

# Recent trends in regional air temperature and precipitation and links to global climate change in the Maharlo watershed, Southwestern Iran

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**Abstract** Trends in air temperature and precipitation data are investigated for linkages to global warming and climate change. After checking for serial correlation with trend-free pre-whitening procedure, the Mann–Kendall test is used to detect monotonic trends and the Mann–Whitney test is used for trend step change. The case study is Maharlo watershed, Southwestern Iran, representing a semi-arid environment. Data are for the 1951–2011 period, from four temperature sites and seven precipitation sites. A homogeneity test investigates regional similarity of the time series data. The results include mean annual, mean annual maximum and minimum and seasonal analysis of air temperature and precipitation data. Mean annual temperature results indicate an increasing trend, while a non-significant trend in precipitation is observed in all the stations. Furthermore, significant phase change was detected in mean annual air temperature trend of Shiraz station in 1977, indicating decreasing trend during 1951–1976 and

increasing trend during 1977–2011. The annual precipitation analysis for Shiraz shows a non-significant decrease during 1951–1976 and 1977–2011. The result of homogeneity test reveals that the studied stations form one homogeneous region. While air temperature trends appear as regional linkage to global warming/global climate change, more definite outcome requires analysis of longer time series data on precipitation and air temperature.

## 1 Introduction

Global warming observed in the last few decades has been linked to large-scale changes in the hydrologic cycle including: increase in the amount of water vapor in the atmosphere, variable precipitation patterns (intensity and extremes), reduced snow cover and widespread ice melting and changes in soil moisture and runoff (Bates et al. 2008). The results have led to a decrease in the available water resources, which is more clearly evident in the dry areas where agricultural water use represents the majority of the water. Thus, the study of changes in precipitation and temperature, as the most important factors in assessing climate change is essential.

Climate change can be detected as a result of change in the state of the climate, normally identified by changes in the mean and/or the variability of the mean properties, persisting for an extended period, which could last for decades or longer. Such changes may be due to natural variability and/or human activity. According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007), the global average surface temperature has increased by about 0.74 °C over the twentieth century.

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Dore (2005) by synthesizing the large literature recording changing patterns of precipitation in the observed data reveals that variance of precipitation has increased just about everywhere, wet areas have become wetter and dry and arid areas have become drier. In addition, the following general changing pattern is emerging: (a) increased precipitation in high latitudes (Northern Hemisphere); (b) reduction in precipitation in China, Australia and the Small Island States in the Pacific; and (c) increased variance in equatorial regions.

Climate change is increasingly recognized as a global challenge to assess climate change/variability in various parts of the world, especially regarding its impacts on the natural and human systems (IPCC 2007). For example, Burns et al. (2007) used Mann–Kendall test to evaluate annual, monthly, and multi-month trends in air temperature, precipitation amount, stream runoff, and potential

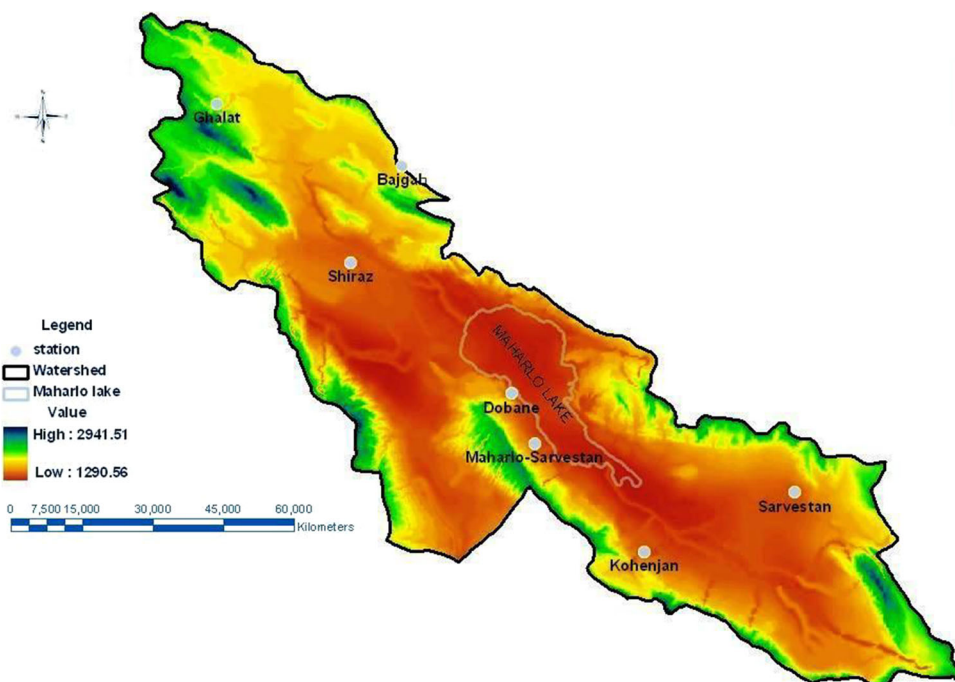
evapotranspiration in the Catskill region of southeastern New York State during 1952–2005. They found a general pattern of warming temperatures and increased precipitation in the region. Fan and Wang (2011) showed that annual mean air temperature has increased by 1.20 °C, and annual precipitation has decreased by 99.20 mm during the past 50 years across Shanxi, China.

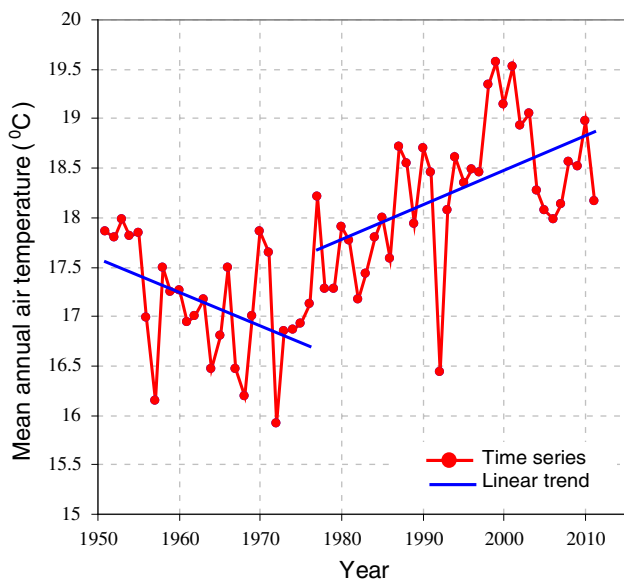
Khattak et al. (2011) revealed an increasing trend in winter maximum temperature with the trend in slopes of 1.79, 1.66, and 1.20 °C per 39 year for the upper, middle, and lower regions, respectively, in the upper Indus River basin in Pakistan. They also reported precipitation trends were inconsistent and showed no definite pattern. For Greece, Marougianni et al. (2013) showed that peak temperature extremes are becoming warmer, especially for the minimum temperatures, while precipitation is decreasing over the area with variable local significance though. De Luis et al. (2012) indicated that mean annual temperature significantly increased in nearly all of Slovenia (except western areas) at rates between 0.15 and 0.36 °C/decade. Warming was most intense strongest in summer and spring in Northeastern Slovenia (0.3–0.4 °C/decade) and weakest in autumn. Precipitation trends were heterogeneous. Annual precipitation decreased significantly in the northwestern part, at 3–6 % per decade. During spring and summer, decrease in rainfall by 3–6 % was detected in Western Slovenia. No significant trends were found for the autumn season. In winter, precipitation decreased, by 3–12 % per decade, in particular in Northwestern Slovenia.

**Table 1** Geographical information of the studied stations

Station name	Elevation (m)	Longitude DMS	Latitude DMS
Bajgah	1,810	29-50-00	52-46-00
Dobane	1,490	29-25-08	52-46-52
Ghalat	2,050	29-49-08	52-19-40
Kohenjan	1,469	29-12-00	52-59-00
Maharlo–Sarvestan	1,490	29-21-00	52-49-00
Sarvestan	1,570	29-16-38	53-13-09
Shiraz	1,488	29-36-00	52-32-00

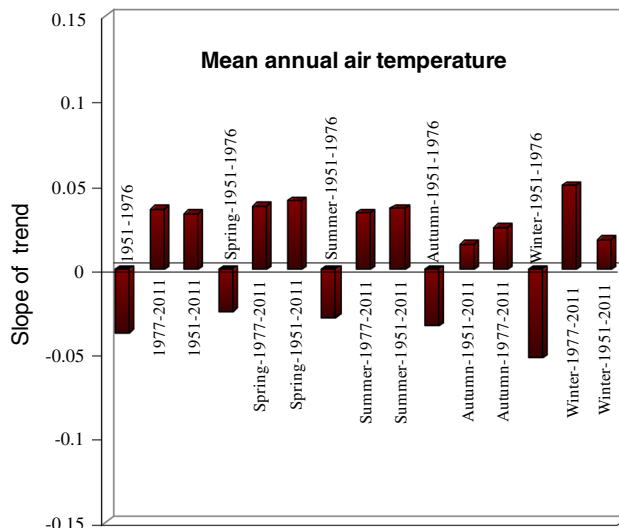
**Fig. 1** Station locations in the study area





**Fig. 2** Mean annual air temperature time series and its linear trend in Shiraz station

Gocic and Trajkovic (2013) showed increasing trends in both annual and seasonal minimum and maximum air temperature series and no significant trends in summer and winter precipitation series in Serbia during 1980–2010. In Nigeria during 1901–2000, Oguntunde et al. (2012) indicated a significant decreasing of temperature during 1931–1960, while 1961–1990 showed a significant increasing of temperature and no significant trend was detected for 1901–1930. They showed annual temperature has risen by 0.03 °C/decade during last century. Chen et al. (2007) reported significant upward trends in the temperature in most parts of the Hanjiang Basin, but no trend in precipitation in the study area. Feng et al. (2011) demonstrate significant increasing trends in annual and seasonal mean temperature series in Nenjiang River Basin, with few spatial differences compared to spatial and temporal variations of the precipitation trend. Significant trends of annual, summer, autumn and winter precipitation series with decreasing trends were detected, which mainly



**Fig. 3** Slopes of trends in mean annual and seasonal air temperature in Shiraz station

concentrate on the right bank, while increasing trends were found on the left bank of the basin.

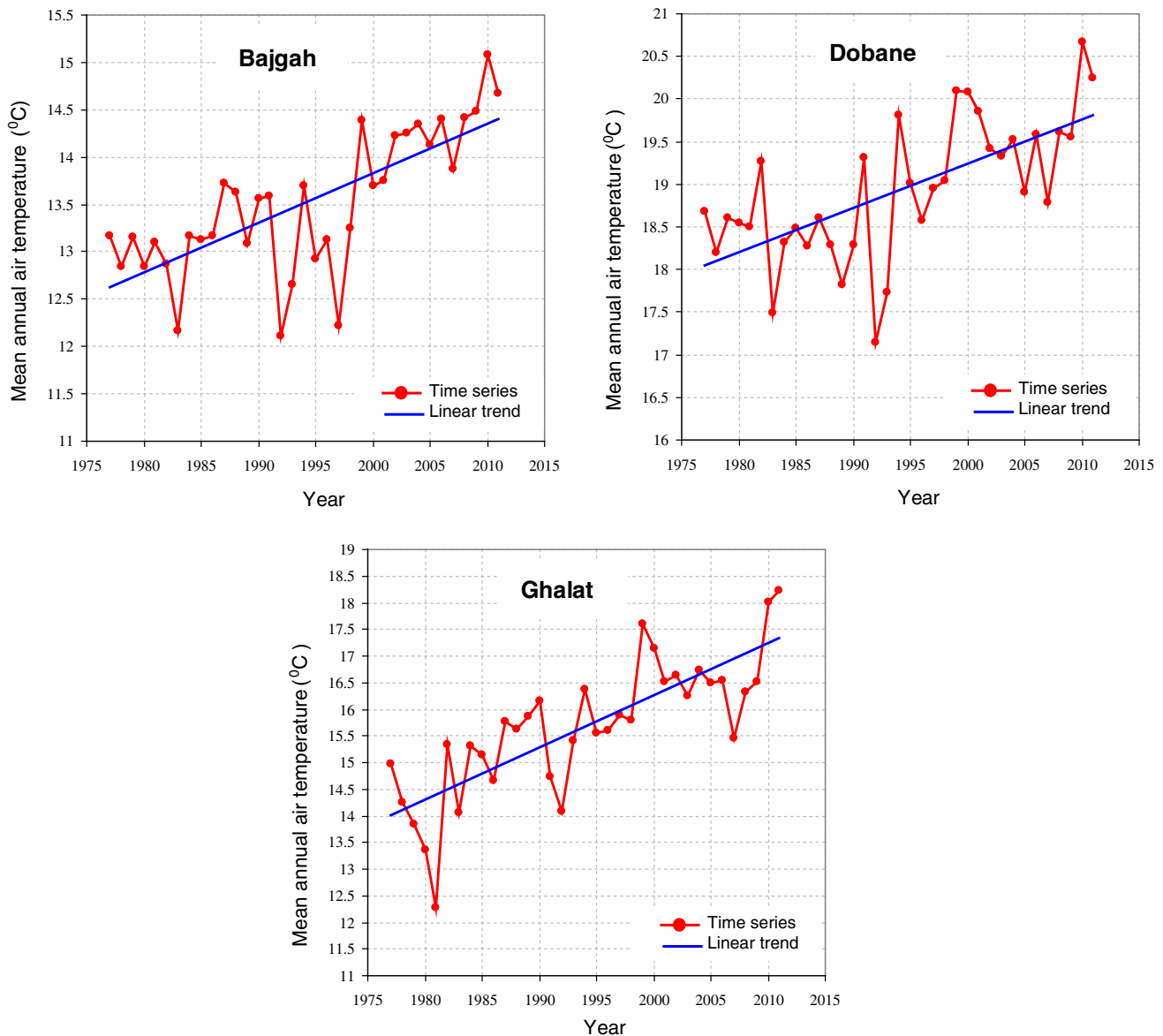
In Hungary during 1901–1998, Domonkos and Tar (2003) indicated a non-significant increasing of mean temperature and significant decreasing of annual precipitation during the twentieth century. Some other works that reported temperature and precipitation trend can be found in Zhang et al. (2000), Suhaila et al. (2010), Hingane et al. (1985), Xu et al. (2003), Terzago et al. (2012), Wolock et al. (1993), Turkes (1996), Kadioglu (1997), Cannarozzo et al. (2006), Kampata et al. (2008), Unkasevic and Tosic (2011), Yaning et al. (2009), among many others.

A review of literature shows that some studies have devoted their efforts to identify possible climate change/variability over Iran, based on the information of individual stations, e.g., Ghahraman (2006) evaluated trend of mean annual temperature at 34 stations in Iran by the Student’s *t* test. He concluded that there was an upward trend in 50 % of the stations, while 41 % of the stations had a downward trend. Modarres and Silva (2007) analyzed annual rainfall, number of rainy days per year and monthly rainfall of 20

**Table 2** Results of Mann–Kendall test at the significance level 5 % for mean annual and seasonal air temperature sub-series

Station	Time series	Z											
		Annual	<i>H</i> <sub>0</sub>	Spring	<i>H</i> <sub>0</sub>	Summer	<i>H</i> <sub>0</sub>	Autumn	<i>H</i> <sub>0</sub>	Winter	<i>H</i> <sub>0</sub>		
Shiraz	1951–2011	5.334	r	5.487	r	5.266	r	3.79	r	2.467	r		
	1951–1976	−2.403	r	−0.971	n	−1.261	n	−1.883	n	−2.053	r		
	1977–2011	3.168	r	2.802	r	2.393	r	1.253	n	2.716	r		
Bajgah	1977–2011	4.723	r	3.46	r	4.842	r	4.656	r	2.291	r		
Dobane	1977–2011	3.874	r	3.056	r	4.141	r	3.488	r	2.193	r		
Ghalat	1977–2011	5.222	r	4.057	r	5.276	r	4.18	r	3.33	r		

*r* null hypothesis rejected, *n* not rejected



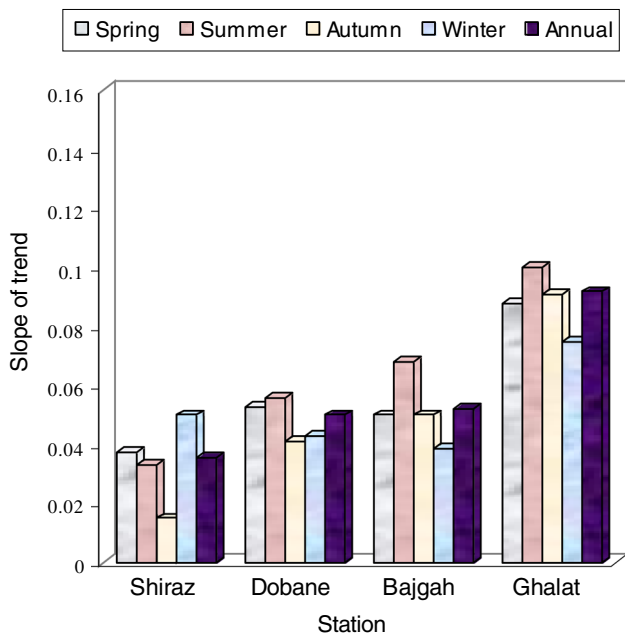
**Fig. 4** Mean annual air temperature time series and its linear trend in Bajgah, Dobane and Ghalat stations of Maharlo watershed (1977–2011)

stations to assess climate variability in arid and semi-arid regions of Iran. Their results showed mixed trends of increasing and decreasing rainfall with no significant trend for annual rainfall and no significant trend for mean number of rainy days per year in 90 % of stations.

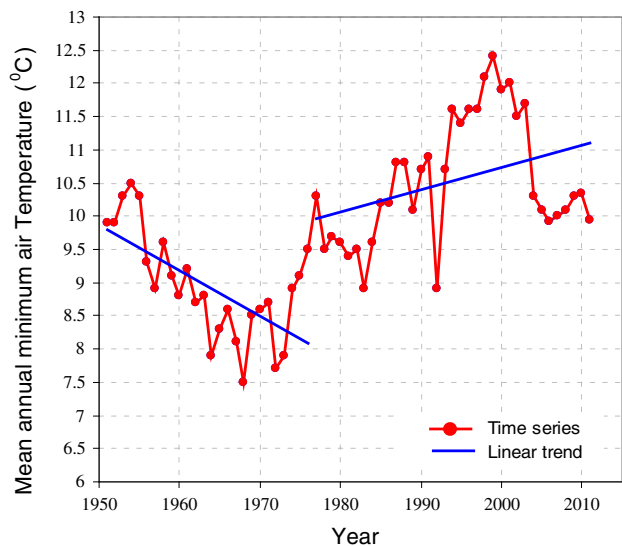
Kousari et al. (2011) evaluated trend analysis of minimum, maximum and mean temperatures, relative humidity, and the precipitation in the eastern and central areas and, to some extent, the northern parts of Iran on monthly and yearly scales in 26 stations. The results indicated a significant decrease in the precipitation in summer and minimum air temperature showed more significant changes compared to the other studied parameters. Modarres and Sarhadi (2009) analyzed the

spatial and temporal trend of the annual and 24-h maximum rainfall in 145 stations of Iran. Their results showed the annual rainfall decreased in 67 % of the stations, while the 24-h rainfall annual maximum increased in 50 % of the stations.

Tabari and Hosseinzadeh Talaei (2011) analyzed temporal variability of maximum and minimum air temperatures for 20 stations from 1966 to 2005 in the western half of Iran in monthly, annual and seasonal scales. The results revealed increasing trends in 85 % of the stations, whereas 15 % of the stations had decreasing trends. Banimahd et al. (2013) investigated precipitation-based climate change and cyclic variation for regions with different climatic conditions and showed that climate change as a result of



**Fig. 5** Slopes of trends in mean annual and seasonal air temperature in Shiraz, Bajgah, Dobane and Ghalat stations of Maharlo watershed



**Fig. 6** Mean annual minimum air temperature time series and its linear trend in Shiraz station

significant variability in annual precipitation could not be confirmed for the stations studied in Iran.

Only a few studies have given attention to the regional trend analysis of climate with high resolution over Iran (e.g., Masih et al. 2011; Marofi et al. 2012). In this case, analysis of the regional trend would seem to be of research interest. The objective of this study is to investigate possible regional trends in watershed scale and step changes in

air temperature and precipitation data, as possible linkages to the global warming/global climate change. The case study is Maharlo watershed located in Fars province, Southwestern Iran.

**2 Materials and methods**

**2.1 The study area and data**

The study area is the Maharlo watershed with a drainage area of 4,272 km<sup>2</sup> located in Fars province, southwestern region of Iran, at 52°11'–53°29'E longitudes and 29°13'–29°59'N latitudes. This urban watershed has a northwest–southeast extent, with 2,019 km<sup>2</sup> of lowland and 2,253 km<sup>2</sup> of highlands. Ghalat Mountain with an elevation of 2,990 m above sea level and the floor of Maharlo Lake with 1,453 m above sea level are the highest and lowest points in the region, respectively. Shiraz and Sarvestan are the most important cities in the region. There is no perennial river in the region and only Khoshk and Chenar–Rahdar ravines of Shiraz plain and Nazarabad ravine in Sarvestan plain pour into Maharlo Lake. Spring time is temperate, followed by a hot summer and mild winter. Since water input rate is usually less than the evaporation rate, a salt layer is always formed on the surface of Maharlo Lake.

In this study input data consist of mean annual, mean annual minimum and maximum air temperature and monthly and annual precipitation, collected by the Iranian Regional Water Resources Departments and also Iranian metrological Organization (Table 1). The studied stations are shown in Fig. 1. As is shown in the table and Fig. 1, there are a total of seven stations (three rain gauge stations and four climatological stations) in the study area. The rain gauge stations only measure rainfall, whereas climatological stations measure rainfall as well as other parameters including temperature. Therefore, there are seven stations with rainfall data and four stations with temperature data.

**2.2 Serial correlation**

Trend-free pre-whitening procedure proposed by Yue et al. (2002) was used to detect a significant trend in a time series data with significant serial correlation, based on the following steps:

Following the works of Theil (1950a, b, c) and Sen (1968), the slope of the trend line (b) is computed.

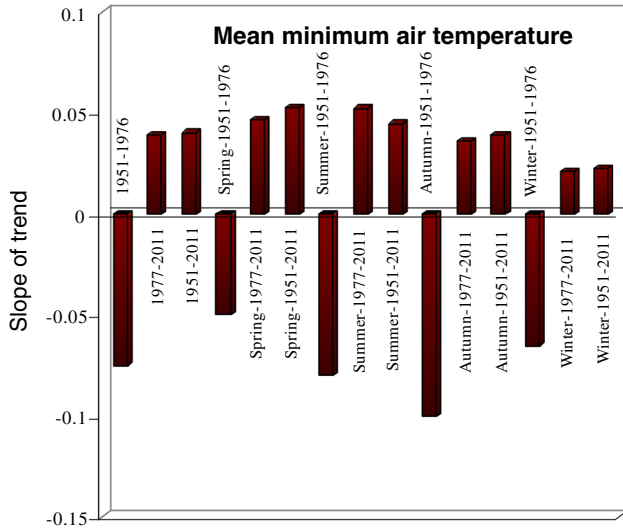
$$b = \text{Median} \left( \frac{X_j - X_i}{j - i} \right) \quad \forall i < j \tag{1}$$

where  $X_j$  and  $X_i$  are respective data values at times  $j$  and  $i$  ( $j > i$ ) for  $N$  pair of data. Then, data series is de-trended by:

**Table 3** Results of Mann–Kendall test at the significance level 5 % for mean annual and seasonal minimum air temperature sub-series

Station	Time series	Z												
			Annual	$H_0$	Spring	$H_0$	Summer	$H_0$	Autumn	$H_0$	Winter	$H_0$		
Shiraz	1951–2011	4.524	r		5.574	r	4.492	r	3.319	r	2.985	r		
	1951–1976	−3.269	r		−1.876	n	−3.204	r	−2.963	r	−2.737	r		
	1977–2011	2.178	r		2.86	r	2.547	r	1.151	n	1.238	n		
Bajgah	1977–2011	5.041	r		2.665	r	4.131	r	2.832	r	1.893	n		
Dobane	1977–2011	2.564	r		2.789	r	3.557	r	0.699	n	1.024	n		
Ghalat	1977–2011	3.756	r		3.286	r	3.103	r	3.214	r	2.29	r		

*r* null hypothesis rejected, *n* not rejected



**Fig. 7** Slopes of trends in mean annual and seasonal minimum air temperature in Shiraz station

$$X'_t = X_t - bt \tag{2}$$

The lag-one serial correlation coefficient ( $r_1$ ) of the detrended series  $X'_t$  is calculated using:

$$r_k = \frac{\frac{1}{n-k} \sum_{t=1}^{n-k} (X_t - \bar{X})(X_{t+k} - \bar{X})}{\frac{1}{n} \sum_{t=1}^n (X_t - \bar{X})^2} \tag{3}$$

If

$$\frac{-1 - 1.645\sqrt{n-2}}{n-2} \leq r_1 \leq \frac{-1 + 1.645\sqrt{n-2}}{n-2} \tag{4}$$

If data are assumed to be serially independent at a specific significance level, no pre-whitening is required (Anderson 1942; Yevjevich 1972; Salas et al. 1980). If data are serially correlated, pre-whitening is required before applying the Mann–Kendall test, applying the trend-free pre-whitening (TFPW) procedure as follows:

First, the lag-one autoregressive component is removed from the  $X'_t$  by:

$$Y'_t = X'_t - r_1 X'_{t-1} \tag{5}$$

Then, trend ( $b \times t$ ) is added to  $Y'_t$ :

$$Y_t = Y'_t + bt \tag{6}$$

It is evident that the blended series  $Y_t$  could preserve the true trend and is no longer influenced by the effects of autocorrelation. Therefore, the Mann–Kendall test is applied to the blended series to assess the significance of the trend.

### 2.3 Mann–Kendall test

Trend analysis was evaluated with the non-parametric Mann–Kendall test (Mann 1945; Kendall 1975), which reliably identifies monotonic linear and non-linear trends in non-normal data sets with outliers (Helsel and Hirsch 2002). The test is based on the statistic  $S$ , which is calculated using the formula:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(x_j - x_k) \tag{7}$$

$$\text{sgn}(x_j - x_k) = \begin{cases} +1 & \text{if } x_j - x_k > 0 \\ 0 & \text{if } x_j - x_k = 0 \\ -1 & \text{if } x_j - x_k < 0 \end{cases} \tag{8}$$

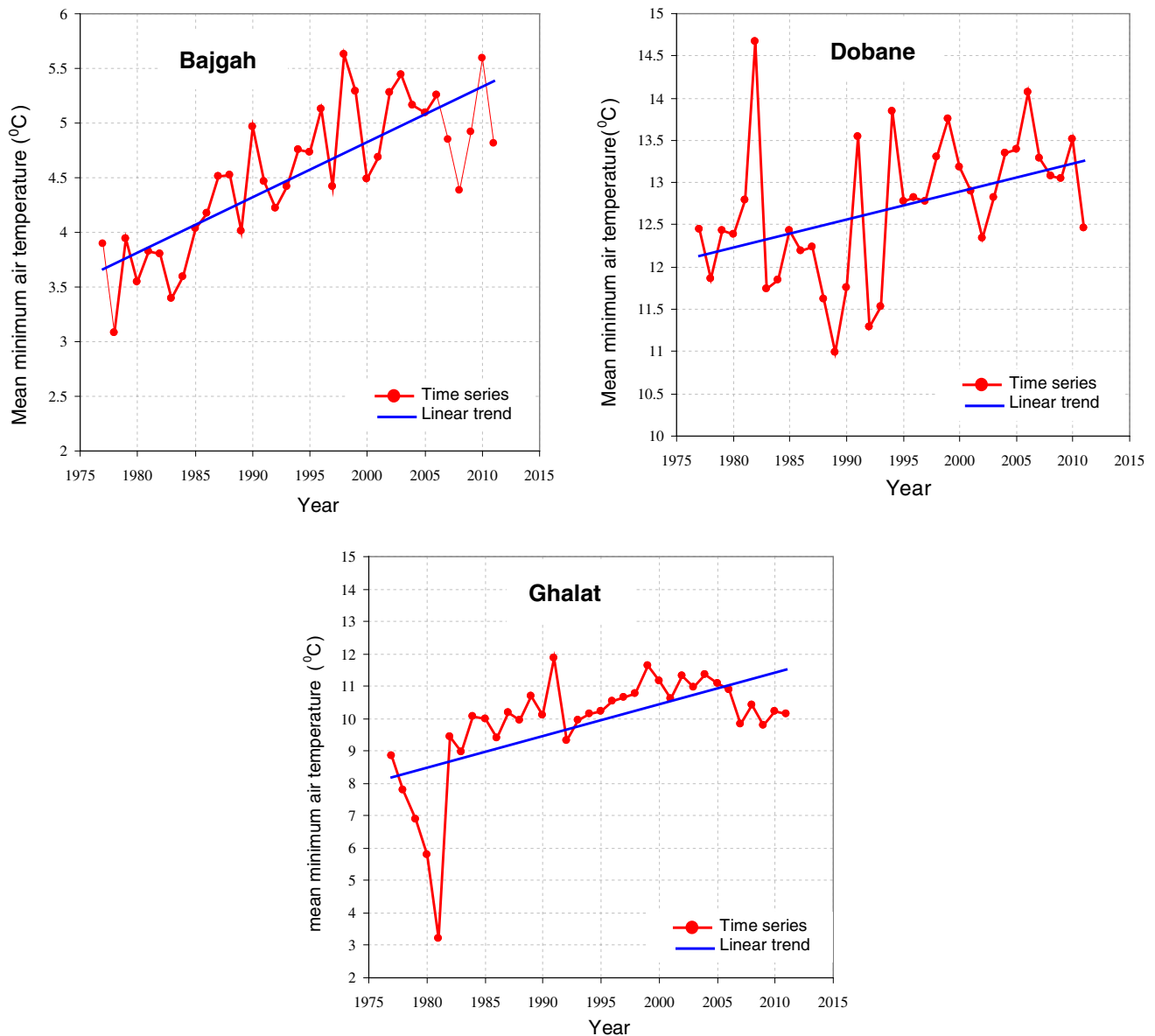
where  $n$  is the number of observed data series,  $x_j$  and  $x_k$  are the values in periods  $j$  and  $k$ , respectively ( $j > k$ ). For  $n \geq 10$ , the sampling distribution of  $S$  is as follows.  $Z$  follows the standard normal distribution:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 \end{cases} \tag{9}$$

where  $\text{Var}(S)$  is determined as

$$\text{Var}(S) = \frac{1}{18} \left[ n(n-1)(2n+5) - \sum_{n-1}^q t_p(t_p-1)(2t_p+5) \right] \tag{10}$$





**Fig. 8** Mean annual minimum air temperature time series and its linear trend in Bajgah, Dobane and Ghalat stations of Maharlo watershed (1977–2011)

where  $q$  is the number of tied groups, and  $t_p$  is the number of data values in the  $p$ th group. If  $|Z| > Z_{1-\alpha/2}$ , null hypothesis is rejected and a significant trend exists in the time series.  $Z_{1-\alpha/2}$  is the critical value of  $Z$  from the Standard Normal Table, for 95 % confidence the value of  $Z_{1-\alpha/2}$  is 1.96. A positive value of  $Z$  indicates an upward trend, and a negative one shows a downward trend. The slope of each trend was identified by the method of Sen (1968) as the median of all possible pairwise slopes.

#### 2.4 Step change analysis

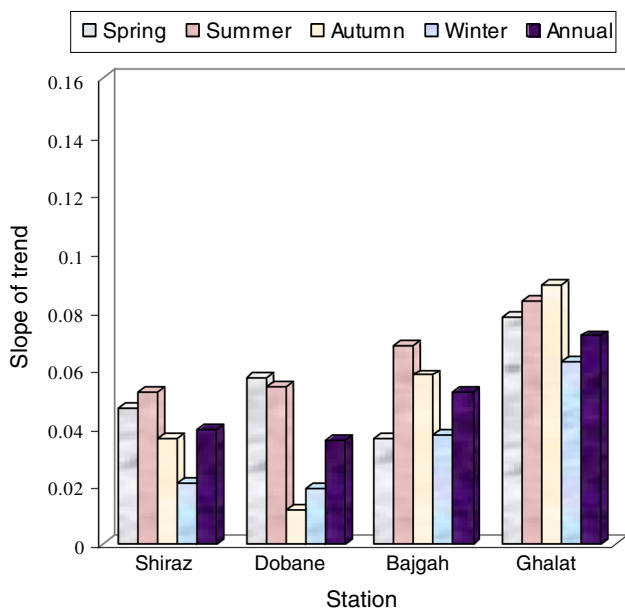
The Mann–Whitney step change test for difference in medians is a non-parametric test of two subsets of data

representing pre- and post-intervention period and goes by many names such as the Wilcoxon rank-sum test, the Mann–Whitney test or the Wilcoxon–Mann–Whitney rank-sum test (Helsel and Hirsch 2002).

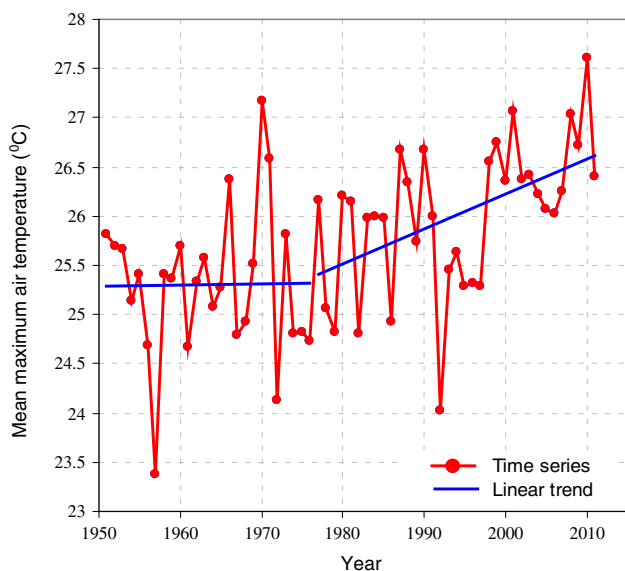
We used the standard procedure in computing the rank-sum test statistic, suggested by CRCCH (2005):

Rank all the data, from 1 (smallest) to  $N$  (largest). In the case of ties (equal data values), the average of ranks is used. The test statistic  $Z_{rs}$  is computed as:

$$Z_{rs} = \begin{cases} (S_m - 0.5 - \mu) / \sigma & \text{if } S_m > \mu \\ 0 & \text{if } S_m = \mu \\ (S_m + 0.5 - \mu) / \sigma & \text{if } S_m < \mu \end{cases} \quad (11)$$



**Fig. 9** Slopes of trends in mean annual and seasonal minimum air temperature in Shiraz, Bajgah, Dobane and Ghalat stations of Maharlo watershed



**Fig. 10** Mean annual maximum air temperature time series and its linear trend in Shiraz station

where

$$\mu = k(N + 1)/2 \tag{12}$$

$$\sigma = [km(N + 1)/12]^{0.5} \tag{13}$$

In the above equations,  $S_m$  is the sum of ranks of the observations in the smaller group,  $k$  is the number of observations in the smaller group,  $m$  is the number of

observations in the larger group and  $\mu, \sigma$  are the theoretical mean and standard deviation for the entire sample, respectively.

The null hypothesis,  $H_0$ , is that no change has existed in the time series or two samples come from the same population (i.e., have the same median) are accepted when the computed  $Z_{rs}$  is less than the  $Z$  value obtained from a normal distribution table at 5 % significance level.

### 2.5 Homogeneity test in trends

The test for homogeneity is described by van Belle and Hughes (1984). This method uses the Mann–Kendall statistic ( $Z$ ) for each station and sum these to compute the total Chi-square statistic, then compute “trend” and “homogeneous” Chi squares:

$$\chi^2_{(total)} = \sum_{i=1}^m Z_i^2 \tag{14}$$

$$\chi^2_{(trend)} = m\bar{Z}^2 \tag{15}$$

where

$$\bar{Z} = \frac{\sum_{i=1}^m Z_i}{m} \tag{16}$$

$$\chi^2_{(homogeneous)} = \chi^2_{(total)} - \chi^2_{(trend)} \tag{17}$$

The null hypothesis that the stations are homogeneous with respect to trend is tested by comparing  $\chi^2$  (homogeneous) to tables of the Chi-square distribution with  $m - 1$  degrees of freedom. If it exceeds the critical value for the pre-selected  $\alpha$ , reject the null hypothesis and conclude that different stations exhibit different trends.

## 3 Results and discussion

### 3.1 Serial correlation

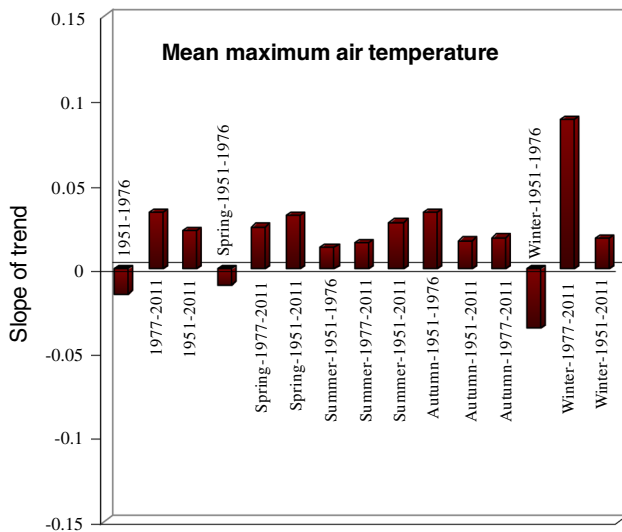
It is essential to examine data series for presence of serial correlation before using the non-parametric trend, test because existence of serial correlation will increase the probability that the Mann–Kendall test detects significant trend (e.g., Von Storch 1995). This leads to an unbalanced rejection of null hypothesis of no trend, whereas null hypothesis is actually true (Yue et al. 2002). In order to remove the influence of serial correlation on the Mann–Kendall test if present, we checked data series by prevalently used method, named as pre-whitening. In this study, the data series did not show any significant serial correlation, therefore we used Mann–Kendall monotonic trend test for the original data series.



**Table 4** Results of Mann–Kendall test at the significance level 5 % for mean annual and seasonal maximum air temperature sub-series

Station	Time series	Z										
			Annual	$H_0$	Spring	$H_0$	Summer	$H_0$	Autumn	$H_0$	Winter	$H_0$
Shiraz	1951–2011	3.959	r		4.051	r	4.555	r	2.043	r	1.557	n
	1951–1976	−0.863	n		−0.487	n	0.463	n	0.994	n	−0.684	n
	1977–2011	2.836	r		1.78	n	1.482	n	0.725	n	2.928	r
Bajgah	1977–2011	4.156	r		2.843	r	3.729	r	1.979	r	2.189	r
Dobane	1977–2011	3.81	r		3.128	r	3.954	r	2.533	r	3.142	r
Ghalat	1977–2011	3.859	r		2.928	r	4.508	r	2.674	r	2.373	r

*r* null hypothesis rejected, *n* not rejected

**Fig. 11** Slopes of trends in mean annual and seasonal maximum air temperature in Shiraz station

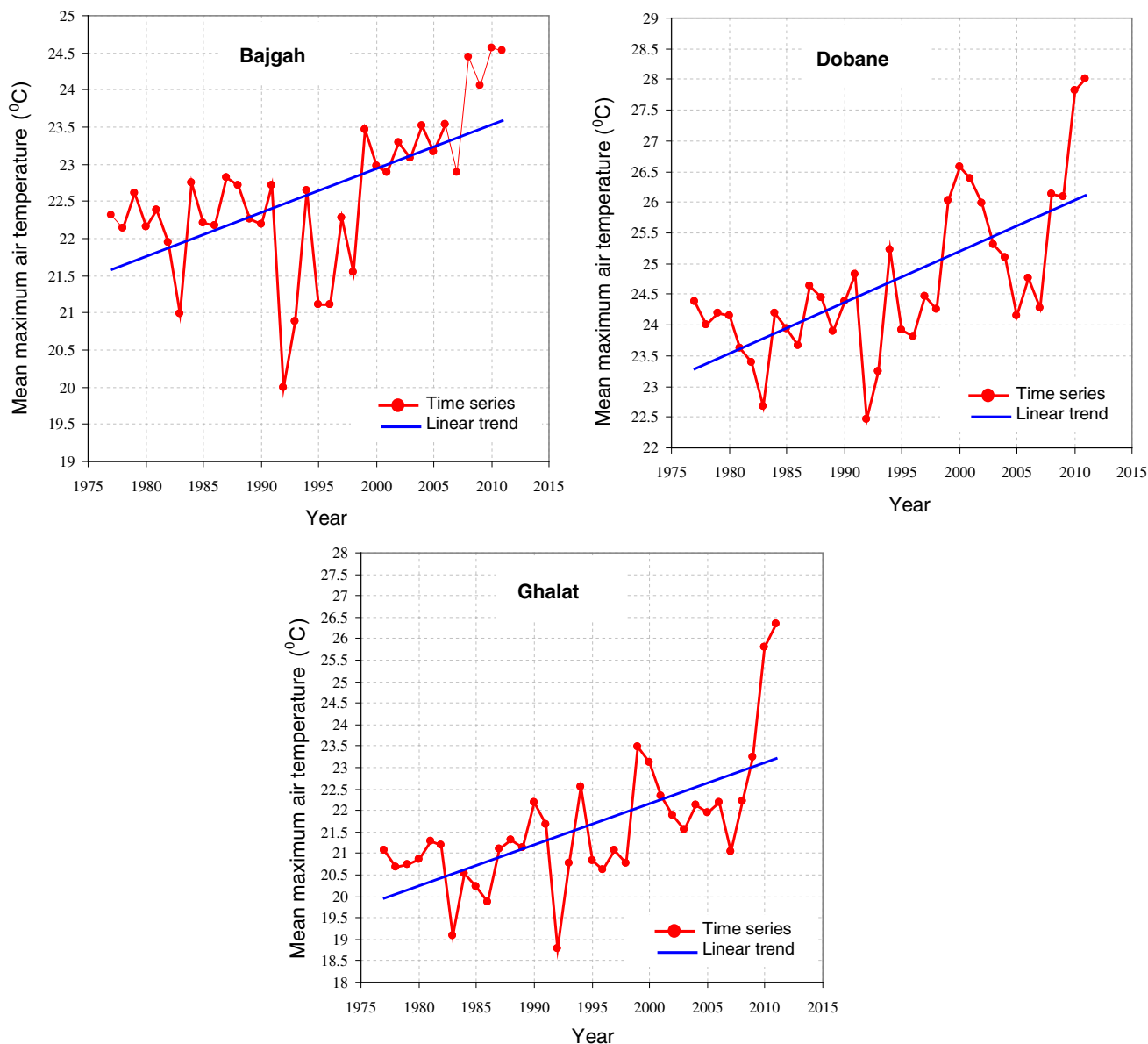
### 3.2 Non-parametric test of the temporal series of mean annual air temperature

Air temperature is one of the most important factors used to evaluate climate change. Among stations in the study area Shiraz station with 61 years of record has the longest set of data, which was used for step change trend. Figure 2 shows the temporal series of mean annual temperature in the Shiraz station of Maharlo watershed from 1951 to 2011. The Mann–Whitney phasic-change test reveals occurrence of step in 1977, which is significant at the 5 % level ( $Z_{rs} = -5.4$ ). This is rather important, indicating a significant phasic increase in the series.

The results of Mann–Kendall monotonic trend test for Shiraz station (Table 2) suggest that there is a significant air temperature decrease from 1951 to 1976 and increase from 1977 to 2011. The results of Mann–Kendall test for Shiraz station also reveal that for the entire period (1951–2011), the air temperature increased. In order to

investigate the main reasons of air temperature increase in the Shiraz station, we used seasonal sub-series of mean annual air temperature, i.e., spring (April to June), summer (July to September), autumn (October to December) and winter (January to March). The arithmetic mean of seasonal temperature is regarded as the integrated temperature series in the drainage basin to carry out the monotonic trend test. Our results reveal that there was an air temperature decrease from 1951 to 1976 in all seasons, and the initial hypothesis at the significance level 5 % was rejected by the seasonal air temperature in winter, but was not rejected in spring, summer and autumn (Table 2). Air temperature increased during 1977–2011 and also during the entire study period of 1951–2011 in all seasons, and the initial hypothesis at the significance level 5 % was rejected by the seasonal air temperature in all seasons except in autumn of 1977–2011 (Table 2). The slope of trend in Shiraz station revealed that the slope coefficient of air temperature trend in winter (0.053) is higher than other seasons during 1951–1976, suggesting that air temperature decrease in winter was higher than other seasons (Fig. 3). The slope coefficient of air temperature trend in winter during 1977–2011 (0.05) and in spring during 1951–2011 (0.041) is higher than in other seasons in 1977–2011 and 1951–2011, respectively, suggesting that temperature increase in those seasons was higher than other seasons and the slope coefficient during 1977–2011 was higher than the entire period of 1951–2011 (Fig. 3).

We used the Mann–Kendall monotonic trend test for other stations in the region only after 1976 when step change occurred because of short historical record in those stations. Figure 4 shows temporal series of temperature in Bajgah, Dobane and Ghalat stations of Maharlo watershed from 1977 to 2011. The results of Mann–Kendall monotonic trend test reveal that there was a significant air temperature increase in all stations for annual and seasonal sub-series of mean annual air temperature and the initial hypothesis was rejected (Table 2). The slope of trend in mean annual and seasonal air temperature for stations under study is shown by Fig. 5.

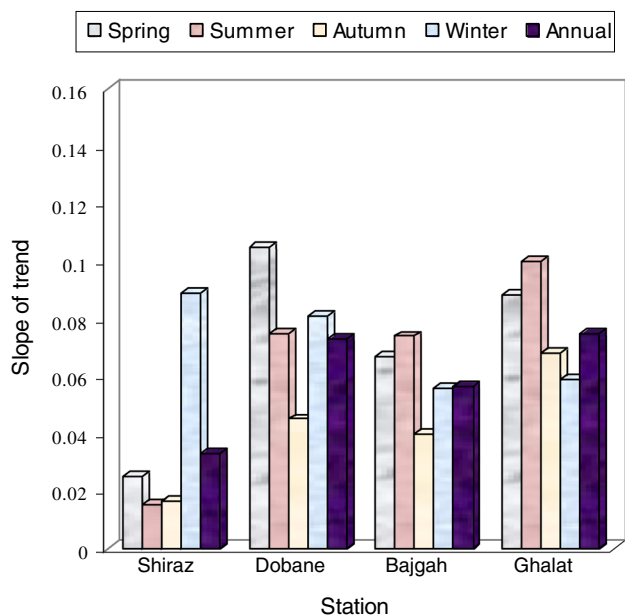


**Fig. 12** Mean annual maximum air temperature time series and its linear trend in Bajgah, Dobane and Ghalat stations of Maharlo watershed (1977–2011)

### 3.3 Non-parametric test of the temporal series of mean annual minimum air temperature

There was more significant decrease in slope of trends in mean annual and seasonal minimum air temperature than in mean annual and seasonal maximum or mean air temperature during 1951–1976 and more significant increases for 1977–2011 and for 1951–2011 except spring during 1977–2011. The temporal series of mean annual minimum air temperature in the Shiraz station from 1951 to 2011 are shown in Fig. 6. The initial hypothesis at the significance level 5 % was rejected for the sub-series during 1951–1976 and 1977–2011 (Table 3). There was air temperature

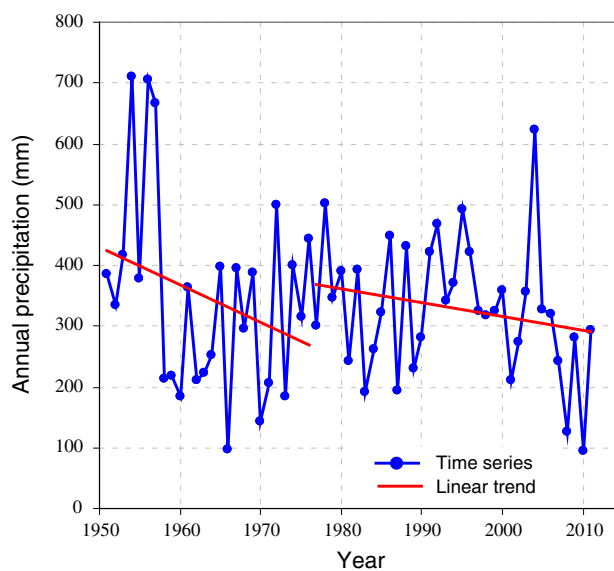
decrease during 1951–1976 in all seasons, and the initial hypothesis at the significance level 5 % was rejected by the seasonal temperatures in all seasons except spring (Table 3). Temperature increase occurred during 1977–2011 and also 1951–2011 in all seasons, and the initial hypothesis at the significance level 5 % was rejected by the seasonal temperatures in all seasons except winter and autumn 1977–2011 (Table 3). The slope of trend in Shiraz station showed that the slope coefficient of minimum air temperature trend in autumn (0.1) is higher than other seasons during 1951–1976, suggesting that temperature decrease in autumn was higher than other seasons (Fig. 7). The slope coefficients of air temperature trends in



**Fig. 13** Slopes of trends in mean annual and seasonal maximum air temperature in Shiraz, Bajgah, Dobane and Ghalat stations of Maharlo watershed

summer during 1977–2011 (0.0522) and spring during 1951–2011 (0.0524) are higher than in other seasons in 1977–2011 and 1951–2011, respectively.

Figure 8 shows temporal series of mean annual minimum air temperature in Bajgah, Dobane and Ghalat stations during 1977–2011. Unlike Shiraz station, there was less significant increase in slope of trends in mean annual and seasonal minimum air temperature than in mean annual and seasonal maximum or mean air temperature during 1977–2011 in other station in the region except for annual and seasonal (autumn and winter) for Ghalat and autumn season for Bajgah station. The results of Mann–Kendall monotonic trend test reveal that there was a temperature increase in all stations for annual and seasonal sub-series of



**Fig. 14** Annual precipitation time series and its linear trend in Shiraz station

mean annual minimum air temperature, and the initial hypothesis was rejected for annual series in all station (Table 3). In Ghalat station, the original assumption was rejected for all seasonal sub-series, for Bajgah station the initial hypothesis was rejected for all seasonal sub-series except for winter season and for Dobane station, the initial hypothesis was rejected in spring and summer seasonal sub-series (Table 3). Figure 9 illustrates the slopes of trend for mean annual and seasonal minimum air temperature of all stations in the region.

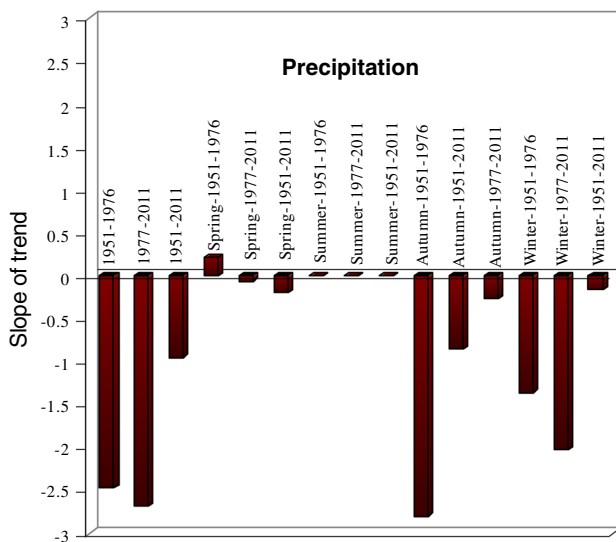
3.4 Non-parametric test of the temporal series of mean annual maximum air temperature

The slopes of mean annual and seasonal maximum air temperature trends were less significant (decreasing),

**Table 5** Results of Mann–Kendall test at the significance level 5 % for annual and seasonal precipitation sub-series

Station	Time series	Z											
		Annual	H <sub>0</sub>	Spring	H <sub>0</sub>	Summer	H <sub>0</sub>	Autumn	H <sub>0</sub>	Winter	H <sub>0</sub>		
Shiraz	1951–2011	-0.896	n	-1.357	n	0.414	n	-0.461	n	-0.218	n		
	1951–1976	-0.838	n	0.331	n	1.391	n	-1.213	n	-0.749	n		
	1977–2011	-1.321	n	-0.227	n	1.096	n	-0.511	n	-1.193	n		
Bajgah	1977–2011	-0.994	n	-0.568	n	-1.078	n	-0.71	n	-1.094	n		
Dobane	1977–2011	-1.136	n	0.312	n	1.087	n	0.071	n	-1.008	n		
Kohenjan	1977–2011	-0.312	n	2.173	r	-0.712	n	-0.795	n	-1.023	n		
Ghalat	1977–2011	-0.625	n	-0.483	n	1.739	n	-0.795	n	-0.17	n		
Maharlo–Sarvestan	1977–2011	-0.199	n	2.017	r	-1.505	n	-0.511	n	-0.653	n		
Sarvestan	1977–2011	-1.457	n	0.171	n	0	n	0.078	n	-1.937	n		

r null hypothesis rejected, n not rejected



**Fig. 15** Slopes of trends in annual and seasonal precipitation in Shiraz station

compared to mean annual and seasonal minimum or mean air temperature during 1951–1976 and less significant (increasing) for 1977–2011 and 1951–2011 periods except spring during 1977–2011. The temporal series of mean annual maximum air temperature in the Shiraz station for 1951–2011 is illustrated by Fig. 10. The initial hypothesis was not rejected for the annual sub-series for the 1951–1976 periods (Table 4). Mean annual maximum air temperature decreased during 1951–1976 in spring and winter, and increased during summer and autumn seasons and the initial hypothesis at the significance level 5 % was not rejected (Table 4). Air temperature increased during 1977–2011 and 1951–2011 periods. The initial hypothesis at the significance level 5 % was rejected for the 1977–2011 and 1951–2011 periods. Furthermore, the initial hypothesis at the significance level 5 % was not rejected for seasonal sub-series, except in autumn during 1977–2011 but rejected for seasonal sub-series in spring, summer and winter during 1951–2011 period (Table 4). The slope of trend revealed that the trend slope coefficient of maximum air temperature in winter (0.035) is higher than other seasons during 1951–1976, suggesting that temperature decrease in winter was higher than other seasons (Fig. 11). The trend slope coefficient of air temperature in winter during 1977–2011 (0.089) and in spring during 1951–2011 (0.032) is higher than other seasons during 1977–2011 and 1951–2011, respectively (Fig. 11). Figure 12 shows temporal series of mean annual maximum air temperature in Bajgah, Dobane and Ghalat stations from 1977 to 2011. The results of Mann–Kendall monotonic trend test reveal that there was a temperature increase in all stations for annual and seasonal sub-series of mean annual

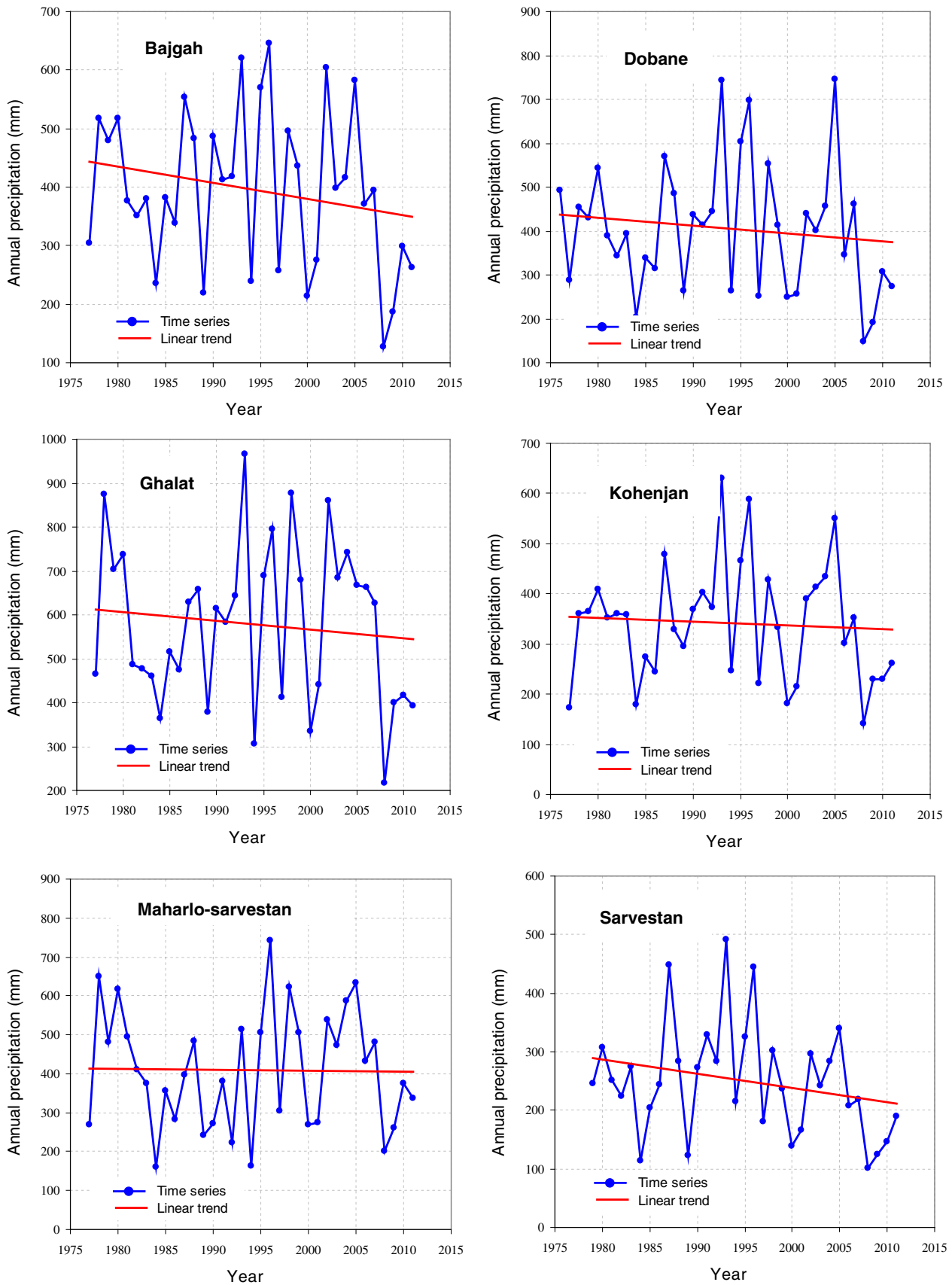
maximum air temperature, and the initial hypothesis at the significance level 5 % was rejected for annual series in all stations (Table 4). Figure 13 shows the slope of trend in the stations in the study area.

### 3.5 Non-parametric test of the temporal series of precipitation

The result of Mann–Whitney phasic-change test in Shiraz station showed that the mean difference between the two sub-series divided by years 2005, 2006, 2007 and 2008 was significant at the 5 % significance level and was highest divided by year 2007 ( $Z = -2.34$ ). For a better understanding of the effect air temperature on precipitation, the Mann–Kendall monotonic trend test for precipitation was used in sub-series divided by year 1977 (when step change of air temperature occurred). The Mann–Kendall monotonic trend test of precipitation series of Shiraz station revealed that the trend of precipitation slightly decreased during 1951–1976, 1977–2011 and 1951–2011 periods, but the slope of decreased trend during 1977–2011 was highest (Table 5; Fig. 14). The initial hypothesis was not rejected at the significance level 5 % in all series (Table 5). In order to investigate the seasonal change of precipitation in Shiraz station, seasonal precipitation data were further analyzed. Figure 15 shows the slope of trend in each season, and also the initial hypothesis was not rejected in all the seasons (Table 5). The Mann–Kendall monotonic trend test was also used for other stations in the region only after 1976 when air temperature step change occurred. Figure 16 shows temporal series of precipitation in Bajgah, Dobane, Ghalat, Kohenjan, Maharlo–Sarvestan and Sarvestan stations from 1977 to 2011. The results of Mann–Kendall monotonic trend test revealed that there was a decrease in all stations for annual sub-series of precipitation, increase in spring season in all stations (except Bajgah and Ghalat), precipitation decrease in autumn (except Dobane and Sarvestan), and precipitation decrease in winter in all station and the initial hypothesis was not rejected for all annual and seasonal time series (except spring season in Kohenjan and Maharlo–Sarvestan station), as shown in Table 5. Slope of annual and seasonal precipitation trends is shown by Fig. 17, because of non-rainy summer in the study area the slope of summer trend is zero.

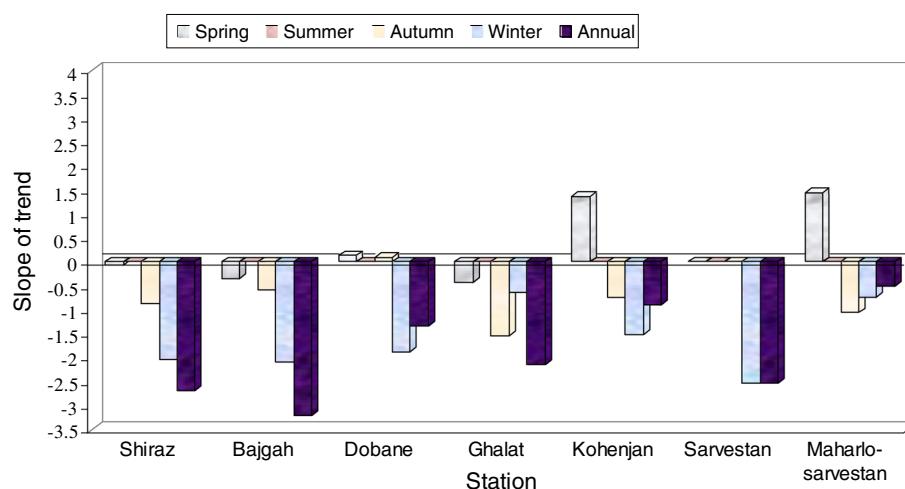
### 3.6 Homogeneity test in trends between stations

The results of the homogeneity test using Mann–Kendall statistics indicate that the air temperature and precipitation amount in stations for annual and seasonal sub-series belong to the same regime, and the study area is a homogeneous region ( $\chi^2$  (homogeneous) was less than the critical value at  $\alpha = 0.05$ ) (Table 6).



**Fig. 16** Annual precipitation time series and its linear trend in stations of Maharlo watershed (1977–2011)

**Fig. 17** Slopes of trends in annual and seasonal precipitation in the stations of Maharlo watershed



**Table 6** Homogeneity test in trends for studied parameters

Parameter	Time series	$\chi^2$ (total)	$\chi^2$ (trend)	$\chi^2$ (homogeneous)
Mean air temperature	Annual	74.62	72.14	2.48
	Spring	45.62	44.72	0.90
	Summer	74.16	69.32	4.83
	Autumn	52.89	46.08	6.80
	Winter	28.52	27.72	0.80
Mean minimum air temperature	Annual	50.84	45.83	5.01
	Spring	33.86	33.64	0.22
	Summer	45.83	44.48	1.36
	Autumn	20.16	15.59	4.58
	Winter	11.41	10.38	1.02
Mean maximum air temperature	Annual	54.72	53.74	0.99
	Spring	29.61	28.51	1.10
	Summer	52.06	46.74	5.32
	Autumn	18.01	15.65	2.36
	Winter	28.87	28.26	0.61
Precipitation	Annual	6.67	2.98	3.69
	Spring	9.52	0.94	8.58
	Summer	9.34	0.03	9.31
	Autumn	2.30	0.82	1.48
	Winter	8.89	4.09	4.80

The critical values for temperature and precipitation at  $\alpha = 0.05$  with 3 and 6 degrees of freedom are 7.81 and 12.59, respectively

#### 4 Conclusions

In the present study, trend analyses of air temperature and precipitation time series (as the most important factors of climate change) were investigated. The Mann–Whitney test for step change and Mann–Kendall test for monotonic trend were applied to the time series of annual and seasonal sub series. Moreover, homogeneity test in trends was used.

Maharlo watershed located in Southwestern Iran was used as the study area. According to the result, the main significant step change between two air temperature sub-series occurred in 1977. A general pattern of significant decrease of mean annual air temperature and non-significant decrease of precipitation were observed during 1951–1976. Furthermore, significant increase of mean annual air temperature and non-significant decrease of precipitation were observed during 1977–2011 and 1951–2011 periods, in the study area.

There were significant downward trends in mean annual and mean annual minimum air temperature at 40 and 80 % of annual and seasonal sub-series, respectively, for the 1951–1976 period. For mean annual maximum air temperature, for the 1951–1976 period, non-significant downward trends were observed in annual, spring and winter sub-series and non-significant upward trends were observed in summer and autumn seasons. For 1977–2011 and 1951–2011 periods, the results showed upward trends, whereas, significant upward trends in mean annual and mean annual minimum and maximum air temperature were 96, 80 and 84 % of annual and seasonal sub-series, respectively. Maximum trends slope coefficient of mean annual and mean annual minimum and maximum air temperature occurred during 1977–2011 in Ghalat station with slope coefficient of 0.1 °C/year in summer, 0.09 °C/year in autumn and 0.1 °C/year in summer, respectively. Significant increase of the air temperature in the Maharlo watershed can be viewed as a local/regional response to global warming and global climate change. Non-significant downward trends occurred for 60 % of annual and seasonal sub-series of precipitation during 1951–1976 and 68 % during 1977–2011 and 1951–2011. The only significant upward trend of precipitation was for spring season in Kohenjan and Maharlo–Sarvestan stations, with slope coefficient of 1.38 and 1.45 mm/year. Homogeneity test in



trend using Mann–Kendall statistics revealed that all annual and seasonal sub-series of temperature and precipitation belong to the same regime and study area is a Homogeneous region. While the results of air temperature trend analysis appear as regional linkage to global warming and global climate change, more definite outcome requires future investigation of precipitation and air temperature data, representing longer time periods.

## References

- Anderson RL (1942) Distribution of the serial correlation coefficients. *Ann Math Stat* 13(1):1–13
- Banimahd SA, Khalili D, Kamgar-Haghighi AA, Zand-Parsa Sh (2013) In-depth investigation of precipitation-based climate change and cyclic variation in different climatic zones. *Theor Appl Climatol*. doi:10.1007/s00704-013-0970-5
- Bates B, Kundzewicz ZW, Wu S, Palutikof J (2008) Climate change and water. Intergovernmental Panel on Climate Change (IPCC)
- Burns DA, Klaus J, McHale MR (2007) Recent climate trends and implications for water resources in the Catskill Mountain region, New York, USA. *J Hydrol* 336:150–170
- Cannarozzo M, Noto LV, Viola F (2006) Spatial distribution of rainfall trends in Sicily (1921–2000). *J Phys Chem Earth* 31:1201–1211
- Chen H, Guo S, Xu CY, Singh VP (2007) Historical temporal trends of hydro-climatic variables and runoff response to climate variability and their relevance in water resource management in the Hanjiang basin. *J Hydrol* 344:171–184
- CRCCH (2005) Co-operative Research Centre for Catchment Hydrology. *TREND User Guide*, p 29
- De Luis M, Cufar K, Saz MA, Longares LA, Ceglar A, Kajfez-Bogataj L (2012) Trends in seasonal precipitation and temperature in Slovenia during 1951–2007. *J Reg Environ Change*. doi:10.1007/s10113-012-0365-7
- Domonkos P, Tar K (2003) Long-term changes in observed temperature and precipitation series 1901–1998 from Hungary and their relations to larger scale changes. *Theor Appl Climatol* 75:131–147
- Dore MHI (2005) Climate change and changes in global precipitation patterns: what do we know? *J Environ Int* 31:1167–1181
- Fan Xh, Wang Mb (2011) Change trends of air temperature and precipitation over Shanxi Province, China. *J Theor Appl Climatol* 103(3–4):519–531
- Feng X, Zhang G, Yin X (2011) Hydrological responses to climate change in Nenjiang River Basin, Northeastern China. *J Water Resour Manage* 25:677–689
- Ghahraman B (2006) Time trend in the mean annual temperature of Iran. *Turk J Agric For* 30:439–448
- Gocic M, Trajkovic S (2013) Analysis of changes in meteorological variables using Mann–Kendall and Sen’s slope estimator statistical tests in Serbia. *J Global Planet Change* 100:172–182
- Helsel DR, Hirsch RM (2002) *Statistical methods in water resources*. United States Geological Survey
- Hingane LS, Rupa Kumar K, Ramana Murthy BhV (1985) Long term trends of surface air temperature in India. *Int J Climatol* 5:521–528
- IPCC (2007) *Climate change 2007—impacts, adaptation and vulnerability*. Contribution of working group II to the fourth assessment report of the IPCC. Technical report, International Panel on Climate Change, Cambridge
- Kadioglu M (1997) Trends in surface air temperature data over Turkey. *Int J Climatol* 17:511–520
- Kampata JM, Parida BP, Moalafhi DB (2008) Trend analysis of rainfall in the headstreams of the Zambezi River Basin in Zambia. *J Phys Chem Earth* 33:621–625
- Kendall MG (1975) *Rank correlation methods*. Charles Griffin, London
- Khattak MS, Babel MS, Sharif M (2011) Hydro-meteorological trends in the upper Indus River Basin in Pakistan. *J Clim Res* 6:103–119
- Kousari MR, Ekhtesasi MR, Tazeh M, SaremiNaeini MA, AsadiZarch MA (2011) An investigation of the Iranian climatic changes by considering the precipitation, temperature, and relative humidity parameters. *J Theor Appl Climatol* 103:321–335
- Mann HB (1945) Non-parametric test against trend. *Econometrica* 13:245–259
- Marofi S, Soleymani S, Salarijazi M, Marofi H (2012) Watershed-wide trend analysis of temperature characteristics in Karun-Dez watershed, southwestern Iran. *Theor Appl Climatol* 110(1–2):311–320
- Marugianni G, Melas D, Kioutsioukis I, Feidas H, Zanis P, Anadranistakis E (2013) Trend analysis for climatic time series for Greece. *Advances in meteorology, climatology and atmospheric physics*. Springer Atmospheric Sciences, pp 583–589
- Masih I, Uhlenbrook S, Maskey S, Smakhtin V (2011) Streamflow trends and climate linkages in the Zagros Mountains, Iran. *J Clim Change* 104:317–338
- Modarres R, Sarhadi A (2009) Rainfall trends analysis of Iran in the last half of the twentieth century. *J Geophys*. doi:10.1029/2008JD010707
- Modarres R, Silva VPR (2007) Rainfall trends in arid and semi-arid regions of Iran. *J Arid Environ* 70:344–355
- Oguntunde PG, Abiodun BJ, Lischeid G (2012) Spatial and temporal temperature trends in Nigeria, 1901–2000. *J Meteorol Atmos Phys*. doi:10.1007/s00703-012-0199-3
- Salas JD, Delleur JW, Yevjevich V, Lane WL (1980) *Applied modelling of hydrologic time series*. Water Resources Publications, Littleton
- Sen PK (1968) Estimates of the regression coefficient based on Kendall’s tau. *J Am Stat Assoc* 63:1379–1389
- Suhaila J, Deni SM, Wan Zin WZ, Jemain AA (2010) Spatial patterns and trends of daily rainfall regime in Peninsular Malaysia during the southwest and northeast monsoons: 1975–2004. *Meteorol Atmos Phys* 110:1–18
- Tabari H, Hosseinzadeh Talae P (2011) Recent trends of mean maximum and minimum air temperatures in western half of Iran. *J Meteor Atmos Phys* 111:121–131
- Terzago S, Fratianni S, Cremonini R (2012) Winter precipitation in western Italian Alps (1926–2010). Trend and connection with the North Atlantic/Arctic Oscillation. *J Meteorol Atmos Phys*. doi:10.1007/s00703-012-0231-7
- Theil H (1950a) A rank-invariant method of linear and polynomial regression analysis, I. *Nederlands Akad Wetensch Proc* 53:386–392
- Theil H (1950b) A rank-invariant method of linear and polynomial regression analysis, II. *Nederlands Akad Wetensch Proc* 53:521–525
- Theil H (1950c) A rank-invariant method of linear and polynomial regression analysis, III. *Nederlands Akad Wetensch Proc* 53:1397–1412
- Turkes M (1996) Spatial and temporal analysis of annual rainfall variations in Turkey. *Int J Climatol* 16:1057–1076
- Unkasevic M, Tosic I (2011) A statistical analysis of the daily precipitation over Serbia: trends and indices. *J Theor Appl Climatol* 106(1–2):69–78

- Van Belle G, Hughes JP (1984) Nonparametric tests for trend in water quality. *Water Resour Res* 20(1):127–136
- Von Storch VH (1995) Misuses of statistical analysis in climate research. In: von Storch H, Navarra A (eds) *Analysis of climate variability: applications of statistical techniques*. Springer, Berlin, pp 11–26
- Wolock DM, McCabe GJ Jr, Tasker GD, Moss ME (1993) Effects of climate change on water resources in the Delaware River basin. *Water Resour Bull* 29:475–486
- Xu ZX, Takeuchi K, Ishidaira H (2003) Monotonic trend and step changes in Japanese precipitation. *J Hydrol* 279:144–150
- Yaning C, Changchun X, Xingming H, Weihong L, Yapeng C, Chenggang Z, Zhaoxia Y (2009) Fifty-year climate change and its effect on annual runoff in the Tarim River Basin, China. *J Quat Int*. doi:[10.1016/j.quaint.2008.11.011](https://doi.org/10.1016/j.quaint.2008.11.011)
- Yevjevich V (1972) *Stochastic processes in hydrology*. Water Resources Publications, Fort Collins
- Yue S, Pilon P, Phinney B, Cavadias G (2002) The influence of autocorrelation on the ability to detect trend in hydrological series. *Hydrol Process* 16(9):1807–1829
- Zhang X, Vincent LA, Hogg WD, Niitsoo A (2000) Temperature and precipitation trends in Canada during the 20th century. *Atmos Ocean* 38:395–429