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Air temperature trends in Baghdad, Iraq for the period 1941-2000

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Abstract- Climate change is considered one of the major world concerns of present times. Air temperature is the most effective meteorological element for detecting climate change. The aim of this research is to investigate trends of temperature in the period 1941-2000 for Baghdad, Iraq. The trends in temperature including minimum, maximum, and mean monthly means were analyzed using the linear regression method. Data were also subjected to 11-year running mean to detect trends. The nonparametric statistics of Man-Kendall was applied to determine the significance of trends. Results showed that there was a warming period during the 1950's to mid-1960's and a cooling period during the period from mid-1960's to 1980's particularly during winter and summer seasons. It was also found that there was a strong tendency for a temperature increasing in the late 1990's during the summer season. Mann–Kendall rank statistics indicated that the mean temperature was significantly increased during the months of April and July and decreased during November.

Index Terms- Climate change; air temperature; Baghdad; Measurements; Man-Kendall test.

I. Introduction

An increasing body of observations and analysis gives a collective picture of a warming world and other changes in the climate system. The global average surface temperature has increased over the 20th century by about 0.6 C. Climate change is threatening the food production, drinking water supplies and sustainable development throughout the world. Rising sea level, extreme weather events and desertification is just a few of the effects, especially threatening the millions of people living in less developed countries. Intergovernmental Panel on Climate Change report (IPCC 2001) [1] expresses that global warming mainly caused by human activities is a reality and there are growing fears of feedbacks that will accelerate this warming. Climate change may have strong implications for political, economic, and social policy [2]. Because climate change affects such a wide variety of disciplines and people, pursuing research in this field can generate important results that should be taken into account in strategic plans and policies [3].

Climate change research has been conducted in many parts of the world including the middle East. Several studies have reported that the Middle East region may face more aridity due to temperature increase and rainfall decrease. Nasrallah and Balling (1995) [4] found a statistically significant temperature increase of 0.07°C/decade over Kuwait during the period of 1950-1990.

In Jordan, located on the northern part of the Arabian Peninsula, Smadi (2006) [5] performed a study to trace changes in annual and seasonal temperature during the 20th century. His results showed a warming trend starting from the years 1957 and 1967 for the minimum and maximum temperatures respectively. Bou-Zeid and El-Fadel (2002) [6] conducted a wide study covering the whole Middle East region. They found that water balance would be highly affected by the increasing temperature trend at a rate of 0.6-2.1°C. Ghahraman (2006) [7] evaluated the long-term trend of mean annual temperature at 34 synoptic stations in Iran with a minimum record of 30 years by the Student's t test. He concluded that there was a positive trend in 50% of the stations, while 41% of the stations had a negative trend. In addition, the behavior of trend direction was different for different climates and no specific pattern was found.. Al-Zawad (2008) [8] studied the impacts of climate change on water resources in KSA using the climate model "PRECIS". The results of this model were fairly correlated to the historic climatic data of the region. He concluded that the temperature, the evaporation and the wind speed have showed an increasing trend on all regions of the country. Tecer and Crite (2009) [9] analyzed the mean, maximum, and minimum temperatures of the city Rize in Turkey to reveal trends, change points, significant warming (cooling) periods. Theyfound that maximum temperatures have dramatically increased with 1.61°C over the last 33 years while annual minimum temperatures have increased by 0.99°C over the same period. Recently, Elnser et al. (2010) [10] have analyzed the temperature trends and distribution in the Arabian Peninsula. They concluded that concluded that KSA as well as the Arabian Peninsula are suffering from a considerable warming temperature trend. Tabari and Talaee (2011) [11] investigated the trends of the annual, seasonal and monthly maximum and minimum air temperatures time series were investigated for 20 stations in the western half of Iran during 1966–2005.Their results indicated that a positive trend was found in in 85% of the stations and there was a negative trend in 15% of the stations in the study region.

II. Materials and Method

Baghdad is the capital of Iraq and its located in the central region of the country. Its geographical coordinates are 333^{o} N and 44.4^{o} E. Winds reaching the city are generally dry and because of the aridity and the relatively cloudless skies, there are large variations in daily temperature as well as between seasons and regions. Monthly means of minimum, maximum, and mean temperature data for Baghdad were obtained from the Iraqi

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Meteorological Office for the period of 1941-2000. Time series analysis methods were used to detect any trends in the parameters under study. The data were subjected to the 11-year running mean to detect trends. A linear trend line was used to the series to simplify the trend. The nonparametric statistics known as Man-Kendall [12] [13] was used. The Mann-Kendall test is a non-parametric test used for identifying trends in a time series data. The test compares the relative magnitudes of sample data rather than the data values themselves. The test statistic S, which has mean zero and a variance computed by Eq. 3, is calculated using Eqs. 1 and 2, and is asymptotically normal:

$$S = \sum_{k=1}^{k=n-1} \sum_{j=k+1}^{j=n} sign(x_j - x_k)$$

where x_1, x_2, ……, x_n represent n data points, x_j represents the data point at time *j*, and

$$sign(x_j - x_k) = \begin{cases} 1 & if\ (x_j - x_k) > 0 \\ 0 & if (x_j - x_k) = 0 \\ -1 & if\ (x_j - x_k) < 0 \end{cases}$$

A very high positive value of S is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend. However, it is necessary to compute the probability associated with S and the sample size, n, to statistically quantify the significance of the trend.

The variance of S, VAR(S), is calculated by the following equation:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5)\right]$$

where n is the number of data points, g is the number of tied groups (a tied group is a set of sample data having the same value), and *t* is the number of data points in the *p*th group.

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The normalized test statistic Z is computed as follows:

$$Z = \begin{cases} \frac{S-1}{[VAR(S)]^{1/2}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{[VAR(S)]^{1/2}} & if\ S < 0 \end{cases}$$

The probability density function for a normal distribution with a mean of 0 and a standard deviation of 1 is given by the following equation:

$$f(Z) = \frac{1}{\sqrt{2\pi}} e^{-Z^2/2}$$

III. RESULTS AND DISCUSSION

Table 1 shows the mean minimum T_{min}, mean maximum T_{max}, and mean temperature
along with their standard deviation (SD) and coefficient variation for each month and for the four seasons, winter, spring, summer, and autumn. These values were computed from the original data. December, January, and February are considered to represent the winter season since these months are characterized by lowest maximum temperature. June, July, and August are characterized by highest maximum temperature and therefore they are considered to represent the summer season. spring and autumn are respectively represented by three months of March, April, May and September, October, November.
Figures 1 to 4 show the trends of $_{Tmean}$, T_{min}, andT_{max} in Baghdad for the winter, spring, summer, autumn It seen from these results that the winter season shows a slight decreasing trends for T_{min}, T_{max}, and T_{mean}. All the three trends for the spring season are increasing. For summer season, T_{min} trend is slightly decreasing while T_{max} trend is notably increasing resulting an increase in the T_{mean} trend. Autumn season is characterized by a decreasing trends in T_{min} and T_{max} and consequently in T_{mean} . Figure 5 shows the trends for the annual temperature. It is clear that T_{min} trend tends to decrease while T_{max} trend is increasing resulting in almost a constant trend for T_{mean}.
The 11-year average means show that there was a warming period during the 1950's to mid-1960's and a cooling period during the period from mid-1960's to 1980's particularly during
winter and summer seasons and to less extent during spring and autumn seasons. The average means also illustrate that there was a strong tendency for a temperature increasing in the late 1990's during the summer season. Table 2 summarizes the linear equations for seasonal temperature.
Table 3 presents the results of Mann–Kendall rank statistics for monthly and seasonal trends.

These results indicate that T_{min} significantly increases during July and decreases during the of November. The T_{max} significantly increases during the months of April and July. The T_{mean} significantly increases during the months of April and July and decreases during November. The results also show that there is a significant increase in T_{max} and T_{mean} during the spring season and a significant decrease in all three temperatures during the autumn season.

Table 1: Monthly and seasonal temperature means

Month	T_{min}	T_{max}	T_{mean}
January	4.09	15.71	9.90
February	5.58	18.64	12.11
March	9.39	22.79	16.09
April	14.75	29.29	22.02
May	19.88	36.10	27.99
June	23.15	41.06	32.10
July	25.20	43.63	34.42
August	24.24	43.36	33.80
September	20.55	39.97	30.26
October	15.87	33.23	24.55
November	9.83	24.20	17.01
December	5.19	17.31	11.25
Winter	4.95	17.22	11.09
Spring	14.67	29.39	22.03

Summer	24.20	42.68	33.44
Autumn	15.42	32.47	23.94
Annual	14.81	30.44	22.62

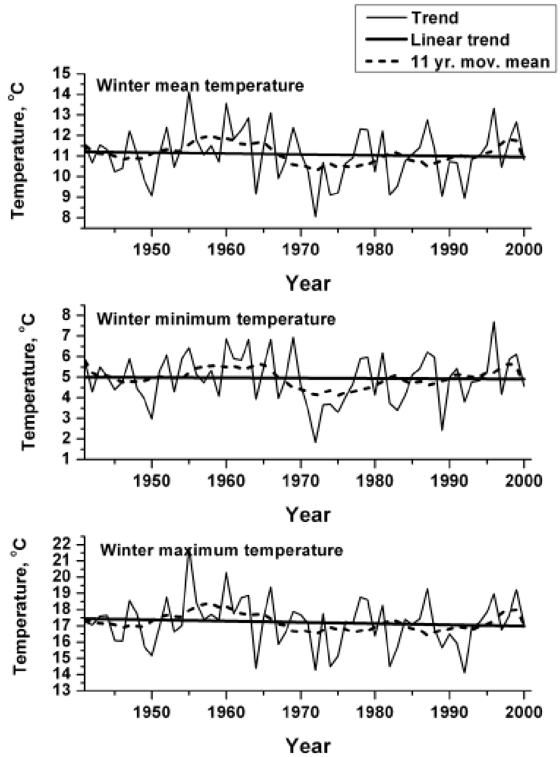

Figure 1. Winter temperature trend at Baghdad

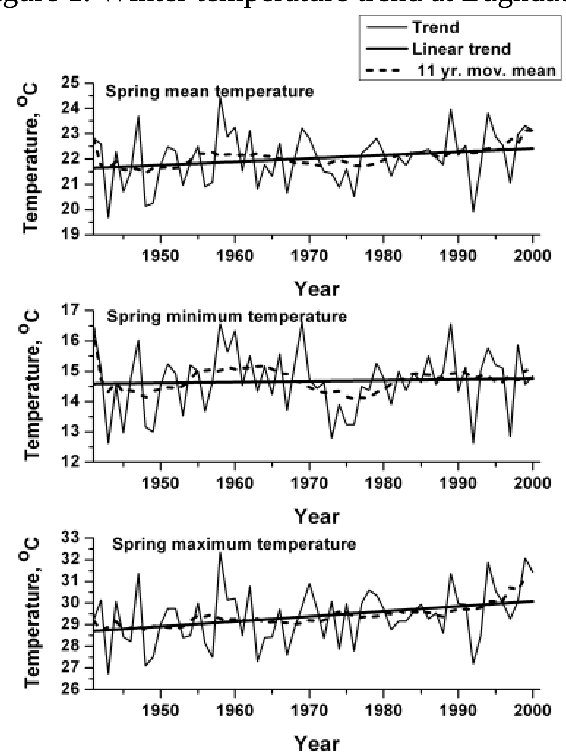

Figure 2. Spring temperature trend at Baghdad

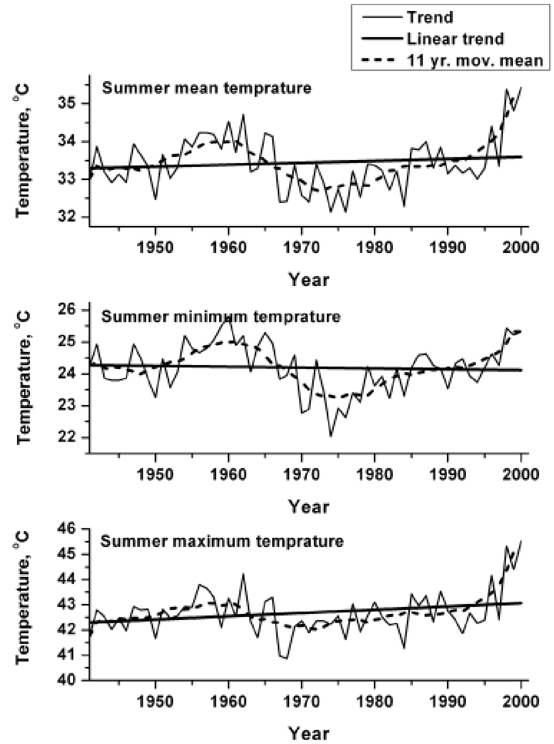

Figure 3. Summer temperature trend at Baghdad

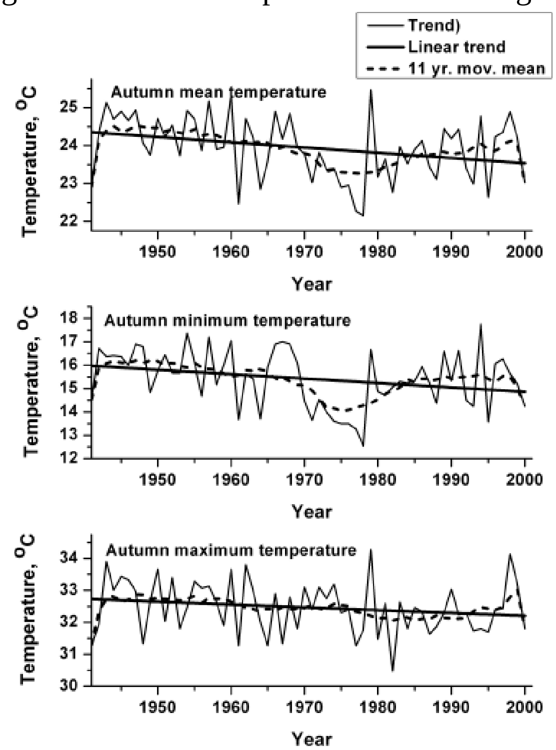

Figure 4. Autumn temperature trend at Baghdad

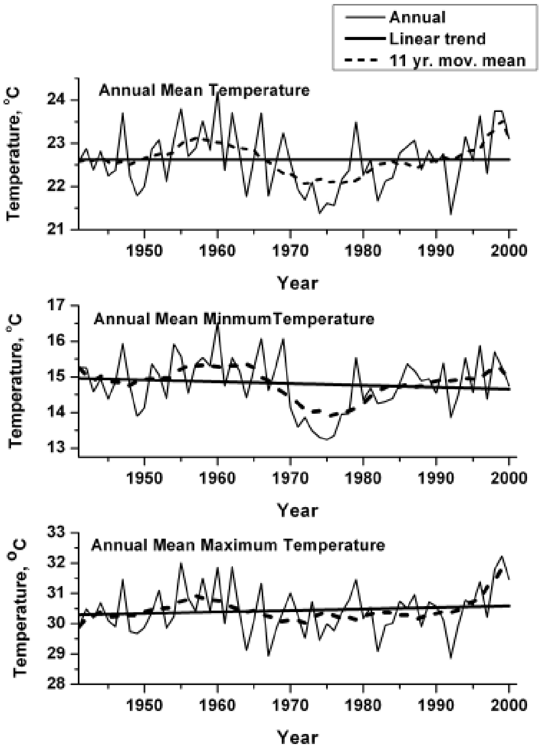

Figure 5. Annual temperature trend at Baghdad

Table 2. Linear equations for seasonal temperatures

Season	Temperature	Linear Equation
Winter	T_{mean}	$y = 19.948 - 0.00450x$
	T_{min}	$y = 7.790 - 0.00144x$
	T_{max}	$y = 32.104 - 0.00755x$
Spring	T_{mean}	$y = -3.755 + 0.01309x$
	T_{min}	$y = 9.020 + 0.00287x$
	T_{max}	$y = -16.530 + 0.02330x$
Summer	T_{mean}	$y = 23.431 + 0.00508x$
	T_{min}	$y = 29.580 - 0.00273x$
	T_{max}	$y = 17.282 + 0.01289x$
Autumn	T_{mean}	$y = 51.282 - 0.01388x$
	T_{min}	$y = 52.688 - 0.01891x$
	T_{max}	$y = 49.877 - 0.00884x$
Annual	T_{mean}	$y = 22.725 - 0.00005x$
	T_{min}	$y = 24.769 + 0.00505x$
	T_{max}	$y = 20.682 + 0.00495x$

Table 3. Results of Mann-Kendall rank statistics

Month	T_{min}	T_{max}	T_{mean}
January	0.002	-0.037	-0.018
February	-0.042	-0.047	-0.052
March	-0.051	0.099	0.041
April	0.140	0.228*	0.193*
May	-0.010	0.147	0.073
June	-0.091	0.096	0.002
July	0.151*	0.182*	0.169*
August	-0.110	0.025	-0.027
September	-0.130	0.031	-0.098
October	-0.128	-0.090	-0.131
November	-0.170*	-0.124	-0.180*
December	0.067	-0.027	0.020
Winter	-0.006	-0.037	-0.033
Spring	0.049	0.209*	0.165*
Summer	-0.006	0.111	0.052
Autumn	-0.204*	-0.167*	-0.197*
Annual	-0.054	0.099	0.006

* significant at 0.05 level

4. Conclusion

In this study, the trends of the monthly, seasonal and annual T_{min}, T_{max}, and T_{mean} time series were examined for 20 Baghdad, Iraq for the period 1941–2000. The most important aspects of the results are the significant increase in T_{max} and T_{mean} during the spring season and a significant decrease in all three temperatures during the autumn season. It was also notable that there was a warming period during the 1950's to mid-1960's and a cooling period during the period from mid-1960's to 1980's particularly during winter and summer seasons. Further analyses for a longer period of time is needed to see if this cyclic behavior of temperature cooling and warming exists for such period.

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