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Rainfall trends in arid and semi-arid regions of Iran

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Abstract

Time-series of annual rainfall, number of rainy-days per year and monthly rainfall of 20 stations were analyzed to assess climate variability in arid and semi-arid regions of Iran. The results showed mixed trends of increasing and decreasing rainfall, which were statistically significant ($p<0.05$ and $p<0.01$) only for Sabzevar and Zahedan stations by the Mann–Kendall test. Also, with the exception of Kashan and Torbat stations there was no statistically significant trend in the mean number of rainy-days per year. Increasing and decreasing monthly rainfall trends were found over large continuous areas in the study region. These trends were statistically significant mostly during the winter and spring seasons, suggesting a seasonal movement of rainfall concentration. Results also showed that there is no significant climate variability in the arid and semi-arid environments of Iran.

Keywords: Climate variability; Nonparametric methods; Mann–Kendall test; Rainy-days

1. Introduction

Iran is located in the mid-latitude belt of arid and semi-arid regions of the Earth. The arid and semi-arid regions cover more than 60% of the country. In this agro-pastoral transition region, the rains are highly variable in time, space, amount and duration, and water is the most important limiting factor for biological and agricultural activities. Seasonal changes in rainfall pattern may alter the hydrological cycle and environmental

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processes (Delitala et al., 2000) as well as the vegetation and the entire ecosystem (Lazaro et al., 2001; Ni and Zhang, 2000).

Many studies have been conducted for regional climate assessment of some countries of southwest Asia such as for Bahrain (Elagib and Abdu, 1997); Syria (Evans and Geerken, 2004) and Arab region (Abahussain et al., 2002). The results of these studies have clearly shown that there is climate variability in these regions as a result of human interference on the ecosystems. Land degradation in Iran has been increased in the last decades as a result of irregular and uncoordinated exploitation of water resources as well as by the extensive land-use and the use of wood and plants as fuel. Such degradation places those areas in serious risk of desertification. However, climate variability and its potential effects on arid and semi-arid regions have not been adequately and carefully investigated, in spite of recent studies presented by Dinpashoh et al. (2004) and Raziei et al. (2005). The impact of human activities on general climate at a global scale is widely accepted. The basic hypothesis of this study was that global climate change could be observed as climate variability in Iran.

Variability in rainfall data may provide a general gauge regarding changes in the natural behavior of ecosystems. A key step in this process is the ability to reveal that a change or trend is present in the rainfall records. The linear relationship is the most common method used for detecting rainfall trends (Hameed et al., 1997; Silva, 2004). On the other hand, the Mann–Kendall (MK) test has been widely used to evaluate a presence of a statistically significant trend in hydrological and climatological time-series (Burn, 1994; Chiew and McMahon, 1993; Douglas et al., 2000; Hirsch and Slack, 1984; Yue et al., 2002). Also, several studies have analyzed rainfall trends in arid and semi-arid regions all over the world. By analyzing temporal trends, Silva (2004) observed climate variability in northeast Brazil. Jiangping et al. (2002) used climatic variables to discuss climate changes in China. They observed that the annual mean values of air temperature, evaporation, sunshine and wind speed have all declined, while annual rainfall and mean relative humidity have slightly increased. Lazaro et al. (2001) observed neither trends nor abrupt changes in the rainfall time-series of a typical Mediterranean semi-arid region in Spain although three periods of fluctuations were observed for these variables. Rainfall is the most important variable for agricultural water management in dryland farming in Iran (Dinpashoh et al., 2004). Moreover, the knowledge of trends in annual rainfall and number of rainy-days are very important for agricultural planning in any region. In this context, the objective of this study was to investigate rainfall variability in arid and semi-arid regions of Iran using non-parametric analysis methods.

2. Study area

Arid and semi-arid regions of the Islamic Republic of Iran lie approximately between 50°E and 64°E in longitude and between 25°N and 37°N in latitude. The mean annual rainfall for these regions ranges from 62.1 to 344.8 mm with a long-term mean of 141.1 mm. The study area and geographical position of the selected stations are presented in Fig. 1.

Iran is surrounded by two mountain ranges, namely Alborz to the north and Zagros to the west and the highest point of the country is located within the Alborz mountain range with an elevation of 5628 m above mean sea level. These mountains avoid Mediterranean moisture bearing systems by crossing through the region to the east. The Zagros mountain range is responsible for the major portion of the rain producing air masses that enter the

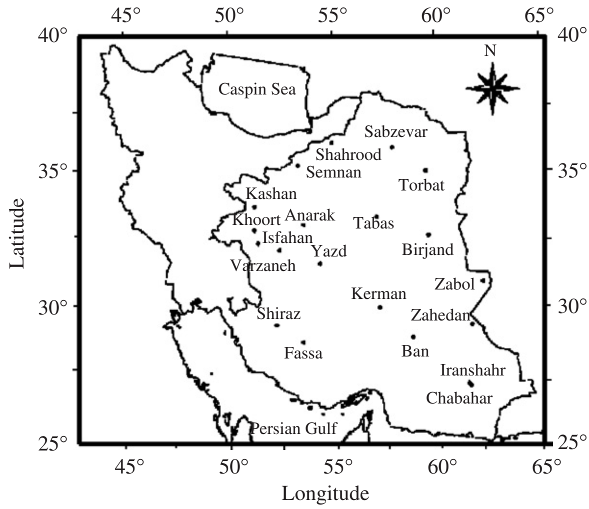

Fig. 1. Spatial distribution of selected stations in arid and semi-arid regions of Iran.

region from the west and northwest, with relatively high rainfall amounts for those areas (Sadeghi et al., 2002). The wet and dry seasons generally occur between November and May and between June and October, respectively. The climate of the region is defined as subtropical with hot and dry weather in the summer. The main cause of annual rainfall variability in Iran is the changing position of synoptic systems and year-to-year variation in the number of cyclones passing through the region.

3. Materials and methods

Rainfall data of twenty stations operated by the meteorological organization of Iran were used to evaluate rainfall variability in arid and semi-arid zones throughout the country (Table 1). These stations were selected because they have rainfall records of at least 30 years and are fairly evenly spread throughout the study region. The data set has included annual rainfall, number of rainy-days per year and monthly rainfall. The number of rainy-days per year was defined as the number of days of the year with a rainfall amount greater than 1 mm.

The homogeneity of the rainfall time-series was determined by Thom test (Thom, 1966) at the 95% confidence level. This test assesses variations of the time-series data from a central value, usually the median. The Thom test is described in detail by Buishand (1982) and Rodrigo et al. (1999).

3.1. Mann–Kendall test

The MK test, usually used to assess the trend of a time-series, was applied by considering the statistic S as:

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

Table 1
Weather stations with geographical coordinates located in the arid and semi-arid regions of Iran

Order number	Stations	Sample size (year)	Latitude (°N)	Longitude (°E)	Altitude (m)
01	Kashan	34	33°59′	51°27′	982
02	Anarak	32	33°20′	53°40′	1416
03	Isfahan	50	32°37′	51°40′	1550
04	Varzaneh	32	32°24′	52°37′	1250
05	Yazd	48	31°54′	54°24′	1230
06	Zabol	38	31°02′	61°29′	489
07	Zahedan	50	29°28′	60°55′	1370
08	Iranshahr	36	27°12′	60°42′	591
09	Shahrood	50	36°25′	54°57′	1345
10	Sabzevar	46	36°12′	57°43′	977
11	Semnan	36	35°33′	53°23′	1170
12	Torbat	42	35°16′	59°13′	1450
13	Tabas	34	33°36′	56°55′	711
14	Khoort	30	33°06′	51°28′	1700
15	Birjand	45	32°52′	59°12′	1491
16	Kerman	45	30°15′	56°58′	1753
17	Shiraz	50	29°36′	52°53′	1488
18	Bam	44	29°06′	58°21′	1067
19	Fassa	34	28°58′	53°14′	1288
20	Chahbahar	33	25°17′	60°37′	08

where the x_j are the sequential data values, n is the length of the time-series and sign$(x_i - x_j)$ is -1 for $(x_i - x_j) < 0$; 0 for $(x_i - x_j) = 0$ and 1 for $(x_i - x_j) > 0$.

The mean $E[S]$ and variance $V[S]$ of the statistic S were obtained as:

$$E[S] = 0, \tag{2}$$

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

where t_p is the number of ties for the pth value and q is the number of tied values. The second term represents an adjustment for tied or censored data. The standardized statistical test (Z_{MK}) was computed by:

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

Positive values of Z_{MK} indicate increasing trends while negative Z_{MK} indicate decreasing trends. When testing either increasing or decreasing monotonic trends at a p significance level, the null hypothesis was rejected for absolute value of Z greater than $Z_{1-p/2}$, obtained from the standard normal cumulative distribution tables. In this work, significance levels of $p = 0.01$ and 0.05 were applied. The non-parametric estimate of the trend slope magnitude was obtained as (Hirsch et al., 1982):

$$\beta = \text{Median}\left[\frac{(x_j - x_i)}{(j - i)}\right] \quad \text{for all } i<j, \tag{5}$$

where x_j and x_i are data points measured at times j and i, respectively.

3.2. Test of randomness

Autocorrelation functions are commonly used for checking randomness in a data set. This randomness is ascertained by computing autocorrelations for data values at varying time lags. If random, such autocorrelations should be near zero for any and all time-lag separations. If non-random, then one or more autocorrelation values will be significantly non-zero. These functions were used to test the randomness of annual rainfall and rainy-days per year time-series.

The randomness of the data set was tested by the autocorrelation function for the confidence bands (CB) given by

$$\text{CB} = \frac{z_i - \alpha/2}{\sqrt{n}}, \tag{6}$$

where z is the percent point function of the normal distribution, n is the sample size and α is the significance level. Thus, the CB have fixed width that depends on the sample size.

4. Results and discussion

4.1. Annual rainfall

The descriptive statistics of annual rainfall such as the coefficient of variation (C_V), coefficients of skewness (C_S) and coefficients of kurtosis (C_k) are presented in Table 2. The mean values of C_V, C_S and C_k for the study region were 44.4%, 0.93 and 9.47, respectively. For all stations C_V was higher than 30%, except for the Torbat station (26.7%) which is located in the northeast of the country. These indexes demonstrate high annual rainfall variability in the arid and semi-arid regions of Iran. Dinpashoh et al. (2004) observed C_V values in Iran ranging from 18% in the north (between Caspian Sea shoreline and Alborz Mountains) to 75% in the southeast (south of the Sistan–Balochistan province).

The highest values of coefficient of kurtosis were found for the Anarak, Varzaneh, Tabas, Shiraz and Chahbahar stations. Despite the low values for the degree of skewness, with the exception of Chahbahar, these stations showed a high degree of peakedness which is quite different from that of a normal distribution. The C_V values decline from the south to north of the country, with a maximum value of 84.7% at the Chahbahar station. In general, C_V decreased slightly ($r = -0.41$, $p<0.1$), C_S remained constant and C_k increased slightly ($r = 0.44$, $p<0.01$) with an increase in annual rainfall. There was a mix of increasing and decreasing of rainfall trends widespread throughout the study area. This result suggests that the rainfall trends in a few provinces must be attributed to local changes in the rainfall regime rather than the large-scale patterns of atmospheric circulation.

The mean annual rainfall of the study region is relatively low, ranging from 62.1 mm at Yazd to 344.8 mm at the Shiraz station. In general, the standard deviation is high, ranging

Table 2
Minimum rainfall (R_m), maximum rainfall (R_x), mean rainfall (R_e), standard deviation (SD), coefficient of variation (C_v), coefficients of skewness (C_s), coefficients of kurtosis (C_k) and time-series trend by Mann–Kendall test (Trend MK). The values in the column *p*-value refer to the significance level of the trends (MK tests)

Stations	R_m (mm)	R_x (mm)	R_e (mm)	SD (mm)	C_v	C_s	C_k	*p*-value	Trend (MK)
Kashan	44.9	259.4	138.3	53.8	38.9	0.4	−0.5	0.52	−0.64
Anarak	19.1	214.0	97.9	51.7	52.9	−0.7	19.1	0.41	0.10
Isfahan	40.2	338.7	122.3	53.3	43.6	1.3	4.1	0.44	0.77
Varzaneh	25.1	145.2	73.1	29.5	40.4	0.0	25.1	0.17	0.17
Yazd	22.6	118.4	62.1	27.1	44.0	0.4	−0.8	0.82	0.22
Zabol	8.7	128.7	62.6	28.3	45.3	0.0	−0.4	0.26	1.12
Zahedan	13.7	196.1	94.2	47.3	50.3	0.5	−0.7	0.01	−1.45[a]
Iranshahr	20.0	285.0	118.7	55.4	46.6	0.5	1.1	0.50	0.68
Shahrood	16.9	343.3	152.4	64.1	42.1	0.6	0.5	0.07	0.81
Sabzevar	31.4	311.2	183.8	61.8	33.6	0.1	−0.5	0.03	1.29[b]
Semnan	60.5	276.1	139.9	56.0	40.1	0.6	−0.1	0.45	0.76
Torbat	156.7	416.5	278.4	74.2	26.7	0.3	−1.0	0.12	0.57
Tabas	22.5	191.2	86.2	38.61	44.8	1.8	22.5	0.64	0.05
Khoort	19.5	261.9	109.4	67.0	61.2	−0.1	0.0	0.51	−0.09
Birjand	64.7	382.0	173.5	58.3	33.6	1.0	2.8	0.42	0.81
Kerman	45.1	374.2	157.5	61.2	38.8	1.0	2.4	0.34	−0.96
Shiraz	96.3	711.1	344.8	130.3	37.8	1.9	96.3	0.69	0.04
Bam	20.4	149.5	64.2	29.3	45.7	1.1	0.9	0.72	0.35
Fassa	85.0	535.5	300.7	116.6	38.8	0.1	−0.5	0.73	0.34
Chahbahar	19.2	538.8	122.2	103.4	84.7	7.8	19.2	0.62	0.06

[a]Trends statistically significant at $p<0.05$.
[b]Trends statistically significant at $p<0.01$.

from 27.1 to 130.3 mm. The MK test indicated statistically significant trends for only two stations. Raziei et al. (2005) pointed out that most of the stations in the arid and semi-arid regions of Iran are characterized by an insignificant annual rainfall trend. Fig. 2 shows decreasing and increasing trends in annual rainfall and a straight line trend for the Zahedan and Sabzevar stations. The annual rainfall showed a decreasing trend of 1.45 mm/year (statistically significant at $p<0.001$) at the Zahedan station and an increasing trend of 1.3 mm/year (statistically significant at $p<0.05$) at the Sabzevar station. The stronger annual rainfall reduction at the Zahedan station is caused by consecutive droughts, blown dust and soil degradation in recent years, which has enhanced the desertification risk in the southeast region of Iran. The autocorrelation functions for the annual rainfall time-series for Zahedan and Sabzevar stations are shown in Fig. 3. It was observed that all autocorrelation coefficients fall within the 95% confidence limits. Therefore, these two time-series are strongly random.

4.2. *Number of rainy-days*

The mean of the number of rainy-days per year was 24.1, which occurred within the 10–50-day range suggested by Noy-Meir (1973). The minimum and maximum numbers of rainy-days per year are 9 and 48 for Torbat and Shiraz stations, respectively. The homogeneity Thom's test for annual number of rainy-days showed that all analyzed time-series were homogeneous at $p<0.05$ according to the Thom test.

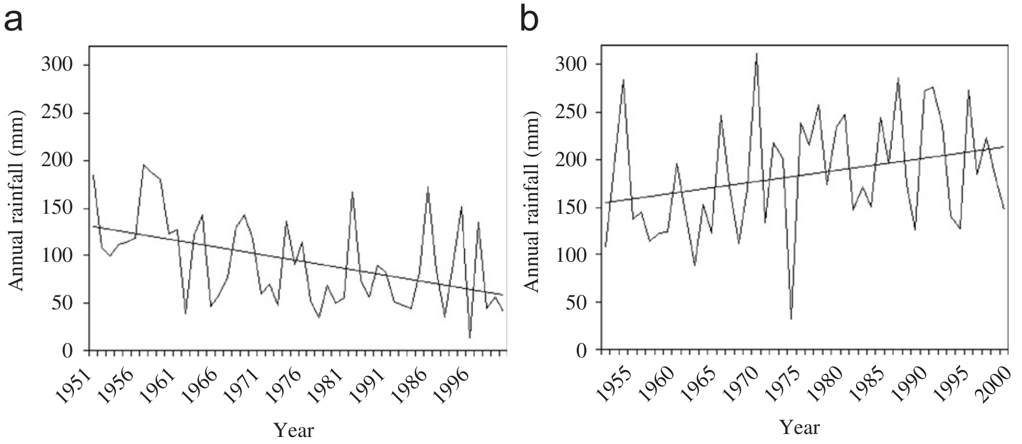

Fig. 2. Annual rainfall fluctuations and straight line trends for stations: (a) Zahedan and (b) Sabzevar.

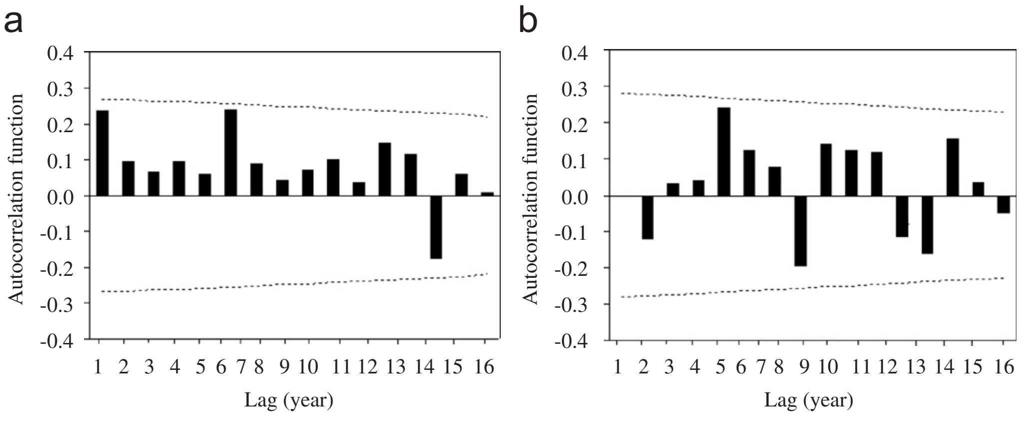

Fig. 3. Autocorrelation plots for stations: (a) Zahedan and (b) Sabzevar. Upper and lower dashed lines are 95% confidence bands.

The negative trend of 2.81 rainy-days per year observed at the Kashan station was due to a reduction of 0.64 mm/year in the annual rainfall. Similarly, the maximum positive trend of 2.19 rainy-days per year observed at the Torbat station was due to an increase of 0.57 mm/year in the annual rainfall. These trends are statistically significant at $p<0.01$ while the decreasing and increasing trends observed in other stations are not statistically significant. Therefore, the decrease in the annual rainfall resulted in a corresponding decrease in the number of rainy-days. The number of rainy-days per year is significantly correlated to the annual rainfall for all stations at 1% or 5% significance levels by t-test (Table 3). Therefore, an approximate value of the annual rainfall may be obtained by simply counting the number of rainy-days. The results also showed that the mean number of rainy-days per year ranged from 9 at Torbat to 27 at the Kashan station. Hess et al. (1995) reported that the decrease in rainfall in northeast arid zone of Nigeria resulted in a decrease in the number of rainy-days per year. Also, Brunetti et al. (2000) observed that the

Table 3
Mean rainy-day per year (MRD), trend value (Trend) and correlation coefficient between rainy-day and annual rainfall (r). The values in the column p-value refer to the significance level of the trends (MK tests)

Stations	MRD	p-value	Trend	r
Kashan	27	0.01	−2.81[b]	0.68[b]
Anarak	21	0.23	0.27	0.69[b]
Isfahan	24	0.57	−0.57	0.80[b]
Varzaneh	24	0.31	0.41	0.56[a]
Yazd	14	0.24	−1.19	0.70[b]
Zabol	12	0.81	0.24	0.71[b]
Zahedan	16	0.14	−1.47	0.51[a]
Iranshahr	15	0.25	1.15	0.84[b]
Shahrood	29	0.39	0.85	0.68[b]
Sabzevar	33	0.43	0.80	0.63[b]
Semnan	27	0.32	−1.00	0.70[b]
Torbat	09	0.01	2.19[b]	0.83[b]
Tabas	37	0.22	0.15	0.52[a]
Khoort	19	0.68	0.05	0.68[b]
Birjand	31	0.91	0.12	0.78[b]
Kerman	30	0.15	−1.42	0.84[b]
Shiraz	48	0.21	0.24	0.57[a]
Bam	14	0.25	−1.15	0.81[b]
Fassa	28	0.09	−1.70	0.67[b]
Chahbahar	15	0.67	−0.05	0.62[b]

[a]Statistically significant at $p<0.05$.
[b]Statistically significant at $p<0.01$.

decrease in the number of rainy-days is more significant than that of annual rainfall in Italy.

Fig. 4 shows the decreasing and increasing trends of rainy-days per year for the Kashan and Torbat stations, respectively. The number of rainy-days per year at the Kashan station had a decrease over the study period of approximately 12–13 days while the Torbat station had an increase of 2–3 days. Out of the 18 other stations, no statistically significant negative or positive trends were observed. However, the Fassa station showed a negative trend of 1.7 days in the number of rainy-days per year at a 10% significance level. The autocorrelation plots for the Kashan and Torbat stations are presented in Fig. 5. Once the autocorrelations are all close to zero for all time-lag separations, the number of rainy-days as well as the annual rainfall time-series are random in Iran.

4.3. Monthly rainfall

The MK test was also applied to detect monthly rainfall trends for all selected stations. The results have clearly shown few stations with statistically significant trends at 1% and 5% significance levels (Table 4). Like annual rainfall and number of rainy-days per year, the monthly rainfall also showed both increasing and decreasing trends depending on the station. Most of the stations showed only one or two months with statistically significant trends. The trend test revealed no statistically significant trends in many other stations like Bam, Semnan, Zahedan, Fassa, Shiraz, Tabas and Varzaneh stations. The major number of positive trends occurs more frequently in March while the major number of negative

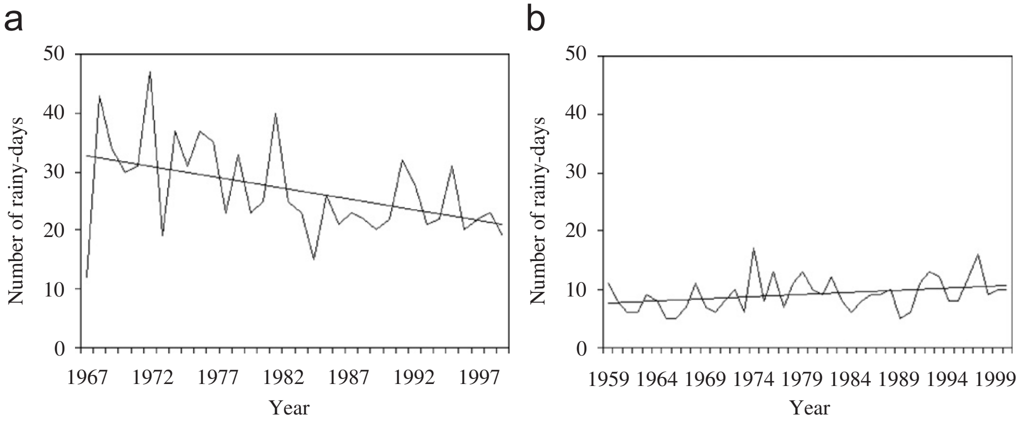

Fig. 4. Annual course of the number of rainy-days per year and straight line trends for stations: (a) Kashan and (b) Torbat.

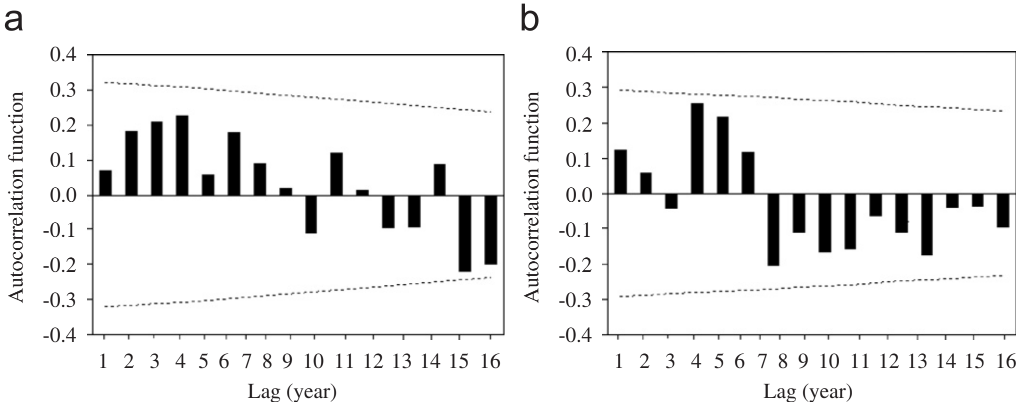

Fig. 5. Autocorrelation plots for stations: (a) Kashan and (b) Torbat. Upper and lower dashed lines are 95% confidence bands.

trends occurs in April. It was also observed that four stations had statistically significant positive trends in March and four stations had statistically significant negative trends in April. This result suggests a seasonal movement toward concentrated rainfall in the winter. Statistically significant trends mostly occur during the months of February, March, April, May and June. In China, the higher trends occur in July and September while the lower trends occur in March (Gemmer et al., 2004). Silva (2004) observed that the rainfall trends in northeast Brazil are higher during the wet season when compared to those of the dry season.

Fig. 6 shows monthly rainfall trends and straight line trends for two stations located in semi-arid (Sabzevar) and arid (Yazd) regions of Iran during the months of February and April, respectively. These figures suggest an increase of approximately 14–15 months at the Sabzevar station and a decrease of 6–7 months at the Yazd station.

Table 4
Trends of monthly rainfall time series for stations of the arid and semi-arid regions of Iran

Stations/Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Kashan	−0.07[a]	−0.06[a]	0.13[a]	−0.09[a]	0.05[a]	−0.21[a]	0.01[a]	−0.12[a]	0.19[a]	0.01[a]	0.05[a]	−0.03[a]
Anarak	0.4[a]	0.19[a]	0.31[c]	0.06[a]	0.22[b]	0.05[a]	0.03[a]	0.04[a]	0.04[a]	0.17[a]	0.08[a]	0.02[a]
Isfahan	−0.02[a]	0.02[a]	0.24[b]	−0.15[a]	−0.08[a]	0.15[a]	0.19[a]	0.05[a]	−0.02[a]	0.08[a]	0.05[a]	−0.03[a]
Varzaneh	0.08[a]	0.15[a]	0.22[a]	−0.11[a]	0.07[a]	0.20[a]	0.07[a]	0.10[a]	0.14[a]	0.12[a]	0.21[a]	0.13[a]
Yazd	0.06[a]	0.08[a]	0.16[a]	−0.23[b]	0.05[a]	0.09[a]	−0.03[a]	−0.14[a]	−0.13[a]	0.04[a]	0.05[a]	0.01[a]
Zabol	0.17[a]	−0.12[a]	0.20[a]	−0.12[a]	−0.09[a]	−0.12[a]	−0.07[a]	−0.06[a]	−0.02[a]	0.06[a]	−0.06[a]	0.20[a]
Zahedan	−0.05[a]	−0.11[a]	−0.13[a]	−0.09[a]	−0.01[a]	0.11[a]	0.02[a]	0.01[a]	0.04[a]	0.17[a]	0.05[a]	−0.08[a]
Iranshahr	−0.15[a]	−0.03[a]	0.26[b]	0.02[a]	−0.09[a]	0.04[a]	−0.14[a]	0.24[a]	−0.15[a]	0.08[a]	0.15[a]	0.05[a]
Shahrood	0.11[a]	0.07[a]	0.15[a]	−0.04[a]	0.05[a]	0.23[b]	0.01[a]	0.02[a]	0.00[a]	0.14[a]	0.03[a]	0.19[b]
Sabzevar	0.08[a]	0.23[b]	0.08[a]	−0.07[a]	−0.02[a]	0.01[a]	0.09[a]	0.08[a]	0.18[a]	0.16[a]	0.03[a]	0.12[a]
Semnan	−0.01[a]	−0.08[a]	0.18[a]	0.02[a]	−0.12[a]	−0.01[a]	0.20[a]	0.04[a]	0.08[a]	−0.06[a]	0.04[a]	0.04[a]
Torbat	−0.01[a]	0.16[a]	0.16[a]	−0.22[b]	−0.05[a]	0.16[a]	0.11[a]	0.09[a]	0.15[a]	0.13[a]	0.08[a]	0.02[a]
Tabas	0.14[a]	0.08[a]	0.13[a]	−0.22[a]	0.08[a]	0.10[a]	0.02[a]	0.07[a]	−0.04[a]	0.09[a]	−0.03[a]	0.12[a]
Khoort	0.09[a]	0.00[a]	0.17[a]	−0.10[a]	0.04[a]	−0.02[a]	−0.13[a]	0.05[a]	0.05[a]	−0.03[a]	−0.12[a]	0.01[a]
Birjand	−0.10[a]	0.13[a]	0.18[a]	−0.2[b]	−0.01[a]	0.12[a]	0.01[a]	−0.03[a]	0.21[a]	0.11[a]	0.01[a]	0.09[a]
Kerman	0.01[a]	−0.08[a]	0.07[a]	−0.12[a]	−0.16[a]	−0.20[a]	−0.13[a]	0.06[a]	−0.03[a]	0.12[a]	−0.11[a]	−0.02[a]
Shiraz	0.08[a]	0.02[a]	0.11[a]	−0.09[a]	0.02[a]	0.26[a]	−0.05[a]	0.14[a]	0.20[a]	0.27[c]	−0.04[a]	−0.04[a]
Bam	0.05[a]	0.01[a]	0.01[a]	−0.14[a]	−0.07[a]	0.06[a]	0.05[a]	0.13[a]	0.06[a]	0.02[a]	−0.19[a]	−0.06[a]
Fassa	−0.01[a]	0.03[a]	0.20[a]	−0.76[c]	−0.04[a]	0.27[a]	−0.17[a]	0.20[a]	0.21[a]	0.16[a]	−0.08[a]	−0.03[a]
Chahbahar	−0.11[a]	−0.10[a]	0.27[b]	−0.15[a]	−0.02[a]	0.02[a]	−0.25[a]	−0.07[a]	−0.05[a]	0.24[a]	0.10[a]	0.10[a]

[a]No significant trend.
[b]Trends statistically significant at $p<0.05$.
[c]Trends statistically significant at $p<0.01$.

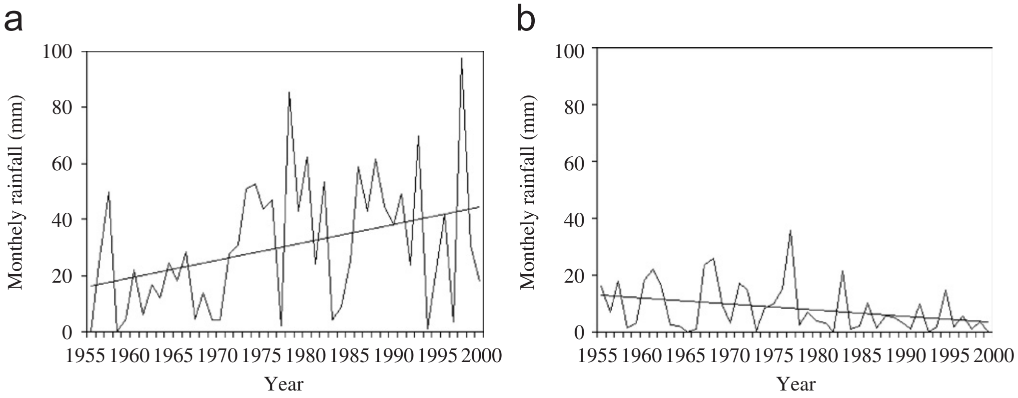

Fig. 6. Monthly rainfall trends and straight line trends for stations: (a) Sabzevar (February) and (b) Yazd (April).

5. Conclusions

This study investigated rainfall variability in arid and semi-arid regions of Iran by analyzing data for annual and monthly rainfall and number of rainy-days per year collected at 20 stations. Results showed that all analyzed time-series were homogeneous at $p<0.05$ according to the Thom test. On the other hand, the Mann–Kendall test applied to the annual rainfall time-series showed statistical significance at $p<0.05$ or $p<0.01$ and increasing and decreasing trends for only two stations. Most of the stations showed no statistically significant negative and positive trends widespread throughout the region. Only local and isolated trends in the rainfall data were found. The stations with significant trends in the number of rainy-days did not show a consistent spatial pattern. Only two time-series of rainy-days and 11 of monthly rainfall with statistically significant trends were found. These results also indicated that for the analyzed time-period, there was no significant climate change in the arid and semi-arid regions of Iran.

The stations with significant annual rainfall trends are evenly distributed to the north and south of the region and the northern stations showed positive trends while the southern stations showed negative trends. The correlations between annual rainfall and number of rainy-days were statistically significant for all stations. Therefore, the number of rainy-days has a significant relation to annual rainfall in Iran. The autocorrelation function plots showed the absence of time cycles in annual rainfall and rainy-days time-series. Monthly rainfall trends, even small, were also identified to be both increasing and decreasing in the region. In general, the significant trends in monthly rainfall occur mostly during the winter and spring. The results also suggest the need for further investigation on local anthropogenic intervention in the environment, which could be one of the major causes of climate change in arid and semi-arid regions.

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