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ORIGINAL PAPER

Spatial and temporal patterns of climate variables in Iraq

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Abstract Temporal and spatial changes in Iraq total precipitations, maximum and minimum temperatures in the period of 1980–2011 are analyzed using 28 meteorological stations data distributed throughout the country. The Mann–Kendall and Spearman's Rho test statistics for annual and seasonal Kendall and Sen's T tests for monthly total precipitation and temperature series are calculated and plotted on maps to display any spatial trend patterns. Serial correlation structure in the data series and homogeneity of trends in monthly series were tested before applying the methods. Non-parametric methods using annual and monthly data over 32 years show almost same temporal and spatial patterns in trends of precipitation (*P*), maximum and minimum temperature (Tmax, Tmin) but some are not statistically significant at the 5 % level. While observation shows decreasing trends in precipitation except for two stations when using monthly data, increasing trend is detected in both temperature series. The Sen's and seasonal Kendall slope estimator are also used to estimate linear trend magnitudes for annual and monthly data to determine the change per unit time in a time series, respectively. The six tests provide the same results about trend in most cases. As a conclusion, all of the study results show that there are not differences in the geographic location of trends (statistically significant or not) in the meteorological variables implying that climatic impacts are spatially uniform in this region. The effect of the North Atlantic Oscillation (NAO) on temporal patterns of climate data in Iraq is also investigated, since it has been suggested that it affects the northern hemisphere climate system. Our study shows that NAO has no detectable influences on climate of this region. This paper is the first comprehensive studies for evidence of climate change with applying tests in this region.

Keywords Trend analysis · Mann–Kendall · Slope estimator · NAO · Iraq

Introduction

The global average temperature was expected to increase +0.74−+0.18 °C between 1906 and 2005 (IPCC 2007). International Panel on Climate Change report also expresses that impact of temperature change in the future is more severe and thus there'll be a shortage in the freshwater availability as a result of climate change. This has additionally detected that decrease in the annual runoff and water availability will project up to 10–30 % in the middle of the twenty-first century (IPCC 2007). Therefore, the increasing efforts have gained to research the effect of climate change on surface temperature and precipitation in all over the world (Zhang et al. 2000, 2014; Partal and Kahya 2006; Al Buhairi 2010; Rahman and Begum 2013). These researchers show that climate change is a global phenomenon, but its impacts vary from region to region on the globe surface. Although, Iraq is also considered as one of the vulnerable regions to climate change in Asia, a limited number of studies appear to be available. Zeid and El-Fadel (2002) used simulations of climate change predictions to evaluate its effect on water resources in Middle East. Although they did not consider predicted precipitation to decrease, they

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found that temperature increases of 0.6–2.1 °C would impact the water balance and reduce available resources. Bilal et al. (2013) used monthly maximum, minimum, and mean temperature data spanning from 1941 to 2000 to detect trend in Baghdad city, Iraq. They utilized linear regression method as well as Mann–Kendall test. They found warming trends for annual maximum and mean temperature though cooling trends for annual minimum temperature but they are not statistically significant. They also emphasized that there was a strong increasing tendency for temperature in the late 1990s during the summer season. Jasem (2012) studied trend characteristics of rainfall for four stations in Iraq during 1941–2000 by using t test. The results show that there was only one significant increasing trend in Rutba station during autumn season. Regarding to annual rainfall data, he detected positive trend in both Basra and Rutba stations while he found negative trend in both Baghdad and Mosul stations. The other studies related with climate change effects in Middle East can be summarized as follows: Partal and Kahya (2006) used the Mann–Kendall and Sen's T tests to reveal trends in the long-term annual and monthly precipitation series. Their results showed that the trends of precipitation were downward across Turkey and both tests obtained more or less similar conclusions. Al Buhairi (2010) analyzed trends in the mean annual, seasonal, and monthly surface temperature in Taiz city, Yemen, during the period 1979–2006. Their results indicated that a statistically significant increasing trend in practically all the months and seasons existed. Tabari and Talaee (2011) examined the trends of the monthly, seasonal, and annual Tmax and Tmin time series during 1966–2005 in Iran for 19 meteorological stations. They found that 85 % of the stations have positive trends while 15 % of the stations have negative trends in the study region. As a conclusion, these studies claim that Middle East region may face more aridity due to increasing temperature and decreasing precipitation in future.

The utilizing tests for revealing of significant trends in the time series of hydro-climatological variables may be sorted as parametric and non-parametric (Shadmani et al. 2012). Parametric trend test is stronger than non-parametric test provided that data are independent and normally distributed. However, non-parametric trend tests can allow incorporating outliers in the data and needing solely that the data be independent. Moreover, they are insensitive to the sort of data distribution (Shadmani et al. 2012). Taking all the good features of the non-parametric test, these tests have been used to reveal of trends in many studies (i.e., Yue et al. 2002; Kahya and Kalayci 2004; Partal and Kahya 2006; Yenigun et al. 2008).

The main objective of this study including detection of climate change is to investigate the temporal and spatial trends of precipitation and temperature via satisfyingly large and long data series in Iraq. The Mann–Kendall and Spearman's Rho test statistics for annual and seasonal Kendall and Sen's T tests for monthly precipitation and temperature series are calculated and plotted on maps to display any spatial trend patterns. The Sen's and seasonal Kendall slope estimator are also used to estimate linear trend magnitudes for annual and monthly data. We confirmed, as in previous studies, that the study region vulnerable to increasing and decreasing trend in temperature and precipitation, respectively. We should mention that the detecting decrease (increase) in precipitation (temperature) may be result in desertification, heat island, global warming, and other signals that exist.

The North Atlantic Oscillation (NAO) exerting a strong control on the climate of the Northern Hemisphere was also investigated in the study because there are lots of studies to put forward linkages between atmospheric circulations and precipitation conditions (e.g., Marshall et al. 2001). During negative NAO years, Iraq experiences wet and cold conditions and dry and hot conditions for the period of positive NAO years (Şarlak et al. 2009). However, our analyses show that NAO has no detectable influences on variation of climate data of this region.

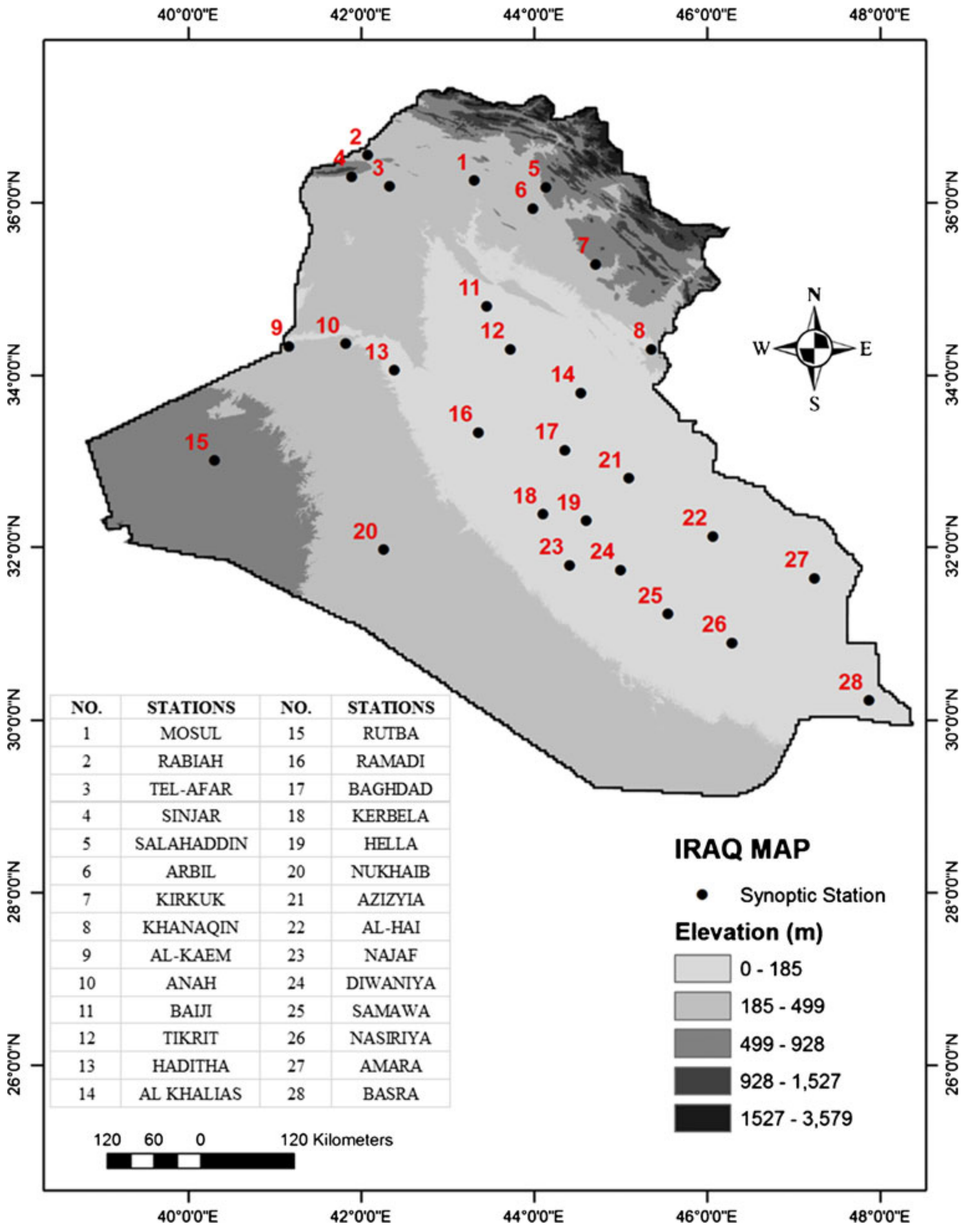
Data and methodology

Iraq is located in south-west Asia at the crossroads of the Middle East. It covers an area of 435,052 km^2, which lies between the latitudes of 29° 5′ and 37° 22′ North and the longitudes of 38° 45′ and 48° 45′ East.

Historical data of monthly total precipitation, maximum and minimum temperature data for the time period 1980–2011 were provided by the Iraqi Meteorological Organization and Seismology (IMOS). The study covers 28 meteorological stations, chosen according to their geographical distribution, data accuracy, and availability, across Iraq. A quality control process involving homogenization was applied to data series. Standard normal homogeneity (SNH) and Pettit tests were utilized for this aim. While 3 out of 28 precipitation series at All-Kaim, Kerbela, and Hilla stations were found to be inhomogeneous according to SNH test, the other series were found to be homogeneous from both of these tests at 5 % significance level. It was decided to utilize the original precipitation data of three stations. Figure 1 shows the spatial distribution and geographic conditions of stations in Iraq.

Trend analysis

There are many non-parametric tests performed in order to detect a climate trend. Some of them are used to detect trends of annual data while the others can be utilized to detect trends of seasonal data. Different non-parametric trend tests and time periods (such as monthly and annual) have been utilized to



NO.	STATIONS	NO.	STATIONS
1	MOSUL	15	RUTBA
2	RABIAH	16	RAMADI
3	TEL-AFAR	17	BAGHDAD
4	SINJAR	18	KERBELA
5	SALAHADDIN	19	HELLA
6	ARBIL	20	NUKHAIB
7	KIRKUK	21	AZIZYIA
8	KHANAQIN	22	AL-HAI
9	AL-KAEM	23	NAJAF
10	ANAH	24	DIWANIYA
11	BAIJI	25	SAMAWA
12	TIKRIT	26	NASIRIYA
13	HADITHA	27	AMARA
14	AL KHALIAS	28	BASRA

Fig. 1 The spatial distribution and geographic conditions of the meteorological stations in Iraq

exhibit the effect of them on trend results in this region. All tests are conducted at 5 % significance level.

Mann–Kendall test (MK)

This technique is the widely used non-parametric tests for detection trends of climatological and hydrological time series. The World Meteorological Organization used and suggested it for detection and estimation trend of environmental data (Yenigun et al. 2008). In this test, the null hypothesis (H_o) is equivalent to non- significant trend in the time series and the alternative hypotheses (H_1) are equivalent to the significant trend in the time series. The MK test statistic, S which has zero mean and a variance (Eq. 3) and the standardized test statistic Z_{MK} are computed as follows (Hirsch and Slack 1984; Douglas et al. 2000):

$$S = \sum_{i=2}^{n} \sum_{j=1}^{i-1} \operatorname{sign}(x_i - x_j) \tag{1}$$

$$\operatorname{sign}(x_i - x_j) = \begin{cases} 1, & \text{if } (x_i - x_j) > 0, \\ 0, & \text{if } (x_i - x_j) = 0, \\ -1, & \text{if } (x_i - x_j) < 0. \end{cases} \tag{2}$$

$$V(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p (t_p - 1)(2t_p + 5)\right] \tag{3}$$

where n is the time series length, x_i and x_j are the successive data values of the time series in the years i and j, t_i is the number of ties for pth value, and q is the number of tied values.

$$Z_{\mathrm{MK}} = \begin{cases} \frac{S-1}{\sqrt{\mathrm{Var}(S)}} & \text{if } S > 0, \\ 0 & \text{if } S = 0, \\ \frac{S+1}{\sqrt{\mathrm{Var}(S)}} & \text{if } S < 0. \end{cases} \tag{4}$$

If the Z_{MK} value is positive, it refers to increasing trends, likewise the negative value of Z_{MK} refers to decreasing trends in the time series. The null hypothesis is rejected when $Z_{\mathrm{MK}} > Z_{1-\alpha/2}$. The critical value of standardized normal ($Z_{1-\alpha/2}$) can be obtained from the standardized normal table; the value of $Z_{1-\alpha/2}$ is 1.96 at the 5 % significant level.

Spearman's rho test (SR)

This technique is the simplest test to reveal trends in the time series. In this test, if the correlation between time steps and climate data are significant at the selected confidence level, it means that trend exists in the time series (Yue et al. 2002). The SR test statistic, Rs and the standardized test statistic, Z_{SR} are computed as:

$$\mathrm{Rs} = 1 - \frac{6\sum_{i=1}^{n}(R_i - i)^2}{n(n^2-1)} \tag{5}$$

$$Z_{\mathrm{SR}} = Rs\sqrt{\frac{n-2}{1-Rs^2}} \tag{6}$$

where R_i is the rank of the ith observation, x_i in the time series. While the positive value of Z_{SR} refers to increasing trends, the negative value of Z_{SR} refers to decreasing trends in the time series. The null hypothesis is rejected at $Z_{\mathrm{SR}} > \mathrm{t}_{(n-2,\ 1-1/2)}$ in favor of statistically significant existence trend. $t_{(n-2,1-\alpha/2)}$, which is 2.04 for $n = 32$ at the 5 % significant level, is a critical value of t acquired from the student t table.

Seasonal Kendall test (SK)

Hirsch et al. suggested this test in 1982. This test is a derivation of the MK test. The test composed of calculating the MK test statistic, S and also variance Var (S), separately for each month. The values of monthly statistics are summed, and then the standardized test statistic is calculated similar to MK test (Hirsch et al. 1982).

The homogeneity of seasonal or monthly data should be checked before performing seasonal trend tests. Since the presence of trend heterogeneity among months can lead to an unreliability of the results, the trend test results are going to be deceptive. Van Belle and Hughes provided homogeneity test in 1984. They took advantage of Chi-square statistic to derive their homogeneity test. The detailed description of the test can be found in Van Belle and Hughes (1984).

Sen's T *test (ST)*

This test is an aligned rank method having procedures that first eliminates the season (block) impact from each datum, and then sums the data over seasons, eventually yield a statistic from these sums. It is distributed free, and not influenced by seasonal fluctuations (Sen 1968; Van Belle and Hughes 1984; Kahya and Kalayci 2004). Test statistic is:

$$T = \left(\frac{12K^2}{n(n+1)\sum_{i,j}\left(R_{i,j} - R_{.j}\right)^2}\right)^{1/2} \times \left(\sum_{i=1}^{n}\left(i - \frac{n+1}{2}\right)\left(R_{i.} - \frac{nK+1}{2}\right)\right) \tag{7}$$

when T is greater than Z_α (=1.645 at 5 % significance level), the null hypothesis of no trend is rejected.

Sen's slope estimator (SS)

This application involves in calculating slopes of all data pairs, Q_i. These slopes are then used in order to estimate the median of these N values of Q_i. The slope Q_i is computed as:

$$Q_i = \frac{x_i - x_j}{i - j} \tag{8}$$

where x_i and x_j are represented the data values during the time period i and j ($i > j$), respectively. SS is the value of Q_i at the median of N. If N is odd, the SS is calculated as $Q_{\mathrm{med}} = Q_{\frac{N+1}{2}}$, otherwise it is calculated by $Q_{\mathrm{med}} = \left[Q_{\frac{N}{2}} + Q_{\frac{N+2}{2}}\right]/2$. Positive value of Q_i refers to upward trends, whereas a negative value of Q_i refers to downward trends in the time series (Sen 1968).

Seasonal Kendall slope estimator (SKS)

The Seasonal Kendall slope estimator is a derivation of SS. Hirsch et al. (1982) indicated that this test can also be used for data containing extreme outliers. The SK and ST tests can only verify whether or not there is a trend. However, SKS test is utilized to determine the slope magnitude. To calculate the SKS, the first step is to calculate the individual slope estimation for each season. The calculation of median of the entire $N' = N_1 + N_2 + \ldots\ldots\ldots + N_k$ individual slope estimates is similar to the SS method.

Table 1 The percentage of stations with significant trends obtaining from MK and SR tests for annual data (1980–2011)

	Trend test for annual data			
	MK		SR	
	Significant positive, %	Significant negative, %	Significant positive, %	Significant negative, %
Precipitation		46		50
Tmax	61		68	
Tmin	68		68	

Results and discussions

Annual data

The existence of positive or negative serial correlation in time series can trigger to comment of trend results incorrectly. Von Storch and Navarra (1995) pointed out this effect on the results of trend analysis and proposed the pre-whitening approach to eliminate it before applying the tests. For this aim, first of all lag-1 serial correlation coefficient is computed for each data series to check the serial dependency. It is found that the lag-1 serial correlation effect on the precipitation data is not statistically significant at the 5 % level for all stations except for Nukhaib station. On the other hand, the serial correlation effect on Tmax and Tmin temperature data is statistically significant for all stations except for nine stations. Therefore, pre-whitening procedure was performed to time series belonging to these stations before applying non-parametric tests to eliminate the serial dependency.

The percentage of significant trends obtaining from MK and SR tests for total annual precipitation, Tmax and Tmin data spanning from 1980 to 2011 are given in Table 1. The MK trend results for total annual precipitation appear to quite consistent with the SR test for all stations excluding for Haditha station. SR test detected a statistically significant trend for this station; however, MK test could not detect statistically significant trend at the same level. Among the 28 stations, a percentage of stations containing negative statistically significant trend is 0.46 (0.5) based on MK (SR) test. One important result that can be deduced is the obvious decreasing trend in precipitation valid in all series presented here.

Annual temperature trends showed warming (positive) for both Tmax and Tmin. Increasing Tmax trends were statistically significant in 17(19) out of 28 stations, while increasing Tmin trends were statistically significant in 16 (19) out of 28 stations based on MK (SR) test.

The MK and SR statistics are plotted on a map in order to show the spatial distribution of trends in annual total precipitation trends in Fig. 2, Tmax and Tmin trends in Fig. 3. Figure 2a–b reveals that some of the stations display significant negative trends suggesting decrease in annual total precipitation. In contrast, some of the stations show no statistically significant decreasing trend.

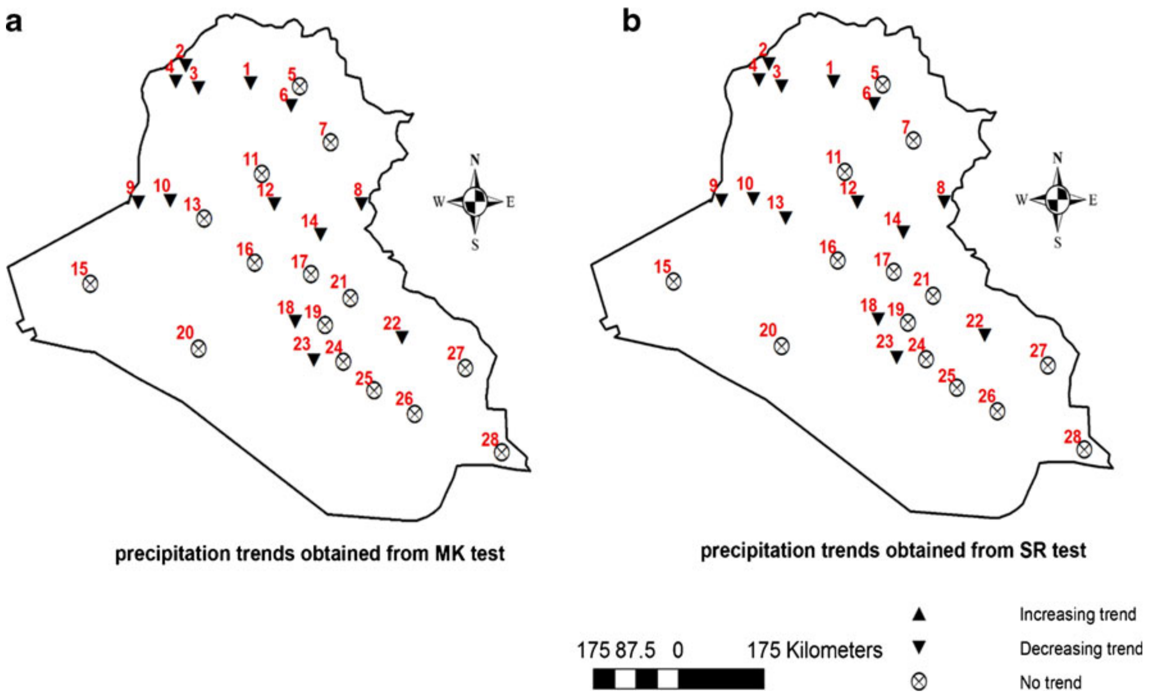
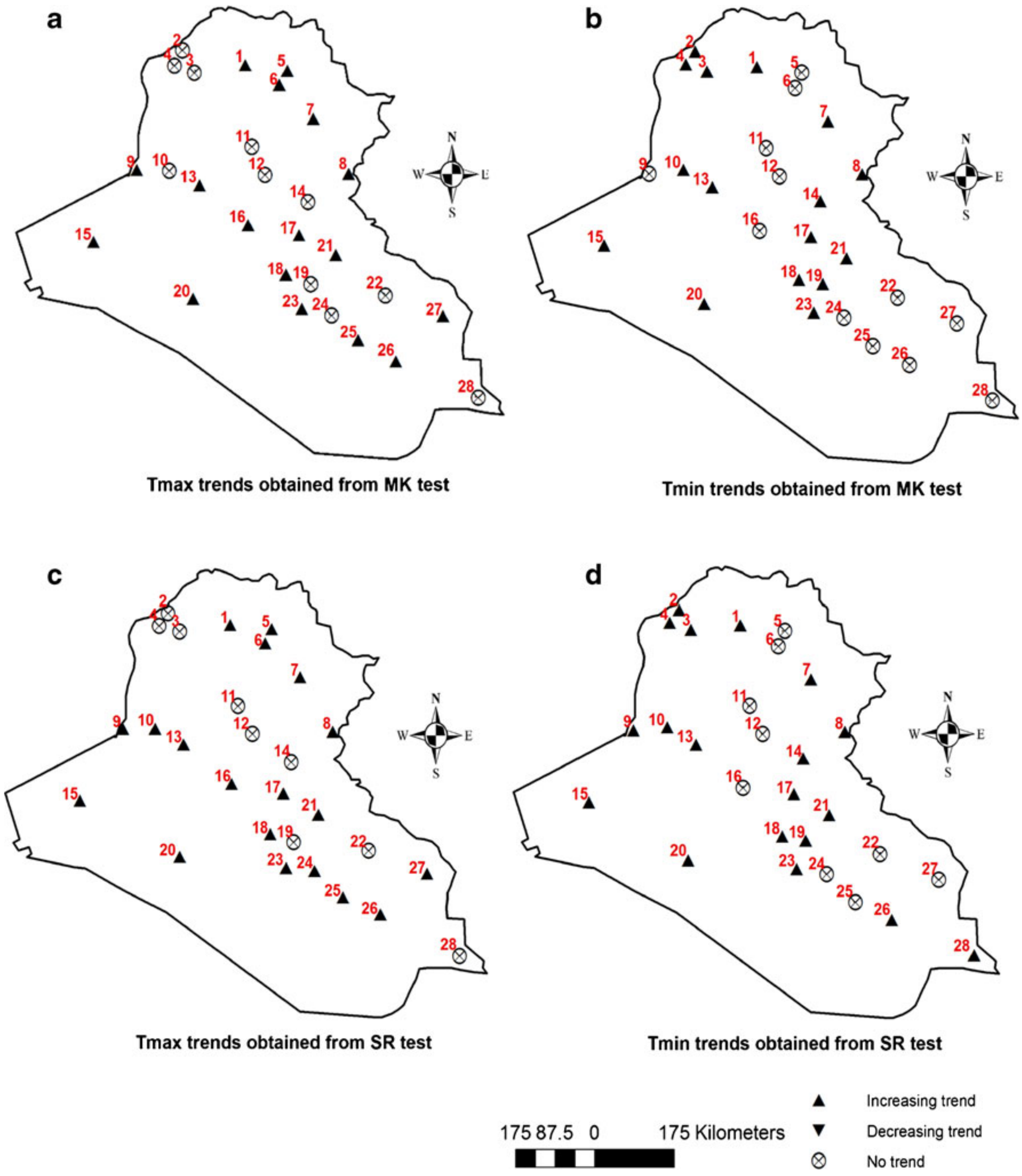


Fig. 2 The spatial distribution of annual precipitation trends obtained from **a** MK and **b** SR



Tmax trends obtained from MK test

Tmin trends obtained from MK test

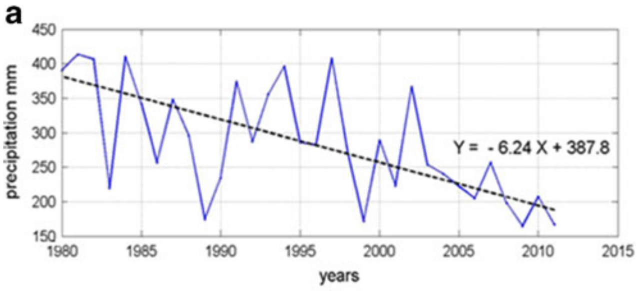
Tmax trends obtained from SR test

Tmin trends obtained from SR test

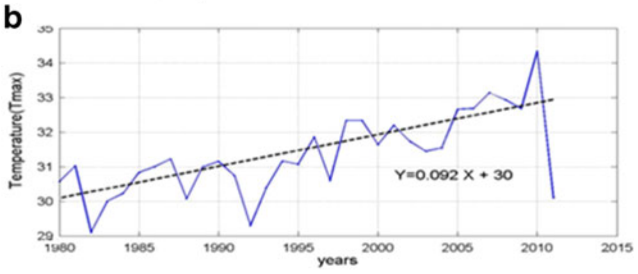
Fig. 3 The spatial distribution of annual Tmax and Tmin trends obtained from **a** MK and **b** SR

As can be seen from Fig. 3, there are significant trends for Tmax in the majority of the north and south of the Iraq. The stations having statistically not significant trends for Tmax seem to be located on specific zone from west to east. This situation is more obvious in Tmax trends than Tmin trends. Actually, one can concluded that almost all parts of Iraq are under a warming trend though some of them are not statistically significant. Although the rate of warming in Tmin is greater than that of Tmax during the last half century in developed country because of urbanization (urban heat islands) and land use change (Tayanç et al. 2009), we could not detect this difference in this region, obviously.

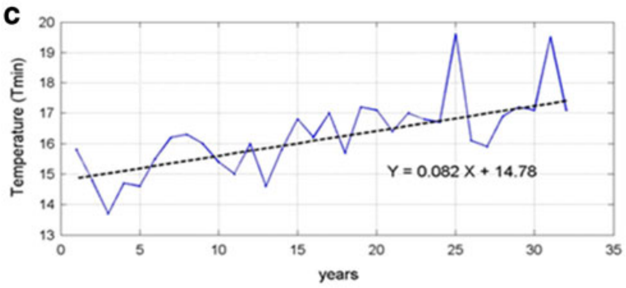
According to SS test, the magnitude of the significant decreasing trends in total annual precipitation data series ranged from 1.3 to 6.23 mm year^{-1}.The observed trends in Mosul, Arbil, Rabiah, Sinjar, and Khanaqin stations were more rapidly decreasing as compared with the other stations. In addition, the highest slope was calculated as 6.23 mm year^{-1} in Khanaqi station and presented in Fig.4a. We should note that all the stations located in Northern Iraq have the higher decreasing slopes than



precipitation trend for KHANAQIN station



Tmax trend for NAJAF station



Tmin trend for NUKHAIB station

Fig. 4 Sen's slope estimator results for annual data series

other region. As for Tmax (Tmin), the highest slope was calculated as 0.092 (0.082) °C/year in Najaf (Nukhaib) station located in southern part of the Iraq (can be seen in Fig.4b–c).

The relationship between annual precipitation and temperature data with the NAO index from 1980 to 2011 was statistically examined to exhibit the impact of the one large-scale atmospheric pattern on climate variables in the Middle East region. Spearman's correlation coefficient was used for this aim. The results are presented in Table 2. They indicated that the correlation between NAO and annual precipitation at all stations were found to be positive. However, all of them were weak and statistically insignificant. The correlations between annual Tmax (Tmin) and simultaneous NAO index were also calculated. As the results show, the strongest negative correlation between annual Tmax (Tmin) and NAO index was determined as 0.54 (0.53) at Samawa (Al-Kaim) station located at the southeast (west) part of Iraq. The correlation coefficient amount indicated that 29 % (28 %) of the annual Tmax (Tmin) variance can be explained by the NAO forcing. Indeed, the correlation between temperature and NAO index were in the range from 0.2 to 0.54, indicating that about 4–29 % of the variance in the pattern of temperature is associated with NAO forcing. The sign of the correlation coefficient is also meaningful. It was found that NAO index has a negative trend during this study period. It implies the tendency of wet and cold climate condition on this region (Şarlak et al. 2009). The negative correlation explains the reason of a few part of detecting hot climate condition because explaining variance of NAO forcing was found as maximum 29 %.

Seasonal data

The SK, ST, and SKS tests were applied to study trends for monthly precipitation and temperature data series expressing in matrix form over the study period (1980–2011). SK, ST and SKS test values, a unique value representing the trend over the entire matrix, were calculated. Serial correlation and homogeneity of monthly trends were tested before performing these tests. Results of homogeneity of trends among months for each climate variables based on this test are summarized in Table 3. According to Table 3, all calculated $\chi^2_{\text{homogeneous}}$ values of stations for P and Tmax are less than χ^2_{critical}(=19.68), on the other hand $\chi^2_{\text{homogeneous}}$ values of four stations for Tmin are greater than critical value (Khanaquin, Anah, Najaf and Diwaniya). In general, if $\chi^2_{\text{homogeneous}}$ is less than χ^2_{critical}, the null hypothesis of homogeneous seasonal trends over time (implying that trends in all months have the same direction and magnitude) should be accepted (Kahya and Kalayci 2004). This implies that SK, and ST tests can be used to detect seasonal trends. Otherwise, the Mann–Kendall test is suggested to apply for each individual season. Since the seasonal trend results of four stations for Tmin obtained from SK and ST tests are questionable, these stations are excluded from the following analysis. The χ^2_{trend} in Table 3 refers to a common trend in all months. The trend is accepted as statistically significant if χ^2_{trend} statistic is greater than 3.84.

The percentage of stations with significant trends obtaining from SK and ST tests for monthly P, Tmax and Tmin are summarized in Table 4. It indicates that SK trend results for monthly precipitation data appear to analogical with the ST test for all stations except for Mosul, Anah, and Nukhaib stations. Among 28 stations, a total number of stations containing negative statistically significant trend is 14 (11) based on SK (ST) test. The other stations have also decreasing trend in monthly precipitation except for Samawa and Amara stations but they are not statistically significant. In fact, Amara station has decreasing (increasing) trend based on SK (ST) test. The spatial

Table 2 The Spearman's rho coefficients for precipitation and temperature with NAO index

Stations	Precipitation				Tmax					Tmin				
	Annual	Winter	Spring	Fall	Annual	Winter	Spring	Summer	Fall	Annual	Winter	Spring	Summer	Fall
Mosul	0.18	−0.1	0.08	0.23	−0.32	−0.43[a]	0.03	−0.34	0.24	−0.46[a]	−0.11	0	−0.48[a]	0.05
Arbil	0.14	−0.02	0.04	0.16	−0.2	−0.18	−0.28	−0.29	−0.08	−0.45[a]	−0.43[a]	−0.37[a]	−0.49[a]	0.11
Salahuddin	0.02	−0.09	0.02	0.16	−0.23	−0.23	−0.18	−0.42[a]	0.11	−0.17	−0.13	−0.38[a]	−0.1	−0.17
Rabiah	0.02	−0.11	−0.03	0.05	−0.25	−0.12	−0.23	−0.55[a]	0.09	−0.27	−0.22	−0.27	−0.23	0.14
Tel affar	0.2	−0.13	0.1	0.15	−0.24	−0.08	−0.24	−0.19	−0.23	−0.44[a]	−0.26	−0.2	−0.48[a]	−0.07
Sinjar	0.11	0.22	0.36[a]	0.04	−0.32	−0.15	−0.06	−0.45[a]	−0.14	−0.31	−0.33	−0.2	−0.56[a]	0.04
Kirkuk	0.12	0.31	0.39[a]	−0.18	−0.3	−0.19	−0.14	−0.35	−0.44[a]	−0.38[a]	−0.4[a]	−0.29	−0.53[a]	−0.12
Baiji	0.12	0.25	0.3	−0.25	−0.43[a]	−0.27	−0.04	−0.4[a]	−0.32	−0.33	−0.35	−0.18	−0.57[a]	−0.04
Tikrit	0.22	0.06	−0.06	0.2	−0.44[a]	−0.31	−0.07	−0.45[a]	−0.2	−0.44[a]	−0.41[a]	−0.34	−0.61[a]	−0.16
Khanaqin	0.07	−0.04	−0.07	0.26	−0.42[a]	−0.23	−0.13	−0.53[a]	−0.25	−0.42[a]	−0.34[a]	−0.17	−0.62[a]	−0.22
Al-Kaim	0.01	0.01	−0.13	−0.15	−0.2	−0.32	−0.14	−0.44[a]	−0.08	−0.53[a]	−0.28	−0.32	−0.61[a]	−0.03
Haditha	0.17	0.11	−0.23	0.08	−0.35[a]	−0.39[a]	−0.04	−0.49[a]	0.1	−0.37[a]	−0.39[a]	−0.25	−0.63[a]	0.13
Anah	0.05	−0.04	−0.18	0.05	−0.41[a]	−0.36[a]	−0.06	−0.43[a]	0	−0.24	−0.29	−0.29	−0.42[a]	0.11
Ramadi	0.28	0.4[a]	−0.05	0.12	−0.41[a]	−0.23	−0.15	−0.46[a]	−0.19	−0.39[a]	−0.12	−0.12	−0.55[a]	−0.02
Baghdad	0.12	0.12	−0.11	0.13	−0.42[a]	−0.31	−0.2	−0.46[a]	−0.18	−0.37[a]	−0.37[a]	−0.22	−0.56[a]	−0.07
Al Khalias	0.3	0.18	−0.03	0.35[a]	−0.4[a]	−0.34	−0.23	−0.43[a]	−0.15	−0.24	−0.35[a]	−0.3	−0.45[a]	−0.05
Rutba	0.02	0.05	−0.16	−0.22	−0.5[a]	−0.27	−0.21	−0.51[a]	−0.2	−0.34	−0.35[a]	−0.1	−0.42[a]	−0.05
Kerbala	0.06	0.04	−0.11	0.19	−0.39[a]	−0.31	−0.27	−0.5[a]	0.15	−0.37[a]	−0.34	−0.25	−0.57[a]	−0.09
Azizyia	0.29	0.09	−0.18	0.29	−0.25	−0.29	−0.11	−0.4[a]	−0.12	−0.25	−0.23	−0.19	−0.58[a]	−0.04
Hilla	0.04	0.01	−0.22	0.07	−0.36[a]	−0.3	−0.13	−0.38[a]	−0.01	−0.37[a]	−0.46[a]	−0.34	−0.47[a]	0.06
Al-hai	0.14	0.14	−0.11	0	−0.43[a]	−0.29	−0.2	−0.49[a]	−0.13	−0.32	−0.21	−0.28	−0.4[a]	−0.13
Najaf	0.13	0.09	−0.06	0.11	−0.49[a]	−0.29	−0.21	−0.53[a]	−0.15	−0.33	−0.32	−0.17	−0.4[a]	−0.01
Diwaniya	0.24	0.12	−0.19	0	−0.42[a]	−0.35	−0.15	−0.5[a]	−0.01	−0.43[a]	−0.27	−0.27	−0.57[a]	−0.09
Nukhaib	0.23	−0.16	−0.07	0.12	−0.3	−0.23	−0.17	−0.48[a]	0.05	−0.38[a]	−0.37[a]	−0.11	−0.53[a]	−0.05
Samawa	0	0.27	−0.09	0.1	−0.54[a]	−0.3	−0.25	−0.45[a]	−0.06	−0.31	−0.23	−0.23	−0.52[a]	0.12
Amara	0.16	−0.02	−0.11	0.04	−0.5[a]	−0.27	−0.2	−0.53[a]	−0.11	−0.35[a]	−0.42[a]	−0.29	−0.58[a]	−0.06
Nasiriya	0.23	0.01	0.03	0.22	−0.41[a]	−0.34	−0.24	−0.55[a]	0.02	−0.29	−0.4[a]	−0.26	−0.58[a]	0.01
Basra	0.26	0.18	0.1	−0.11	−0.43[a]	−0.21	−0.41[a]	−0.38[a]	−0.26	−0.38[a]	−0.29	−0.39[a]	−0.47[a]	0.17

[a] Correlation coefficient is statistically significant at 95 % level

distribution of monthly total P trends according to SK and ST test are plotted on a map in Fig. 5.

Regarding to monthly temperature series, the results of significance trend showed similarity of 100 % between two tests. That means, significant trends were more common in temperature than precipitation. Although monthly temperature data have significant increasing trend in Tmax for all stations (Table 4), the statistically significant increasing trends were observed for all stations except for Salahuddin station in Tmin.

According to SKS estimator, all stations except for Azizyia showed a downward slope for monthly precipitation data. The magnitude of significant decreasing trends varied from 0.0133 to 0.543 mm year^{-1}. Actually, Rabiah station located in the northern Iraq had a maximum downward trend with a slope of 0.543 mm year^{-1}. As for Tmax (Tmin), the highest slope of the significant upward trend were observed as 0.1, 0.1 (0.87) °C year^{-1} in Najaf, Nasiriya (Nukhaib), while lowest slope of the significant upward trend were observed as 0.03 (0.024) °C year^{-1} in Rabiah (Samawa).

In this study, the impact of the NAO on seasonal precipitation, Tmax, and Tmin was also calculated during winter (December–Febraury), spring (March–May), summer (June–August), and fall (September–November) seasons. As shown in Table 2, the majority of the correlation coefficients between the winter (and fall) precipitation and the corresponding NAO index were positive. In fact, about 68 and 75 % of the stations have positive correlations in the winter and fall season, respectively. The positive correlation coefficient is statistically significant at Ramadi (Al-Khalias) for winter (fall) season. The correlation coefficient amount indicated that 16 % (12 %) of the winter (fall) variance can be explained by the NAO

Table 3 Results of homogeneity of trends between months based on the Van Belle and Hughes

Station	Precipitation		Max. Temperature		Min. Temperature	
	$x^2_{\mathrm{hemogenous}}$	x^2_{trend}	$x^2_{\mathrm{hemogenous}}$	x^2_{trend}	$x^2_{\mathrm{hemogenous}}$	x^2_{trend}
Mosul	7.3	5.3^{a}	8.1	43.5^{a}	15.4	26.7^{a}
Arbil	7.9	6.4^{a}	3.8	19.0^{a}	4.5	18.4^{a}
Salahuddin	15.6	0.95	7.2	35.5^{a}	4.4	0.1
Rabiah	6.3	11.4^{a}	19.6	8.2^{a}	15.4	33.5^{a}
Tel Affar	9.4	9.0^{a}	8	25.0^{a}	9	32.9^{a}
Sinjar	8.5	6.6^{a}	5.9	52.5^{a}	6	52.1^{a}
Kirkuk	6.4	7.2^{a}	11.8	13.9^{a}	10.6	32.7^{a}
Baiji	8.4	2.5	6.6	30.8^{a}	13.6	30.0^{a}
Tikrit	5.7	4.6^{a}	6.6	20.3^{a}	13.6	21.9^{a}
Khanaqin	7.2	6.2^{a}	9.1	61.4^{a}	20.1^{b}	
Al-Kaim	6.8	9.1^{a}	6.4	30.8^{a}	9.8	37.5^{a}
Haditha	9.3	10.7^{a}	3.7	41.8^{a}	18.4	35.7^{a}
Anah	4.9	5.2^{a}	7.8	27.0^{a}	19.8^{b}	
Ramadi	4.9	0	11.2	49.4^{a}	18.3	35.0^{a}
Baghdad	6	1.1	10.1	37.8^{a}	13.6	36.1^{a}
Al Khalias	9.1	8.9^{a}	9.4	28.9^{a}	9.4	10.2^{a}
Rutba	7.9	6.2^{a}	9.6	52.5^{a}	11.6	49.7^{a}
Kerbala	5.1	1.1	12.9	36.9^{a}	18.3	43.3^{a}
Azizyia	3.3	1.8	13.1	11.4^{a}	10.5	10.4^{a}
Hilla	3.9	1.1	15	20.6^{a}	11.2	25.1^{a}
Al-Hai	6.1	1.4	5.5	29.2^{a}	24.4	56.4^{a}
Najaf	9.3	0.5	5.5	67.0^{a}	19.8^{b}	
Diwaniya	4.2	1.7	6.7	31.5^{a}	22.2^{b}	
Nukhaib	2.1	3.85^{a}	5.1	38.2^{a}	9.5	43.9^{a}
Samawa	4.3	0.1	9.6	15.8^{a}	8	7.4^{a}
Amara	4.8	0.4	15.8	48.5^{a}	8.6	46.3^{a}
Nasiriya	8.6	2	6.8	60.2^{a}	13.6	43.1^{a}
Basra	8.6	2	9.2	52.9^{a}	16.1	21.2^{a}

[a] A common trend in all months is significant, in precipitation and temperature, the critical values of $x^2_{\mathrm{homogeneous}}$ and x^2_{trend} at $\alpha = 5$ % level equal to 19.68 and 3.84, respectively

[b] The monthly trends are non-homogeneous

Table 4 The percentage of stations with significant trends obtaining from SK and ST tests for seasonal data (1980–2011)

	Trend test for Seasonal data			
	SK		ST	
	Significant positive	Significant negative	Significant positive	Significant negative
Precipitation		50		39
Tmax	100		100	
Tmin	96		96	

forcing. However, these amounts are too small to get conclusion that NAO influences the winter and fall precipitation in Iraq. On the other hand, the relationships between the spring precipitation and corresponding NAO phase are mostly characterized as a negative correlation in Iraq except for nine stations. The correlations between them are also very weak.

The correlations between the seasonal Tmax (Tmin) and the corresponding NAO index were generally found as negative. The negative correlations between the summer Tmax (Tmin) and the NAO index were found to be significant at all stations except for four (two) stations. The strongest negative correlations of 0.55 (0.63) were calculated at Nasiriya (Haditha) station. The correlation between summer Tmax (Tmin) and NAO index were in the range

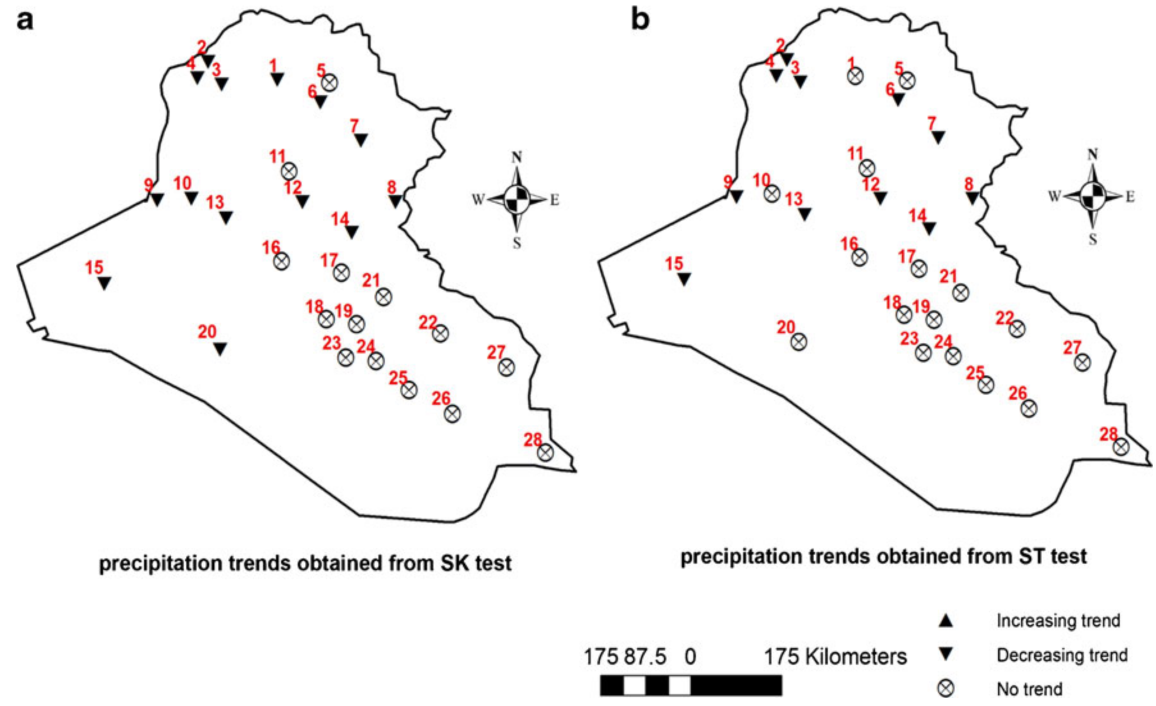


Fig. 5 The spatial distribution of monthly precipitation trends obtained from **a** SK and **b** ST

from 0.2 (0.1) to 0.55 (0.63), indicating that about 4 (1)–30 (40)% of the variance in the pattern of temperature is associated with NAO forcing as in annual one. From these results, it can be concluded that the impacts of NAO on temperature variability is stronger during summer than other seasons.

Conclusions

The trend for annual and monthly precipitation and temperature data series from 28 stations distributed in different regions of Iraq were temporally and spatially analyzed. The annual and monthly data series results showed that upward and downward trend for Tmax–Tmin and P, respectively. Therefore, these indicators displayed the climate change effect on the study area. We confirmed, as in previous studies, that the study region vulnerable to increasing and decreasing trend in temperature and precipitation, respectively. Although decreasing (increasing) precipitation (temperature) amounts can be related to trend of NAO, our analysis showed that NAO effect was not found to influence precipitation patterns in this region. However, this situation is not valid for temperature pattern. It was found that approximately 29 % of annual temperature variance was influenced by the NAO forcing. Moreover, it was found that 30 (40)% of summer Tmax(Tmin) variance was influenced by NAO event. The impact of NAO on precipitation and temperature in this study are consistent with some previous study conducted in other regions in Middle East such as Saudi Arabia, Iran and Kuwait. For example, Hafez and Almazroui (2013) found that the surface air temperature was significant negative correlated with the NAO, while the relationship between the precipitation and NAO were a positive correlation over Saudi Arabia during the period 1979–2011. In addition, Almazroui (2012) revealed that the statistically significant negative correlations for temperature was prominent over Saudi Arabia during the winter and summer, while insignificant correlation during the autumn. In Iran region, Masih et al. (2011) provided that the relationship between NAO index and precipitation was very weak, while they indicated negative significant correlations for temperature in the western part of Iran. Marcella and Eltahir (2008) emphasized insignificant correlation between Kuwait rainfall and NAO on a monthly or yearly time scale. These studies are meaningful to approve the results of the present study. Since our study shows that NAO has no detectable influences on climate of this region, heat island, desertification and greenhouse effect on variables should be considered to explain the existing climate pattern variance.

Finally, the obtained results clarify and give an indication about the temporal and spatial behavior of precipitation and temperature over the regions. We should emphasize that the increase in population together with the decreasing in precipitation and increasing in temperature can produce the stress on limited water resources in Iraq.

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