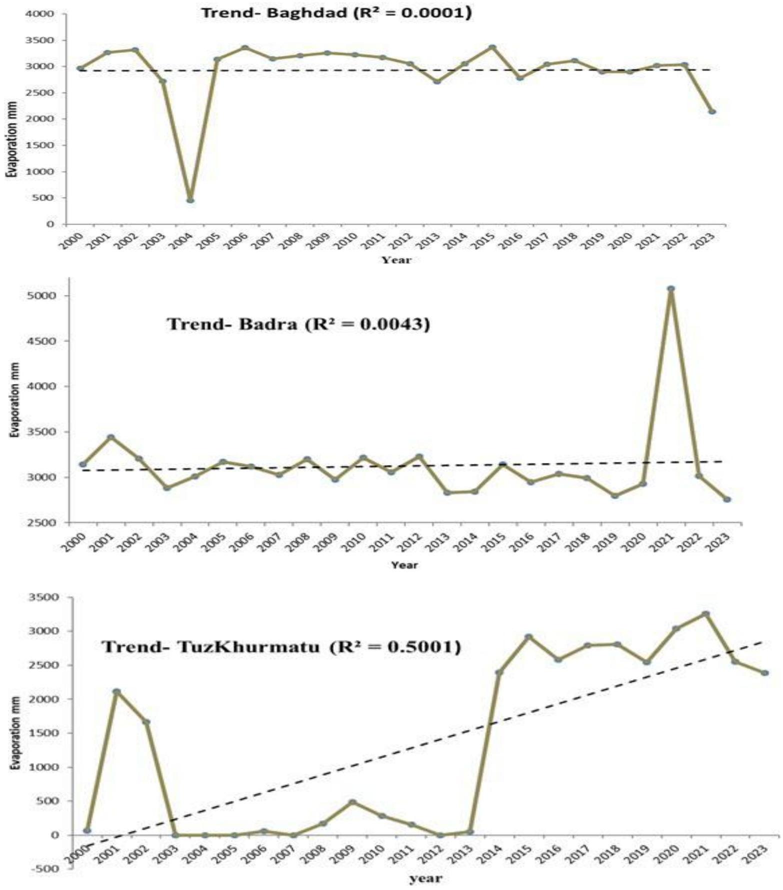

Figure 3 Annual trend of evaporation amounts (mm) for the period 2000–2024.

4.1. Climate trend analysis

Analysis of climatic trends is an essential tool for long-term trends assessment of climatic variables (e.g., temperature, precipitation and evaporation) which are related with the effects of climate change. The objective of this investigation is to detect if these variables are increasing, decreasing or oscillating over time for the purpose of evaluating the extent of climate change effects and planning suitable adaptation tactics. The summary statistics of maximum, minimum, and mean temperatures from Baghdad station (table 2) showed an upward pattern in annual temperatures, indicating a direct category 1 impact on climate change. Precipitation rates declined, while evaporation rates increased, indicating increased loss of surface water and a threat to water security in the urban precinct. There is a marked rise in temperature at Badra station indicating the ongoing drought conditions and decrease in rainfall are not beneficial. The rate of evaporation has also risen substantially, which could further contribute to the risks of drought and land degradation to the area. The maximum trend of temperature growth is recorded at Tuz Khurmatu station (the rate of temperature increased in the most rapid way in all three stations). With visible variations in the rate of precipitation rather than one constant slow-down -a sign of a more changeable climate. The greatest rates of evaporation are also registered, posing even further challenges to maintain the availability of water sources to be used in the agricultural sector. Taken together, these trends have highlighted the increasing severity of climate change in Iraq and underscore the significance of developing robust adaptation measures, in category of water resource management, agriculture, and urban settings to deal with upcoming heatwaves and droughts [31].

Table 2 General trend analysis of Baghdad, Badra, and Tuz Khurmatu governorates for the period (2000-2024).

Variable	Baghdad	Badra	Tuz Khurmatu
Temperature	Increasing trend (significant rise in annual temperatures)	Increasing trend (consistent rise in temperature)	Highest rate of increase in temperature among the three regions
Precipitation	Decreasing trend (declining rainfall levels)	Decreasing trend (consistent decline in rainfall)	Fluctuating trends (irregular rainfall, not consistent decline)
Evaporation	Increasing trend (linked to rising temperatures)	Increasing trend (significant rise in evaporation rates)	Highest increase in evaporation rates (linked to high temperatures)
R^2 (Correlation)	High R^2, indicating a strong relationship between time and temperature	Moderate R^2, indicating a visible but weaker trend	High R^2, particularly with temperature and evaporation
Impact	Increased water loss due to evaporation, potential water scarcity	Increased water stress, risk of drought, soil degradation	High evaporation and irregular rainfall threaten agricultural water supply

Figure (4-a): Displayed are the monthly precipitation distribution for Baghdad, Tuz and for Badra showing a seasonal variation. Rainfall starts to increase with the start of the winter, and it peaks in January and February - especially in Tuz and Badra - because of the Mediterranean low pressure and its associate's systems. During spring rains amounts decrease, Tuz remaining as region with the highest rainfall, followed by Badra. On the other hand, Baghdad repeatedly gets lesser rain - probably because of its lower altitude and being away from significant geophysical sites. In all three, the summer (June to August) sees negligible amounts of precipitation Figure 4-b shows the monthly mean evaporation rate (mm) for Baghdad, Tuz and Badra that indicates variation in the evaporation by season throughout the year [32]. There's a general tendency in those curves, with evaporation increasing slowly from Ja-nuary to peak in July and then decreasing slowly to reach it's minimum in December. This pattern is greatly determined by the climatic conditions associated with temperature and insolation in the region. Winter (January–March) is characterized by cooler temperatures and endizes with reduced solar radiation, resulting in relatively low amounts of evaporation, their value is between 50 and 150 mm per month for all the cities. When springtime comes (April-June), temperature starts to rise, and the sun becomes more powerful that makes evaporation increase obviously. In June, evaporation exceeds 300 mm and is nearly 450 mm in Baghdad and around 500 mm in Badra. In the summer months of July and August, the cities have a maximum rate of evaporation, with Baghdad having the maximal rate of evaporation from open water surface at greater than 500 mm in July and located in a hot dry continental climate region [33]. Tuz, on the contrary, has a minimum level of evaporation that may be reflected by its specific geographic location and local climates. With the onset of autumn there is a gradual reduction in temperature, resulting in a fall in that decrease to winter less than 100 mm by December for all cities [34]. The linkage of evaporation with climatic factors such as temperature and solar radiation and the climatic variation between cities (due to geographical differences in the elevation and other local climatic effects) can be easily seen in the graph [35]. Finally, despite its simplicity, this is a graph that conveys interesting scientific information about seasonal influences the weather has on the rate of evaporation that can be convenient in some disciplines, such as agriculture, management water resources, and city planning in arid and semi-arid settings [36]. Figure (4-c) shows the average monthly temperatures in three Iraqi cities, reflecting the seasonal climate pattern throughout the year. In winter, temperatures are relatively low, ranging from 10 to 15°C in January and February [37]. As spring begins, temperatures gradually rise, surpassing 25°C in May. Temperatures peak in July and August, reaching between 37°C and 40°C in all 3 cities, reflecting the hot summer climate in these arid or semi-arid regions [38]. Badra is the hottest city during this period, possibly due to geographical factors like elevation or topography Then temperatures gradually start to decrease by the end of summer, calling back autumn, and drop below 30°C in September and October and return to the 12–17°C range which is the mild and enjoyable winter weather of November and December [39]. This seasonal temperature variation indicates the influence of the seasonal variations of solar radiation on these two city climates and demonstrates the similarity, generally speaking, of the thermal patterns of the cities, albeit with regional exceptions [40-43].

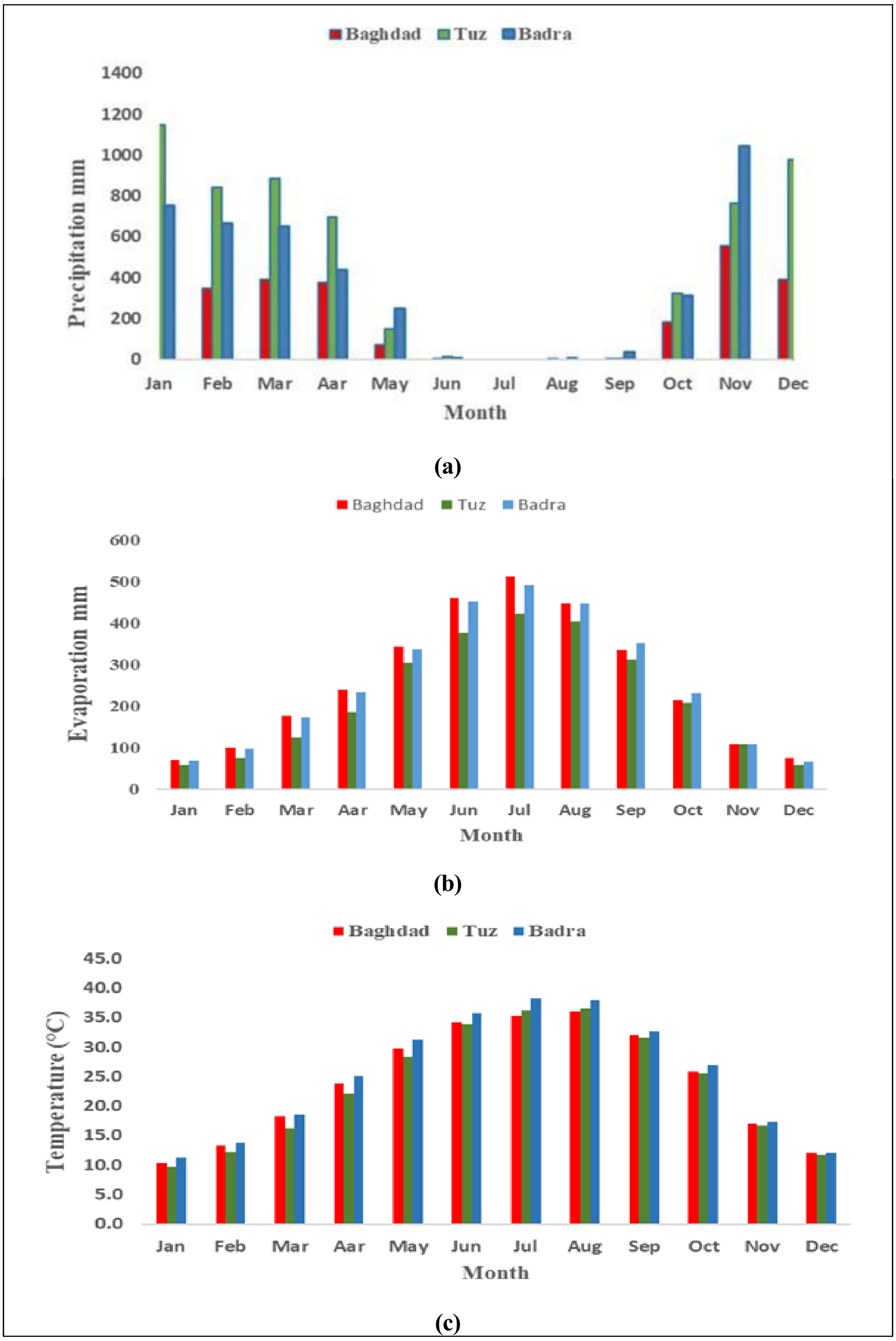

Figure 4 The Monthly Average a) Precipitation, b) Evaporation and c) Temperature in Baghdad, Tuz, and Badra.

5. CONCLUSIONS

The study showed significant increase in temperature of all the stations studied that may be attributed to climate change and general warming effect. On the other, there is a decline or variability in rainfall, particularly in the two selected stations (Baghdad and Badra), which may adversely impact the renewable water source in the area. Moreover, the rates of evaporation exceeded a considerable increase, especially in Tuz Khurmatu, by increasing the loss of water, thus, increasing the difficulty of the current climatic variability. The association between climatic elements and time was more significant for temperature and evaporation than for the rain, and this indicates that time has a greater effect on temperature and evaporation, reflected in the high R^2 values that were obtained, which makes the dependence we identify on time even stronger. This confirms that the area is experiencing a trend toward drier and warmer conditions and puts the necessity of implementing an adaptation strategy into perspective to address these future challenges. The trend analysis figures revealed a seasonal pattern for the rainfall and temperature distribution in Baghdad, Tuz and Badra, which is significantly related to geographic nature and elevation. For example, Tuz and Badra get more rain than Baghdad are drier than Basra because of their proximity to the Zagros Mountains, which enhance orographic and in which the additional rainfall is discharged. Baghdad on the other hand does receive less rainfall as the city lies in subtropical desert climatic region due to the topographical distribution of the area and lacks proximity to bodies of water. With respect to evaporation, the trends of this phenomenon are growing gradually with the rise of temperature during spring, and they peak during the summer mainly in the case of Baghdad that features a hot and dry atmosphere. In the meantime, Tuz and Badra have smaller evaporation rates for their local climate.

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