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Mann–Kendall trend analysis of surface air temperatures and rainfall in Iraq

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Abstract—In this study, trends of the seasonal and annual maximum (T_{max}), minimum (T_{min}), and mean (T) air temperatures, as well as rainfall amounts (R_a) time series were investigated for eleven stations in Iraq for the period 1972–2011 (40 years). Four statistical tests including homogeneity, Mann–Kendall (MK), Sen's slope estimator and linear regression were used for the analysis. The results revealed that annual mean of T_{max}, T_{min}, and T time series showed statistically significant increasing trends over 81.8, 100, and 100% of the stations at the 0.001 level and they experienced an increase of 0.50, 0.67, and 0.58 °C/decade, respectively; while the annual rainfall has shown decreasing trends at 90.9% of the stations and it experienced a decrease of –20.50 mm/decade. Seasonally, the highest increase of T_{max}, T_{min}, and T values have been found over the extreme south of the country during summer at the rates of 1.47, 1.06, and 1.16 °C/decade, respectively, while the highest decrease of R_a values has been found in the northern part of the country during winter at the rate of –36.35 mm/decade.

Key-words: climate change, air temperature, rainfall, Mann-Kendall test, trends, Iraq

1. Introduction

The detection and attribution of global climate change resulting from anthropogenic activities are one of the main themes of current climatological research. Several studies of long-term time series of temperatures have been done on global scale (*Jones,* 1994; *Nicholls et al.,* 1996; *Watson et al*., 1998; Jones *et al.*,1999; *Folland et al.,* 2001; *Eichner et al.,* 2003; *Rybski et al*., 2006; *Efstathiou et al.,* 2011; *Varotsos et al.*, 2013) and regional scale (*Marco et al.,* 2003; *Arora et al.,* 2005; *Smadi*, 2006; *Chen et al.*, 2007; *Rebetez* and *Reinhard*, 2008; *Busuioc et al*., 2010; *Tabari* and *Talaee*, 2011a; *Stephenson, et al*., 2014). The main finding of the results have shown that the Earth's surface air temperature has increased by 0.6 °C – 0.8 °C during the 20th century. The increasing of the air temperature proved to be nonlinear and non-homogenous at global scale (*Croitoru et al*., 2012). Associated with global warming, there are strong indications that rainfall changes are already taking place on both global (*Diaz et al*., 1989; *Hulme et al*., 1998; *Lambert et al*., 2003; *Dore*, 2005) and regional scales (*Yu* and *Neil*, 1993*; Gemmer et al*., 2004; *Smadi* and *Zghoul*, 2006; *Kayano* and *Sansıgolo,* 2008; *Busuioc et al*., 2010; *Tannecia et al.*, 2014). There have not been any internationally published works on surface air temperature and rainfall changes over the past century in Iraq. The detailed analysis and understanding of trends of climate events in Iraq are important to reduce the climate-induced dryness and the impact of temperature extremes on society, agriculture and environment. Therefore, this study was carried out for analysing the seasonal and annual trends in mean maximum, minimum, and mean air temperatures, as well as rainfall amounts. The Mann-Kendall test, the Sen's slope estimator, and the linear regression in Iraq from 1972 to 2011 were used.

2. Study area and data

Iraq is located in southwest Asia between latitudes 29°5′ – 37°22′ N and longitudes 38°45′ – 48°45′ E. The surface of Iraq is 438,317 km^2 (*Fig. 1*). Topographically, Iraq is shaped like a basin, consisting of the Great Mesopotamian alluvial plain of the Tigris and Euphrates rivers. This plain is surrounded by mountains in the north and east, which can reach altitudes of 3611 m above sea level, and by desert areas in the south and west, which account for over 40 percent of the land area. Iraq is characterized by four distinct topographic features:

a. Mesopotamian plain. This alluvial plain occupies a quarter of the area of Iraq.

b. Desert plateau. This area is located in the west of Iraq and occupies about less than half of Iraq.

c. Mountainous region. This region is located in the northern and north-eastern part of Iraq.

d. Hilly region. This is a transition zone between the low-lying Mesopotamian plain in the south and the high mountains in the far north and north-eastern part of Iraq.

Diverse topography of Iraq plays an essential role in its climate. Being situated in the north part of the subtropical region, Iraq is characterized by relatively low winter temperature, dry and hot summer, and two short transitorial seasons (spring and autumn). It seems that the differences in temperature have great impacts on Iraq's extreme climate. Iraq lies within the northern temperate zone, but the climate is continental and subtropical. Winters are usually cool to cold, with an average daily temperature that might reach 16 °C dropping at night to 2 °C. Summers are dry and hot to extremely hot, with a temperature of over 43 °C during July and August, yet dropping at night to 26 °C (*Al-Ansari et al.,* 2013). The rainfall in Iraq is tracking the climate of the Mediterranean Sea. Most amount of rainfall falls during the seasons of winter, spring, and autumn, while summer is rainless. Average annual rainfall is 154 mm, and it ranges from less than 100 mm over 60% of the country in the south up to 1200 mm in the north-east (*Al-Ansari et al.,* 2013; *Al-Ansari* and *Knutsson*, 2011).

Climatic data were available over the 40-year period from 1972 until 2011 at eleven stations. The monthly mean daily values of measured mean minimum air temperature, T_{min} (^{o}C), mean maximum air temperature, T_{max} (^{o}C), mean air temperature T (^{o}C), and total rainfall amount R_a (mm) at the eleven selected stations have been taken from the Iraq Meteorological Authority (IMA). The stations have been chosen based on data availability and to cover the whole area of Iraq. Site of each station has remained the same, with almost negligible change since the beginning of the data records. The selected stations and their geographical coordinates as well as the observation periods of temperature and rainfall are given in *Table 1* and *Fig. 1*. Three statistical techniques were used in this research: a homogeneity test, the widely used non-parametric Mann–Kendall test, and Sen's slope estimator. The homogeneity test of the data series was carried out by applying the Abbe-test (*Schoenwiese*, 1992; *Schaefer*, 1996). All data series were shown to be homogeneous at all stations. To estimate the slope of an existing trend, the Sen's nonparametric method (*Sen*, 1968) was also used. Whether or not a constant increasing or decreasing trend was occurring, the MK (*Kendall*, 1938, *Mann*, 1945, *Kendall*, 1975; *Zhang et al.*, 2001) test for trend was also applied. In this test, the significance levels are 0.001, 0.01, 0.05, and 0.1 (*Salmi et al.*, 2002, *Luo et al.*, 2008), from very high significance to non-significance. SPSS and Excel programs were used to analyze temporal and spatial temperature and rainfall changes. The Excel template MAKESENS (*Salmi et al.*, 2002) was also used to detect trends by the MK test.

Table 1. List of the eleven meteorological stations in Iraq, their geographical coordinates, as well as the observation periods of the air temperature and rainfall at each station.

Stations	**Latitude (N)**	**Longitude (E)**	**Elevation (m) above M.S.L**	**Observation period for air temperatures and rainfall**
Mosul	36° 19′	43° 07′	223	1972–2011
Sulaymaniya	35° 32′	45° 26′	884.8	1972–2011
Kirkuk	35° 28′	44° 23′	330.8	1972–2011
Khanaqin	34° 16′	45° 17′	202	1972–2011
Baghdad	33° 19′	44° 25′	31.7	1972–2011
Rutba	33° 02′	40° 17′	630.8	1972–2011
Al-Hai	32° 01′	46° 02′	17	1972–2011
Diwaniya	31° 59′	44° 59′	20	1972–2011
Samawa	31° 19′	45° 17′	6	1972–2011
Nasiriya	31° 03′	46° 14′	5	1972–2011
Basra	30° 30′	47° 50′	2.4	1972–2011

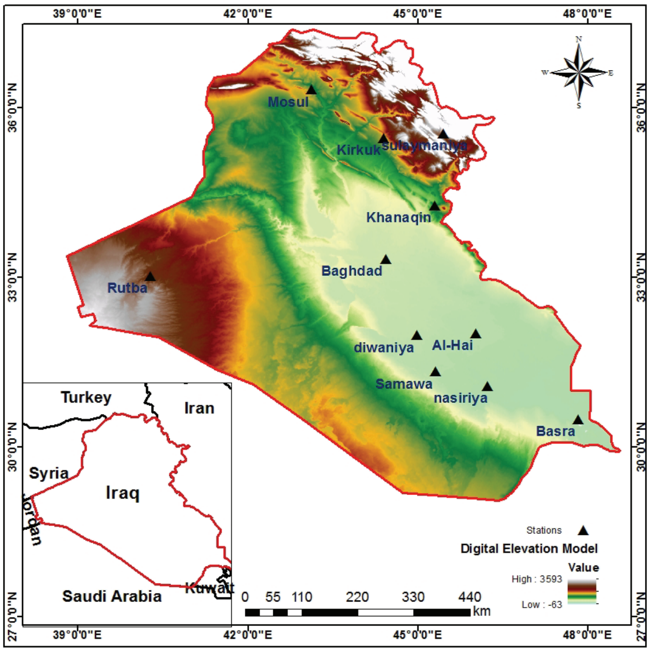


Fig. 1. Map of Iraq including the eleven selected stations.

3. Results and discussion

3.1. Trends of mean maximum temperature

Fig. 2 illustrates the annual anomalies of mean maximum temperature (T_{max}, °C) at the eleven selected stations in Iraq. Statistical properties of the seasonal and annual T_{max} series were tested and presented in *Table 2*. In winter, it can be clearly seen that 63.6, 27.3, and 9.1% of stations have experienced significant positive trend at the 0.01, 0.05, and 0.1 levels, respectively. According to the MK test. The trends range from 0.42 °C/decade at Basra in the south (significant at the 0.05 level) to 0.75 °C/decade at Sulaymaniya in the north (significant at the 0.01 level) (*Figs. 2.* and *6* and *Table 2*).

In spring, significant positive trends are observed for all stations (except Samawa, which has non-significant trend). It was found that 45.4, 27.3, and 18.2% of the stations have experienced significant positive trend at the 0.001, 0.01, and 0.1 levels, respectively, while the trends are not significant at only 9.1% of the stations. Trends ranged between 0.20 °C/decade at Samawa and 0.86 °C/decade at Khanaqin; the trend for Khanaqin is significant at the 0.001 level, while it is not significant for Samawa. During summer, all stations showed strong evidence of significant positive trend (except Kirkuk station which has non-significant trend). It can be seen that 45.4 and 45.5% of the stations have experienced significant positive trend at the 0.001 and 0.01 levels respectively, while the trends are not significant at only 9.1% of the stations. The trends range from 0.15 °C/decade (non-significant trend) at Kirkuk to 1.47 °C/decade (significant at the 0.001 level) at Basra (*Figs. 2* and *6* and *Table 2*).

On the contrary, negative and non-significant positive trend patterns dominated during autumn (*Table 2*). It can be seen that 9.1 and 9.1% of the stations have experienced significant positive trend at the 0.01 and 0.1 levels, respectively, while the trends are not significant at 72.7% of the stations. The trends range from –0.02 °C/decade at Diwaniya (non-significant trend) to 0.5 °C/decade at Basra (significant at the 0.05 level). From the beginning of 1972 until 1995, a cooling pattern was found at all stations, while subsequently warming pattern was identified until the end of the study period, and the change is statistically significant. The annual and seasonal trend analyses reveal that most warming in reference to T_{max} was observed in both winter (0.56 °C/decade) and spring (0.55 °C/decade), while the average trend over the whole country of Iraq was found to be 0.50 °C/decade. Annually, it was found that 81.8, 9.1, and 9.1% of the stations have experienced significant positive trend at the 0.001, 0.01 and 0.05 levels, respectively (*Figs. 2* and *6* and *Table 2*).

Table 2. Trends of maximum (T_{max}), minimum (T_{min}) and mean (T) temperatures (^{o}C/decade), by Mann-Kendall Sen's test

Station	Element	Winter	Spring	Summer	Autumn	Annual
Mosul	T_{max}	0.53^{**}	0.43^{+}	0.33^{**}	0.25^{-}	0.36^{***}
	T_{min}	0.13^{-}	0.29^{+}	0.45^{***}	0.53^{**}	0.37^{***}
	T	0.30^{+}	0.39^{*}	0.38^{***}	0.47^{*}	0.36^{***}
Sulaymaniya	T_{max}	0.75^{**}	0.50^{**}	0.40^{**}	0.18^{-}	0.59^{***}
	T_{min}	0.75^{***}	0.59^{***}	0.64^{***}	0.41^{*}	0.62^{***}
	T	0.71^{***}	0.58^{**}	0.58^{***}	0.36^{*}	0.61^{***}
Kirkuk	T_{max}	0.48^{*}	0.42^{+}	0.15^{-}	0.01^{-}	0.26^{*}
	T_{min}	0.39^{**}	0.55^{***}	0.80^{***}	0.28^{-}	0.56^{***}
	T	0.44^{**}	0.51^{**}	0.56^{***}	0.17^{-}	0.43^{***}
Khanaqin	T_{max}	0.61^{**}	0.86^{***}	0.65^{***}	0.20^{-}	0.68^{***}
	T_{min}	0.39^{*}	0.91^{***}	1.04^{***}	0.83^{***}	0.81^{***}
	T	0.62^{**}	0.88^{***}	0.85^{***}	0.56^{***}	0.74^{***}
Baghdad	T_{max}	0.69^{**}	0.42^{**}	0.36^{**}	0.16^{-}	0.45^{***}
	T_{min}	0.57^{***}	0.78^{***}	1.06^{***}	0.72^{**}	0.79^{***}
	T	0.55^{**}	0.64^{***}	0.74^{***}	0.46^{**}	0.64^{***}
Rutba	T_{max}	0.49^{*}	0.41^{**}	0.48^{***}	0.18^{-}	0.44^{***}
	T_{min}	0.48^{**}	0.79^{***}	0.92^{***}	0.82^{***}	0.77^{***}
	T	0.51^{**}	0.66^{***}	0.69^{***}	0.57^{**}	0.58^{***}
Al - Hai	T_{max}	0.65^{**}	0.68^{***}	0.53^{***}	0.22^{-}	0.55^{***}
	T_{min}	0.67^{***}	1.03^{***}	0.97^{***}	0.65^{***}	0.86^{***}
	T	0.65^{***}	0.95^{***}	0.71^{***}	0.47^{**}	0.73^{***}
Diwaniya	T_{max}	0.57^{**}	0.50^{***}	0.35^{**}	-0.02^{-}	0.41^{***}
	T_{min}	0.63^{***}	0.71^{***}	1.00^{***}	0.87^{***}	0.84^{***}
	T	0.55^{**}	0.66^{***}	0.69^{***}	0.48^{**}	0.61^{***}
Samawa	T_{max}	0.43^{+}	0.20^{-}	0.34^{**}	0.08^{-}	0.30^{**}
	T_{min}	0.14^{-}	0.47^{***}	0.42^{**}	0.44^{*}	0.39^{***}
	T	0.34^{+}	0.35^{**}	0.36^{**}	0.25^{-}	0.31^{***}
Nasiriya	T_{max}	0.54^{**}	0.73^{***}	0.68^{***}	0.33^{+}	0.62^{***}
	T_{min}	0.36^{**}	0.79^{***}	0.82^{***}	0.50^{***}	0.63^{***}
	T	0.46^{**}	0.78^{***}	0.79^{***}	0.46^{**}	0.61^{***}
Basra	T_{max}	0.42^{*}	0.85^{***}	1.47^{***}	0.50^{**}	0.83^{***}
	T_{min}	0.37^{*}	0.85^{***}	0.86^{***}	0.72^{***}	0.71^{***}
	T	0.37^{*}	0.81^{***}	1.16^{***}	0.61^{***}	0.77^{***}
Average	$\boldsymbol{T_{max}}$	**0.56**	**0.55**	**0.52**	**0.19**	**0.50**
	$\boldsymbol{T_{min}}$	**0.44**	**0.71**	**0.82**	**0.62**	**0.67**
	$\boldsymbol{T}$	**0.50**	**0.66**	**0.68**	**0.44**	**0.58**

The significance levels tested are 0.001 (***), 0.01 (**), 0.05 (*), 0.1 (+), and >0.1 (–) (*Salmi et al.,* 2002).

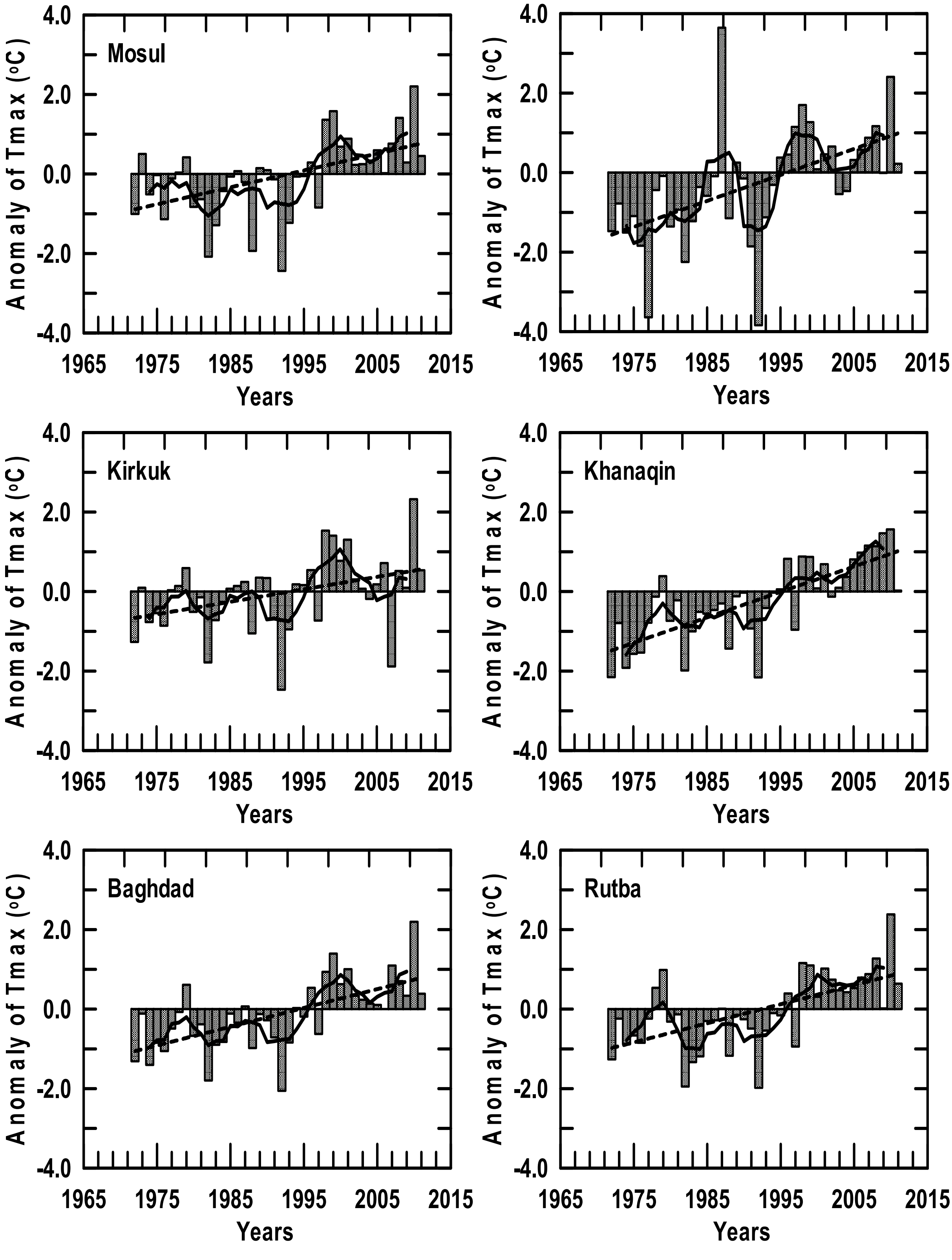


Fig. 2. Anomalies of maximum temperatures (T_{max} °C) for the eleven selected stations during the studied period (1972–2011), for the baseline (1982–2011) average. The bars indicate the anomalies of the years, the zigzag line represents five-year means, and the straight line indicates the long-term linear trends.

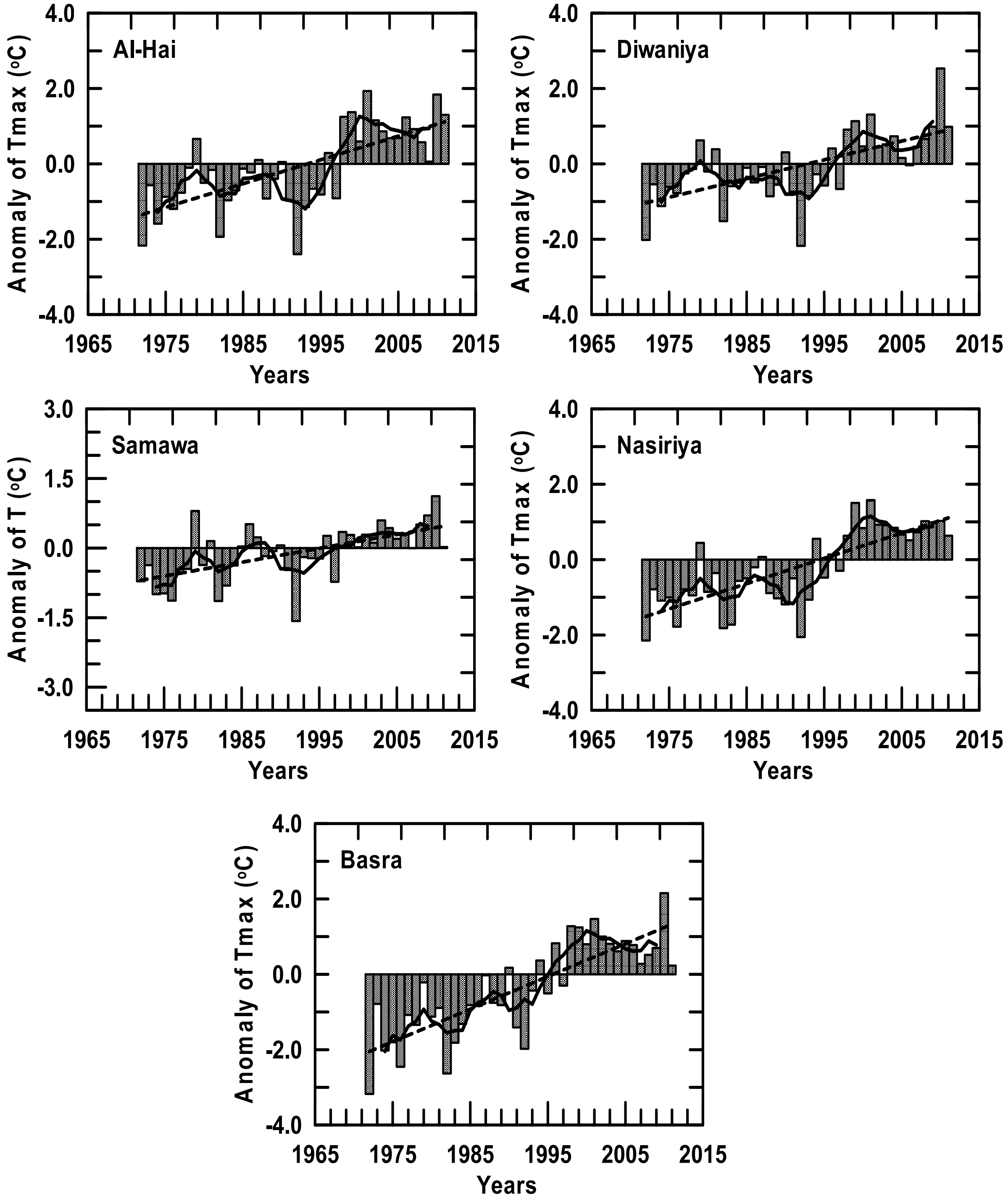


Fig. 2. (Continued).

In spring and summer, the significant positive trends of T_{max} are clearly observed with vider spatial distribution than winter and autumn. The strongest significant positive (1.47 ^{o}C/decade) and negative (–0.02 ^{o}C/decade) trends occurred in summer and autumn and reported at Basra and Diwaniya, respectively (*Fig. 6* and *Table 2*). It is clear that the long-term changes in maximum temperature during winter, spring, and summer showed an increasing trend, which is statistically significant for the four last decades, while the autumn showed different pattern.

3.2. Trends of mean minimum temperature

Fig. 3 illustrates the annual anomalies of minimum temperature (T_{min}, ^{o}C) at the eleven selected stations in Iraq. Statistical properties of the seasonal and annual T_{min} series were tested using the Mann-Kendall test and presented in *Table 2*. It is clearly seen that all stations have experienced significant positive trend during winter, except for the two stations of Mosul and Samawa. It was found ,that 36.4, 27.3, and 18.2% of the stations have experienced significant positive trend during winter at the 0.001, 0.01, and 0.05 levels, respectively, while the trends are not significant at only 18.2% of the stations. The trends range from 0.13 °C/decade (non-significant trend) at Mosul to 0.75 ^{o}C/decade (significant at the 0.001 level) at Sulaymaniya. In spring, all stations have experienced significant positive trend. It was found that 90.9 and 9.1% of the stations had experienced significant positive trend at the 0.001 and 0.1 levels, respectively. Al-Hai, which is located in the southern part of the country, has experienced the highest positive trend (1.03 ^{o}C/decade), while Mosul in the northern part has experienced the lowest positive trend (0.29 ^{o}C/decade). Negative trends were not observed at the stations during this season. In summer, the trends were positive and significant at the 0.001 and 0.01 levels for 90.9 and 9.1% of the stations, respectively. It was found, that the trend values ranged between the lowest positive trend (0.42 ^{o}C/decade) at Kirkuk in the north to the highest positive trend (1.06 ^{o}C/decade) at Basra in the extreme south. In autumn, all stations have experienced significant positive trend (except Kirkuk). The trends range from 0.28 °C/decade (non-significant trend) at Kirkuk to 0.87 ^{o}C/decade (significant at the 0.001 level) at Diwaniya. It could be noticed, that 54.5, 18.2, and 18.2% of the stations have experienced significant positive trend during autumn at the 0.001, 0.01, and 0.05 levels, respectively, while the trends are not significant at only 9.1% of stations (*Figs. 3* and *6* and *Table 2*).

There is a general tendency for the warming trend during the study period. The annual and seasonal trend analyses reveal that most of the warming in reference to T_{min} was found in spring (0.71 ^{o}C/decade) and summer (0.82 ^{o}C/decade), respectively, while the average trend over the whole Iraq country is 0.67 ^{o}C/decade. Annually, it could be noticed that minimum temperature showed a significant positive trend in 100% of the stations at the 0.001 level, while there is not any stations in the whole Iraq which have significant/non-significant negative trend (*Figs. 3* and *6* and *Table 2*).

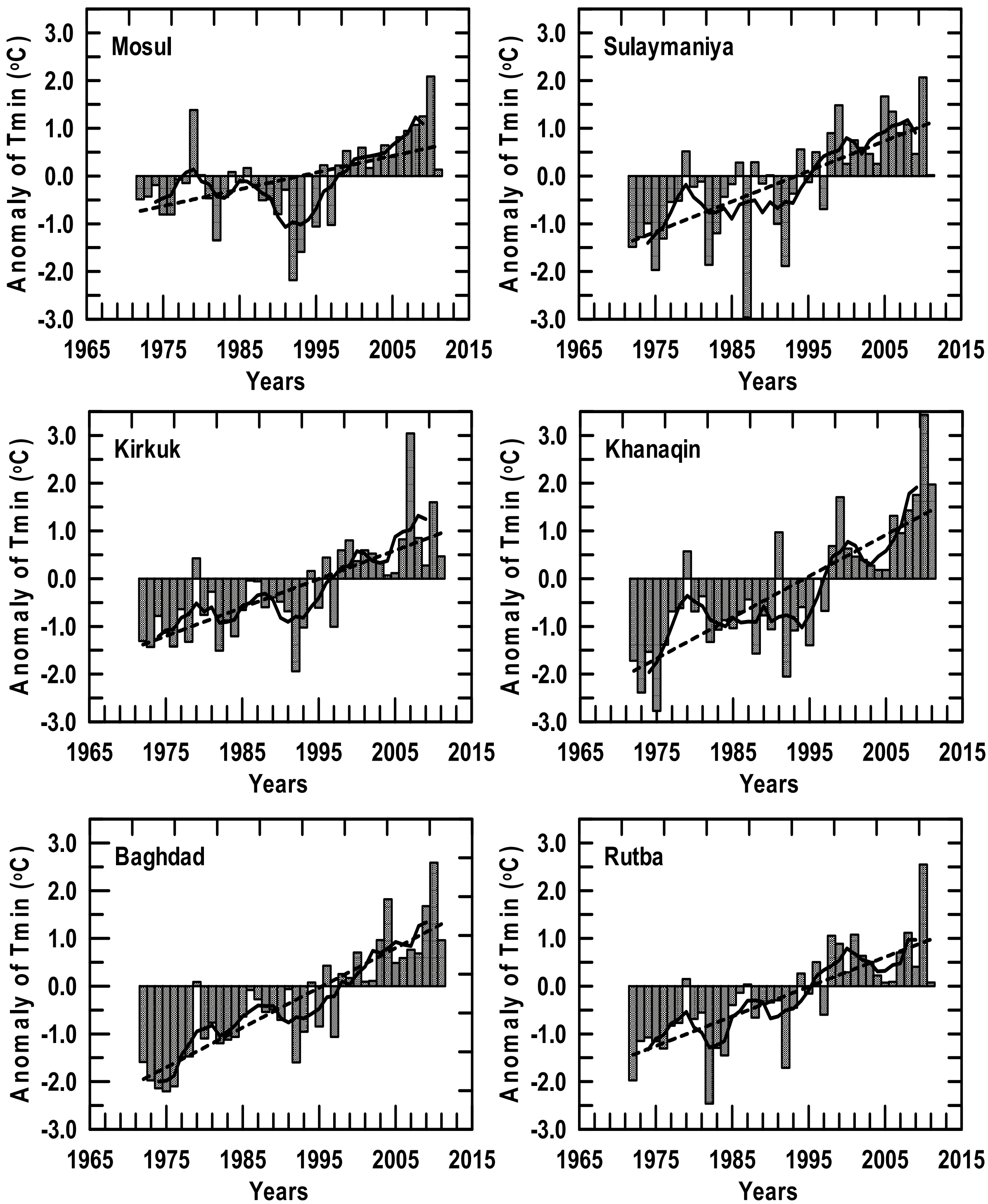


Fig. 3. Anomalies of minimum temperatures (T_{min}, °C) for the eleven selected stations during the studied period (1972–2011), for the baseline (1982–2011) average. The bars indicate the anomalies of the years, the zigzag line represents five-year means, and the straight line indicates the long-term linear trends.

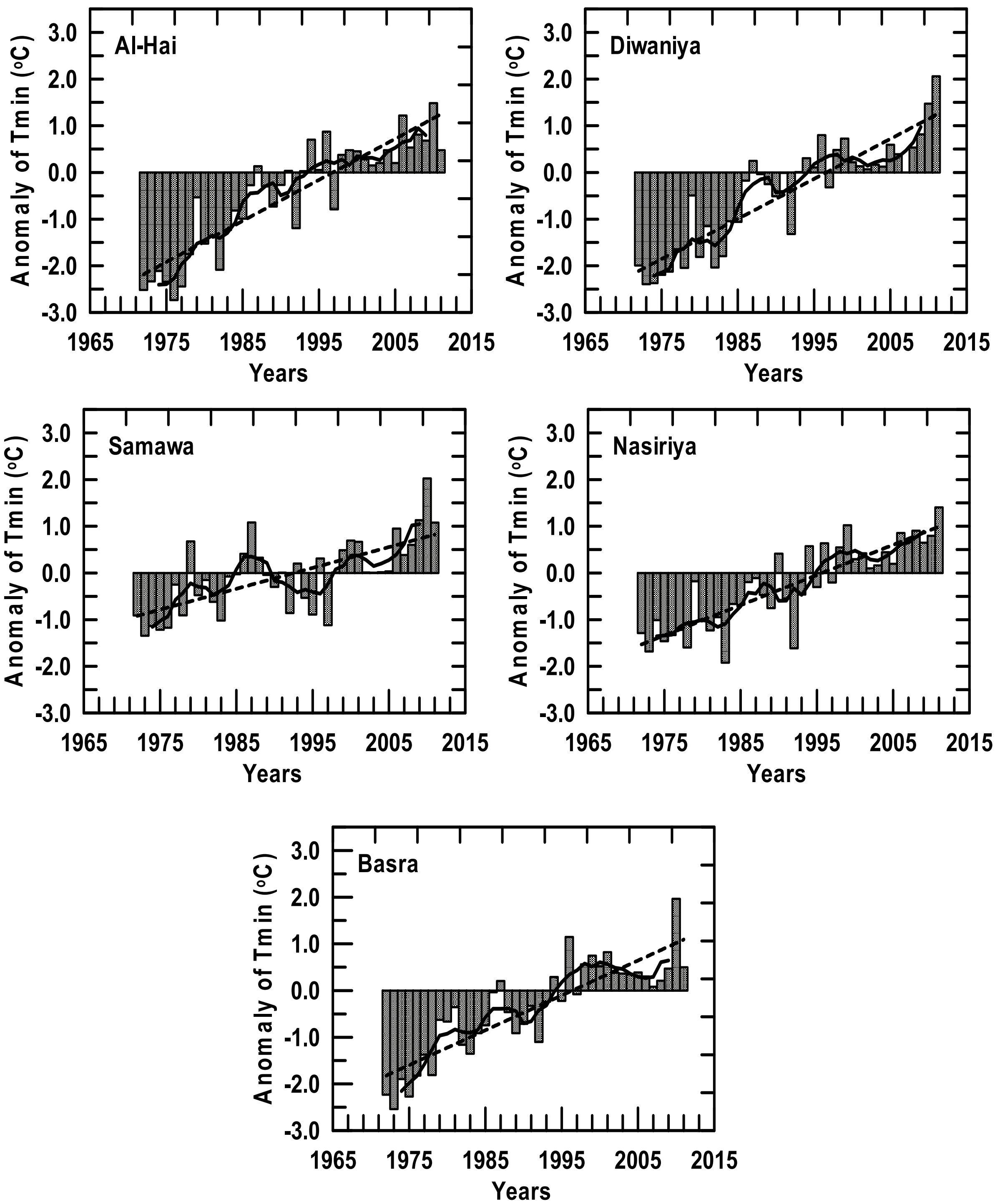


Fig. 3. (Continued).

3.3. *Trends of mean temperature*

Fig. 4 illustrates the annual anomalies of mean temperature (*T,* °C) at the eleven selected stations in Iraq. Statistical properties of the seasonal and annual *T* series were also tested and presented in *Table 2*. It was found, that according to the MK test for trend, all stations have experienced significant positive trends (warming pattern) of the annual mean temperature.

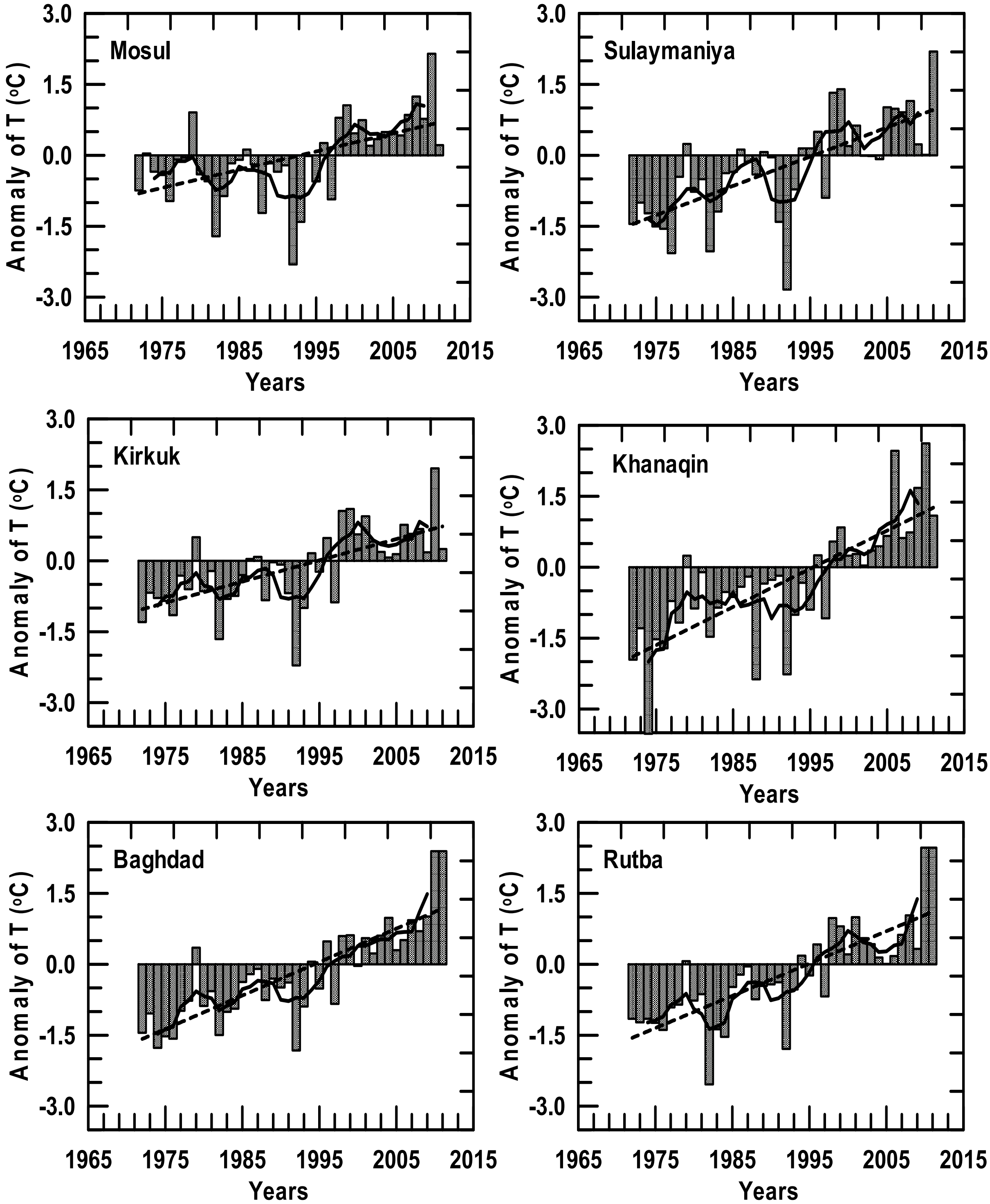


Fig. 4. Anomalies of mean temperatures (T, °C) for the eleven selected stations during the studied period (1972−2011), for the baseline (1982−2011) average. The bars indicate the anomalies of the years, the zigzag line represents five-year means, and the straight line indicates the long-term linear trends.

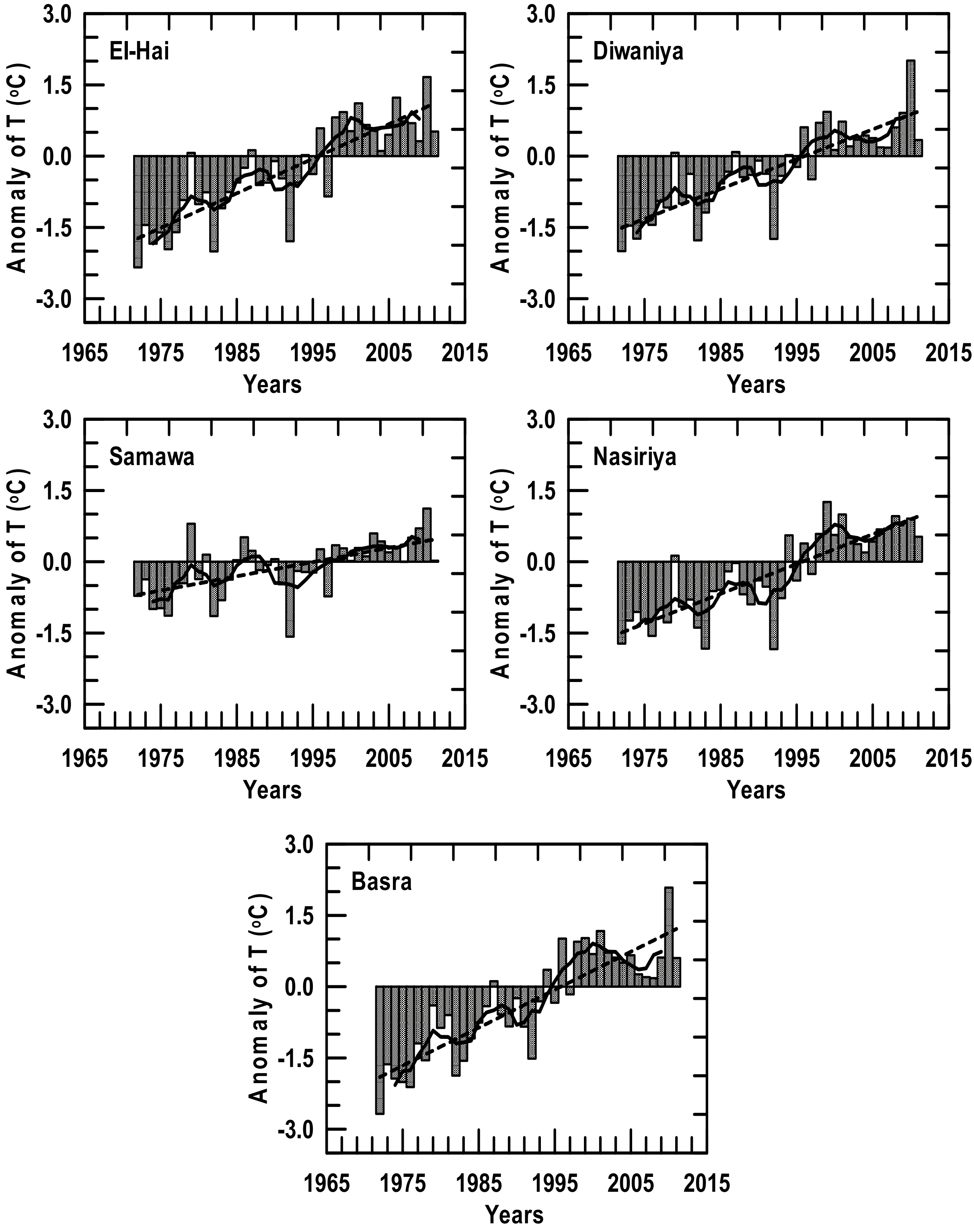


Fig. 4. (Continued).

In winter, all stations have experienced positive trend. It was found that 18.2, 54.5, 9.1, and 18.2% of the stations have experienced positive trend during winter at the 0.001, 0.01, 0.05, and 0.1 levels, respectively. Also, it can be noticed, that Mosul has the lowest and non-significant positive trend

(0.30 °C /decade), while Sulaymaniya has the highest significant positive trend (0.71 °C /decade) at the 0.001 level. During spring, ten stations show strong upward tendency trends, whereas 90.9% of the stations have experienced significant positive trend at the 0.001 level while 9.1% of the stations have positive trend at the 0.1 levels. It could be noticed, that the trends ranged between 0.35 °C/decade at Samawa and 0.95 °C/decade at Al-Hai; the trends for Samawa and Al-Hai are significant at the 0.01 and 0.001 levels, respectively (*Figs. 4* and *6* and *Table 2*).

All eleven stations also showed strong evidence of a significant positive trend during summer, while there is not any station with negative trend during this season. It could be noticed, that 90.9 and 9.1% of the stations have experienced strong significant positive trend at the 0.001 and 0.01 levels, respectively. Trends range between 0.36 °C/decade at Samawa and 1.16 °C/decade at Basra, and they are significant at the 0.01 and 0.001 levels, respectively. In autumn, the significant positive trend could be generally identified at all stations except for Kirkuk (0.17 °C/decade) and Samawa (0.25 °C/decade), which have non-significant trends, while Basra has the highest significant positive trend (0.61 °C/decade) at the significance level of 0.001. It was found that 18.2, 45.5, and 18.2% of the stations have experienced strong significant positive trend at the 0.001, 0.01, and 0.05 levels, respectively, and the trend is not significant at only 18.2% of the stations. Seasonally, there is not any stations in the whole Iraq which have significant/non-significant negative trend (*Figs. 4* and *6* and *Table 2*).

Annually, it is noticed that the mean temperature showed a significant positive trend at the 0.001 level for all stations, while there is not any stations in the whole Iraq which have significant/non-significant negative trend in the whole Iraq. It was also found, that the significant positive trends of T varied between the lowest value (0.31 °C/decade) at Samawa and the highest value (0.77 °C/decade) at Basra; the trends for both Samawa and Basra are significant at the 0.001 level (*Fig. 6* and *Table 2*).

The results are generally in agreement with those in many studies worldwide, which have shown a trend of increasing air temperature (*Jones* and *Moberg,* 2003; *Luterbacher et al.,* 2004; *Rebetez* and *Reinhard,* 2008; European Environment Agency reports (EEA), 2008; *Croitoru et al.*, 2012; *Piticar* and *Ristoiu*, 2012; *Ionita et al.*, 2013; *Croitoru* and *Piticar*, 2013; *Tannecia et al.*, 2014).

3.4. Trends of total rainfall

Total rainfall (R_a, mm), is the other important climate parameter in the present study. Statistical properties of the seasonal and annual R_a series at the eleven selected stations in Iraq were tested using the MK test and presented in *Table 3* and illustrated by *Fig. 5*.

Table 3. Trends of total rainfall amounts, Ra (mm/decade), by Mann- Kendall Sen's test

Station	Winter	Spring	Summer	Autumn	Annual
Mosul	-23.50^{+}	-3.45^{-}	0.00^{-}	-1.53^{-}	-32.25^{*}
Sulaymaniya	-24.00^{-}	-3.50^{-}	0.00^{-}	0.39^{-}	-35.52^{-}
Kirkuk	-20.95^{-}	-7.69^{-}	0.00^{-}	-1.32^{-}	-36.06^{*}
Khanaqin	-36.35^{**}	-4.83^{-}	0.00^{-}	2.31^{-}	-41.96^{***}
Baghdad	-9.85^{+}	0.65^{-}	0.00^{-}	0.51^{-}	-12.10^{*}
Rutba	-11.75^{**}	-2.29^{-}	0.00^{-}	0.47^{-}	-9.38^{-}
Al – Hai	-12.87^{+}	-0.91^{-}	0.00^{-}	-1.41^{-}	-24.72^{**}
Diwaniya	-8.69^{+}	-0.61^{-}	0.00^{-}	1.81^{-}	-10.13^{-}
Samawa	-4.40^{-}	0.68^{-}	0.00^{-}	2.00^{-}	0.26^{-}
Nasiriya	-10.68^{+}	0.52^{-}	0.00^{-}	-0.04^{-}	-7.83^{-}
Basra	-7.27^{-}	0.67^{-}	0.00^{-}	0.29^{-}	-15.77^{*}
Average	**−15.48**	**−1.89**	**0.00**	**0.32**	**−20.50**

The results distinctly revealed that, during winter, all stations have experienced negative trend. It was found that 18.2 and 45.4% of the stations have experienced significant negative trend during winter at the 0.01, 0.1 levels, respectively, while 36.4% of the stations have non-significant negative trend. The highest significant negative trend (–36.35 mm/decade) was found at Khanaqin, while the lowest negative trend (–4.4% mm/decade) was found at Samawa; the trend for Khanaqin is significant at the 0.01 level, while Samawa showed non-significant decreasing trend. During spring, only four stations (36.4% of stations) have experienced non-significant positive trend, while the remaining stations (63.6% of stations) have experienced non-significant negative trend. It could also noticed, that Samawa experienced the highest non-significant positive trend (0.68 mm/decade) while Kirkuk experienced the lowest non-significant negative trend (–7.69 mm/decade), see *Figs. 5* and *6* and *Table 3*.

In summer, the climate of Iraq is rainless and clear skies prevail. Therefore, all stations show no trend during this season. During autumn, only seven stations (63.6% of stations) have experienced non-significant positive trend, while the remaining four stations (36.4% of the stations) have experienced non-significant negative trend. It could be noticed that the highest positive trend during the autumn season (2.31 mm/decade) occurred at Khanaqin station, while the lowest negative trend (–1.53 mm/decade) occurred at Mosul station (*Figs. 5* and *6* and *Table 3*).

Annually, negative trends of total rainfall have been observed at all stations except Samawa, which showed non-significant positive trend (2.31 mm/decade). It was found that 9.1, 9.1, and 36.4% of the stations have experienced significant negative trend at the 0.001, 0.01, and 0.05 levels, respectively, while 36.4 and 9.1%

of the stations showed non-significant negative and positive trends respectively. The trends range from –7.83 mm/decade at Nasiriya to –41.96 mm/decade at Khanaqin; the trend for Khanaqin is significant at the 0.001 level, while Nasiriya showed non-significant negative trend (*Figs. 5* and *6* and *Table 3*).

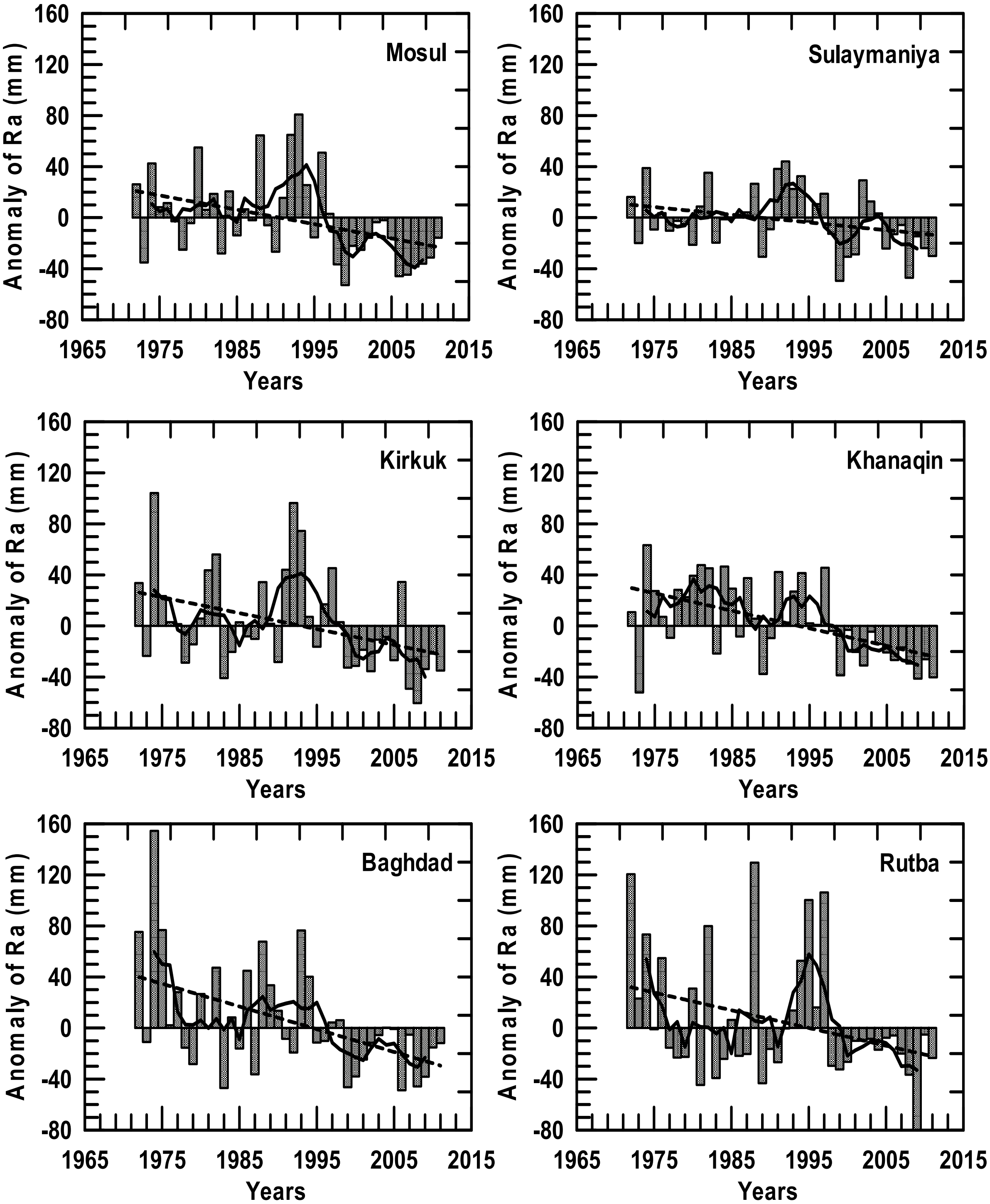


Fig. 5. Anomalies of the rainfall amount (*Ra*, mm) for the eleven selected stations during the studied period (1972−2011), for the baseline (1982−2011) average. The bars indicate the anomalies of the years, the zigzag line represents five-year means, and the straight line indicates the long-term linear trends.

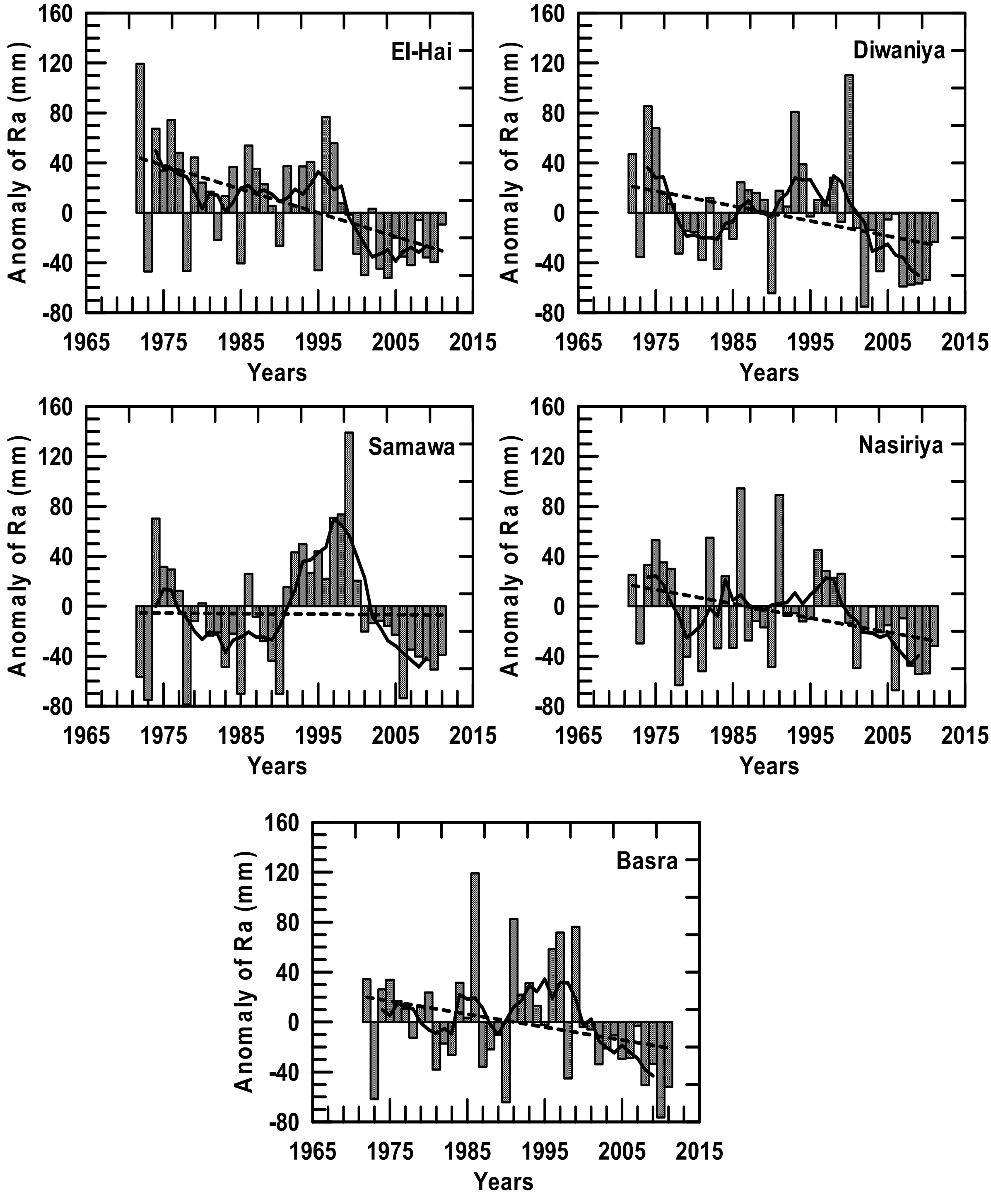
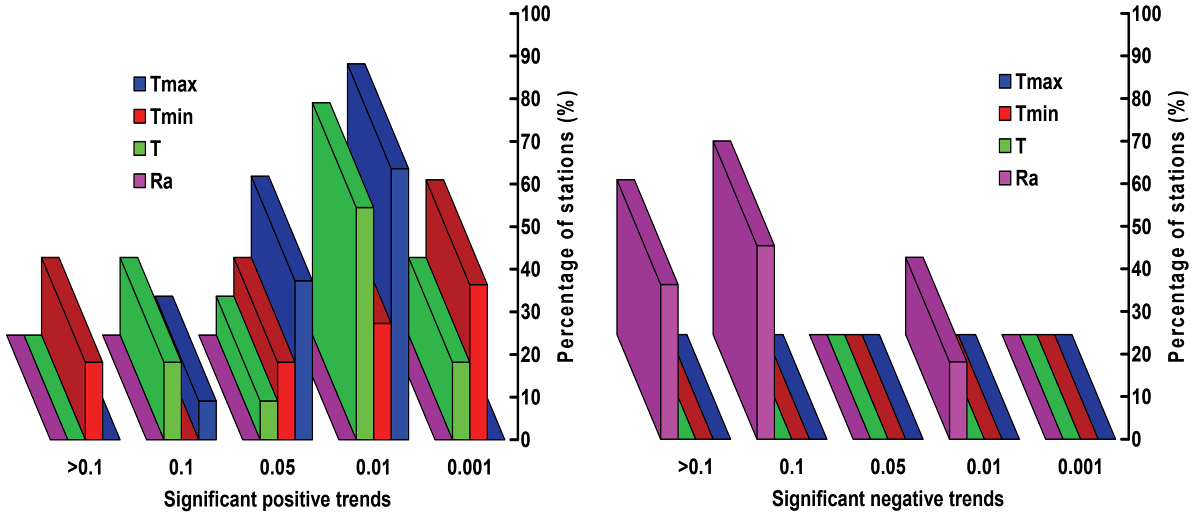


Fig. 5. (Continued).

It could be concluded, that the trends of R_a were negative over the whole country of Iraq except for Samawa, where the observed rainfall has slightly increased. The average rate of R_a decreased over the whole Iraq, and it has been found –15.48 mm/decade, –1.89 mm/decade, –0.32 mm/decade during winter, spring, and autumn seasons, respectively, and –20.5 mm/decade annually, while no consistent changes were found during the summer season. Majority of the trends indicated reduced precipitation during winter. It is also noticed, that the rainfall showed a negative trend in 90.9% of the stations, but there is 9.1% of the stations with positive trend in the whole Iraq (see *Fig. 6* and *Table 3*). This result agrees with the findings of *Raziei et al*., (2005) and *Tabari* and *Talaee* (2011b), who found a significant negative trend in the annual precipitation series in Iran.

(a) Winter



(b)
Spring

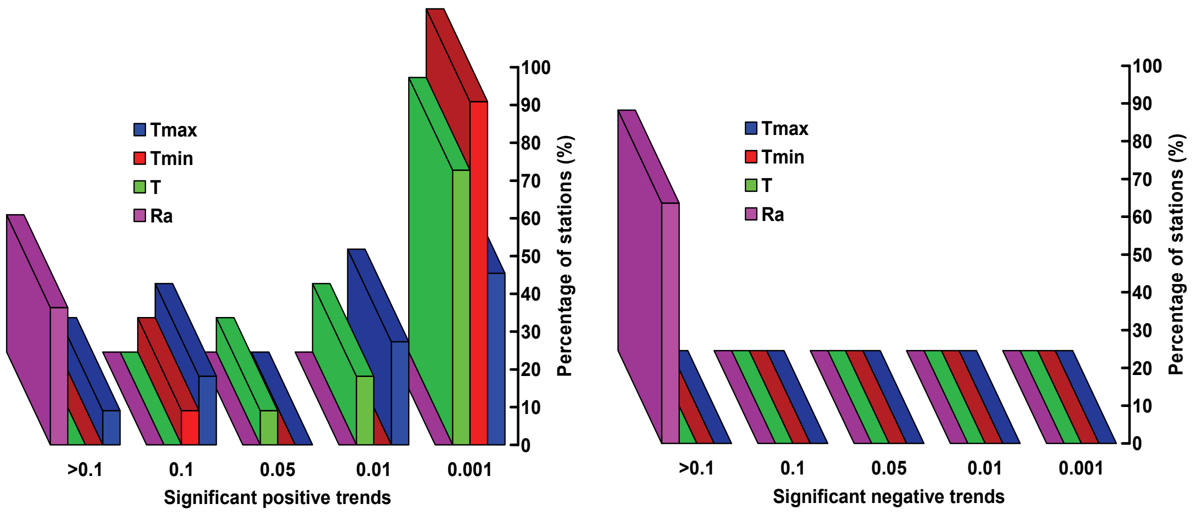


Fig. 6. The percentage of stations with significant positive and negative trends for T_{max}, T_{min}, T, and Ra by the Mann-Kendall test during (a) winter, (b) spring, (c) summer, (d) autumn, and (e) annual.

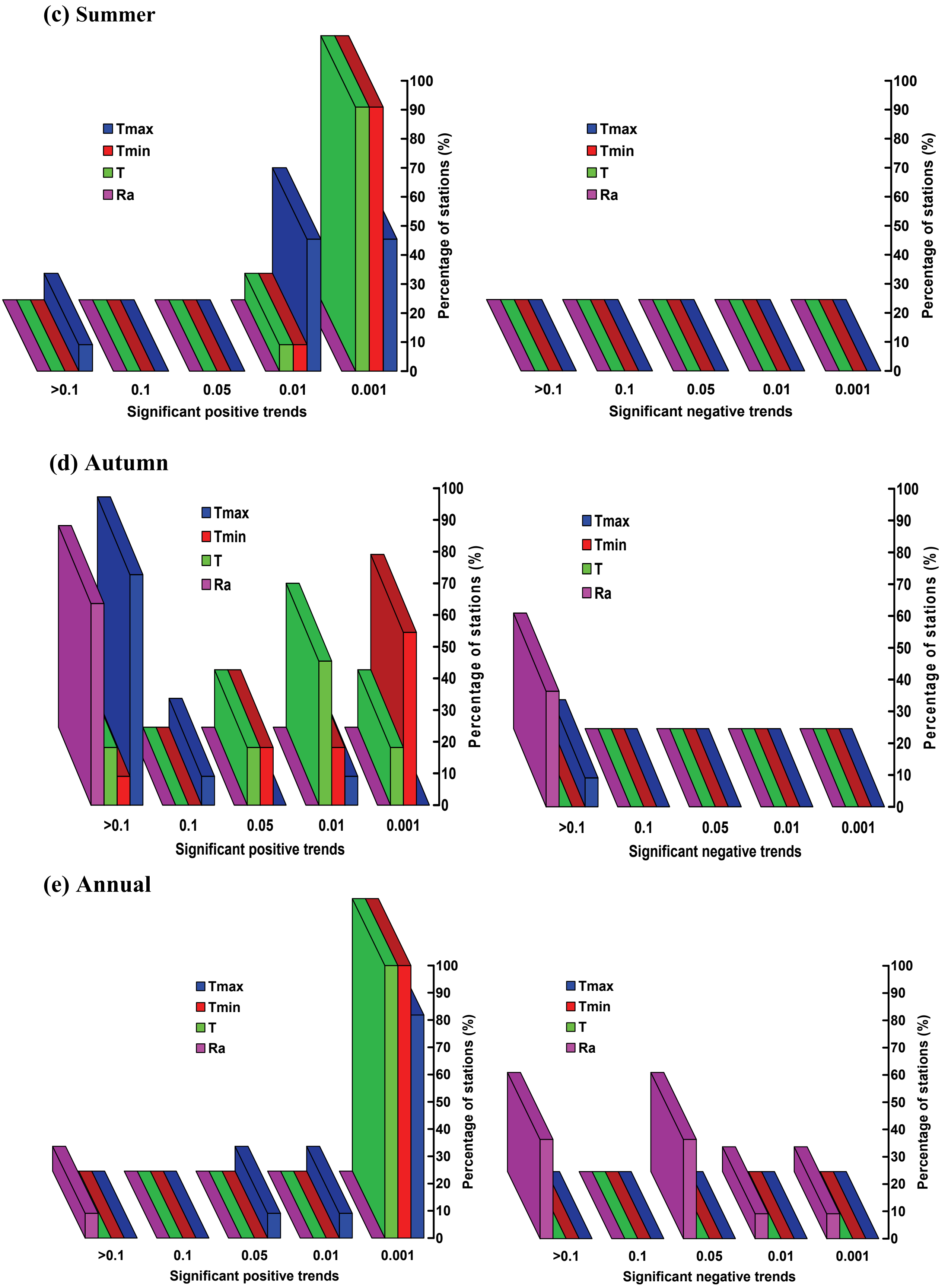


Fig. 6. (Continued).

4. *Conclusions*

The present study is mainly concerned with the changing trend of air temperatures and rainfall in Iraq. A complete set of measurements for maximum (T_{max}), minimum (T_{min}) and mean air temperatures (T) in addition to rainfall amounts (R_a) for the period 1972–2011 at 11 meteorological stations in Iraq have been used. Statistical tests including the Mann-Kendall test, the Sen's slope estimator, and linear regression were used for the analysis. Final results and conclusions could be summarized in the following points:

1. Annual mean of T_{max}, T_{min}, and T time series showed statistically significant increasing trends over 81.8, 100, and 100% of the stations at the 0.001 level, and they experienced an increase of 0.50, 0.67, and 0.58 °C/decade, respectively.
2. The significant positive trends of T_{max}, T_{min}, and T can be observed clearly during spring and summer than during winter and autumn.
3. There is not any stations which have significant or non-significant negative trend for air temperatures in the whole Iraq except Diwaniya, where the trend of T_{max} was weakly negative during autumn.
4. Annual rainfall has shown decreasing trends at all stations (except Samawa), and it experienced an decrease of –20.50 mm/decade.
5. Seasonally, the highest increase of T_{max}, T_{min}, and T values have been found at the extreme south of the country (Basra) during summer at the rates of 1.47, 1.06, and 1.16 °C/decade, respectively, while the lowest increase of the air temperatures prevail in the northern part of the country, especially at Kirkuk.
6. The highest decrease of R_a values has been found in the northern part of the country (Khanaqin) during winter at the rate of –36.35 mm/decade.
7. The warming pattern occurred shortly after 1995 at all stations.

Changes in air temperature and rainfall amounts will have significant impacts on biodiversity and food security in Iraq. Therefore, substantial reductions of heat-trapping gas emissions and adaptation strategies are crucial in Iraq.

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