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Dry spell trend analysis of Isfahan Province, Iran

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ABSTRACT: In the present study the spatiotemporal trend analysis of the annual maximum dry spell length (AMDSL) and the annual number of dry spell periods (ANDSPs) of Isfahan Province in the center of Iran has been conducted based on daily rainfall records taken from 17 rain gauge stations. The autocorrelation functions (ACFs) of dry spell time series showed the randomness of dry spells. The use of Mann-Kendall test for trend revealed two stations with significant negative trend of the AMDSL located in east and west of the province. The trend analysis of the ANDSP showed three stations with significant upward trend in east and one station with significant negative trend in the west of the province. The sequential Mann-Kendall test showed an evidence of an individual abrupt change in the magnitudes of dry spells from 1980s, especially in eastern arid and semi-arid regions of the province. However, the binomial and uniform distribution of Mann-Kendall statistics reveals that individual trend in a region is not strong enough to conclude the large-scale regional climatic effects on dry spell characteristics in the entire Isfahan Province. Copyright © 2008 Royal Meteorological Society

KEY WORDS dry spell; trend analysis; Mann-Kendall; sequential Mann-Kendall; climate change

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1. Introduction

There is a growing evidence of hydrological trend and long-term variability in the 20th century. Since the report of IPCC (1995) raised the question 'Has the climate become more variable or extreme?' trends of climate extremes have received increasing attention from many researchers in a variety of hydrological studies. Most previous studies concerning long-term climatological trends have focused on surface air temperature and precipitation.

Annual and monthly rainfall series are common variables used in trend and climate change analysis. IPCC (2007) reported that, during recent decades, precipitation has tended to increase in mid-latitudes, decrease in the Northern Hemisphere subtropical zones, and increase generally throughout the Southern Hemisphere.

Lettenmaier *et al*. (1994), Turkes (1996), Zhang *et al*. (2000), Gonzalez Hidalgo *et al*. (2003), Gong *et al*. (2004), del Rio *et al*. (2005), and Partal and Kahya (2006) are some examples of the researchers who have investigated recent rainfall trends in different geophysical fields. The change in daily extreme, which is very important aspect of precipitation in semi-arid region, has received much interest in recent years. Gong *et al*. (2004) considered daily extremes, the number of rainy days, precipitation intensity, maximum daily rainfall, persistence of daily rainfall, and dry spell duration. Qian and Lin (2005) used daily precipitation and daily temperature based on 494 stations in China in order to identify the trend in climate extremes. They found increasing trend in the number of rainy days and decreasing trend in the number of wet days. Schmidli and Frei (2005) investigated long-term variations and trends of extreme variables, i.e. heavy precipitation events, spells of intense precipitation and dry spells, of 100 rain gauges in Switzerland during 20th century. They found increasing trends for heavy precipitation and dry spells.

Extreme temperature series have also received increased attention during the last decades of the 20th century (Balling *et al*., 1990; Esterling *et al*., 2000). Temperature records across the world indicate that there has been an increase in the mean global temperature at about 0.6 °C since the start of the 20th century (Nicholls *et al*., 1996; Unkasevic *et al*., 2005) and that this increase is associated more strongly with warming in daily minimum temperature rather than with a change in maximum temperatures (Esterling and Horton, 1997). Temperature extremes are key aspects of any climate change because ecosystem and social response are more sensitive to them. Mearns *et al*. (1984) and Hansen *et al*. (1988) concluded that relative small change in the mean temperature could produce substantial changes in the frequency of the extreme temperature.

There is also strong evidence that rainfall changes associated to global warming are already taking place on global and regional scale. The trend was globally positive throughout the 20th century, although large areas were characterized by negative trend (IPCC, 2007).

In addition to the natural features of the climate systems, the global climate change is also said to be

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related to anthropogenic influences (Jain and Lall, 2000; Sharma *et al*., 2000). The effect of human beings on the long-term trends in hydrological time series has, therefore, received a great attention worldwide. The example of decreasing precipitation because of increasing deforestation was presented by Meher-Homji (1991). Similarly, Kothyari and Singh (1996) showed increasing temperature and decreasing precipitation trends since the mid-1960s as a result of deforestation. Sharma *et al*. (2000) also showed some evidence of increasing temperature and decreasing precipitation and discharge particularly during low flow season, as a result of anthropogenic effects.

Recently, Serra *et al*. (2006) studied dry spell trend in Catalonia (NE spain). They found decreasing trend for the number of annual dry spells but increasing trend for the annual maximum dry spells. In China, Gong *et al*. (2004) found significant positive trend in the length of dry spells in different regions of China. Schmidli and Frei (2005) found a very small number of stations with statistically significant dry spell trend in Switzerland.

The primary objective of this study is to investigate recent trends in dry spells of Isfahan Province, in the center of Iran. The introduction is followed by a description of the dry spell dataset used in this study for trend analysis. During the past decades, numerous parametric and nonparametric techniques for the detection of long-term trends in time series were developed (Lettenmaier, 1976; Hirsch *et al*., 1991). They will be briefly described in Section 3. Section 4 is devoted to the results and discussions of trend analysis and a brief conclusion is presented in Section 5.

2. Data set

Isfahan Province is located in the center of Iran (Figure 1). The eastern regions of the province are located in the western margins of arid and semi-arid regions of Iran. The western regions of the province lay in the eastern hill slopes of Zagrous Mountains. The mean annual rainfall of western region is 800 mm, while it is about 75 mm in eastern arid region. The average coefficient of variation (CV) of rainfall in the province is 34%. Winter and fall rainfall consists of 48.4 and 27.6% of total annual rainfall, whereas it is 23 and 1% for spring and summer season, respectively. The average maximum temperature in the province varies from 16.2 to 28.2 °C and the average minimum temperature varies from 6.3 to 1.1 °C. July and August are the warmest and January and February are the coldest months of the province.

There are 17 rain gauges in Isfahan Province with sufficient length of daily rainfall record, at least 30 years, which are used in this study to investigate dry spell trend in Isfahan Province. The data set of this study includes two variables. The first variable is the annual maximum dry spell length (AMDSL) and the second is the annual number of dry spell period (ANDSP). The first variable shows the longest period of days without

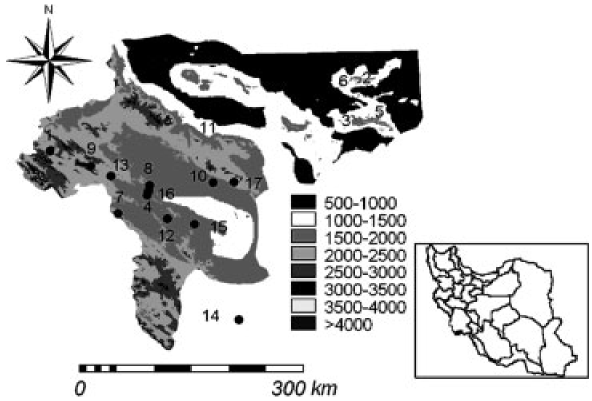

Figure 1. Digital Elevation Model (DEM) of Isfahan, location of Isfahan Province in Iran and measuring stations in Isfahan Province (the name and the number of stations are listed in Table I).

rainfall in each year and the second is the number of periods without rainfall in each single year. The annual maximum dry spells increase from 206 in the western region to 322 days in the eastern region of the province. The number of annual dry spells varies from 21 to 49 dry spell periods eastward toward arid and semi-arid regions of Iran. These two variables may cause major reduction in soil moisture and ground water which are important water resources for agricultural activities and development in Isfahan Province, particularly for hydrology cycle of arid and semi-arid region of the province.

The Exploratory data analysis is based on the calculation of descriptive statistics of data. Table I shows maximum, average, and standard deviation (SD) of the selected variables.

The average AMDSL of Isfahan Province is 157 days (44% of the year) and the average ANDSP is 18 periods. Maximum dry spell lengths are observed at Jandagh and Kuhpayeh Stations in eastern semi-arid region of the province, whereas the minimum dry spell lengths belong to Aznaveleh and Tad Stations in western humid region of the province.

3. Methods used

3.1. Test for randomness

One of the problems in detecting trends in hydrologic time series is the effect of serial correlation. If there is a positive serial correlation in time series, the nonparametric test will suggest a significant trend in time series (Burn and Hag Elnur, 2002; Yue *et al*., 2002; Partal and Kahya, 2006). To avoid this problem, we check the autocorrelation structure of dry spell time series. If the time series is random, the autocorrelation coefficients are not statistically different from zero. In other words, the autocorrelation coefficients do not cut the confidence interval (CI) at any desire level of significant, i.e. 95%.

The CIs are given by

$$\mathrm{CI} = \frac{z_\alpha - \alpha/2}{\sqrt{\mathrm{n}}} \quad (1)$$

Table I. Descriptive statistics of selected variables.

Station number	Station name	Time period	AMDSL			ANDSP		
			Maximum (day)	Mean (day)	SD (day)	Maximum	Mean	SD
1	Aznaveleh	1965–1999	206	123	39	49	26	8
2	Chahmalek	1966–1999	258	176	47	33	16	6
3	Choopanan	1966–1999	317	183	46	21	13	4
4	Falavarjan	1968–1999	237	138	44	32	21	5
5	Garmeh	1966–1999	280	181	48	25	13	5
6	Jandagh	1964–1999	322	166	58	23	13	4
7	Klishad	1965–1999	260	166	44	27	18	4
8	Khomenishahr	1967–1999	234	156	43	30	19	5
9	Kordolia	1967–1999	208	128	36	37	27	5
10	Kuhpayeh	1964–1999	309	188	60	29	12	6
11	Mahabad	1966–1999	292	175	56	21	12	5
12	Mahyar	1967–1999	231	157	45	28	19	5
13	Karvand	1967–1999	254	124	51	34	21	4
14	Mobarakeh	1968–1999	260	169	53	20	14	4
15	Jarghooyeh	1965–1999	314	157	61	30	16	8
16	Tad	1965–1999	217	158	38	33	19	5
17	Yazdabad	1965–1999	238	131	49	39	23	7

SD, standard deviation.

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

3.2. Test for homogeneity

Different methods and tests have been introduced to test the homogeneity of hydroclimatic variable (Buishand, 1982; Wijngaard *et al.*, 2003).

A climatic variable is said to be 'homogeneous' when its variations are caused only by fluctuations in weather and climate (Lazaro *et al.*, 2001). To test the homogeneity of a climatic time series, the 'run test' is applied in this study because it is a common valid method suggested by many investigators. In this test, time series of length n and x_{med} or the median of the time series are considered. We assign a code called 'a' for any value $x_j > x_{\mathrm{med}}$ and a code called 'b' for any value $x_j < x_{\mathrm{med}}$. Each uninterrupted series of 'a' and 'b' codes is called a 'run'. The distribution of the number of runs (N) approximates a normal distribution with the following average (E) and variance (Var):

$$E(R) = \frac{N+2}{2} \quad \mathrm{Var}(R) = \frac{N(N-2)}{4(N-1)} \tag{2}$$

The Z statistics is defined as:

$$Z = \frac{R - E(R)}{\sqrt{\mathrm{Var}(R)}} \tag{3}$$

For significance level of $\alpha = 0.01$ and $\alpha = 0.05$, the null hypothesis of homogeneity is verified if $|Z| \le 2.58$ and $|Z| \le 1.96$, respectively.

3.3. Mann-Kendal test for trend

This test, usually known as Kendall's τ statistics, has been used in hydrology and climatology to test randomness against trend of hydrologic time series. As it is a rank-based procedure, it is robust to the influence of extremes and good test for skewed data. For any sample of n variables, $x_1, \ldots, x_n$, the null hypothesis states that the sample is independent and identically distributed. The alternative hypothesis of a two-sided test is that the distributions of x_i and x_j are not identical for all k, $j \le n$ with $i \ne j$.

The MK test is based on test statistic S defined as follows:

$$S = \sum_{i=2}^{n} \sum_{j=1}^{i-1} \mathrm{sign}(x_i - x_j) \tag{4}$$

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 may be given as:

$$E[S] = 0 \tag{5}$$

$$\mathrm{Var}[S] = \frac{n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)}{18} \tag{6}$$

where t_p is the number of ties for the pth value and q is the number of tied values. The second term represents

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an adjustment for tied or censored data. The standardized test statistic (Z_{MK}) is computed by:

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{\mathrm{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\mathrm{Var}(S)}} & \text{if } S < 0 \end{cases} \quad (7)$$

A positive Z_{MK} indicates an increasing trend, whereas a negative Z_{MK} indicates a decreasing trend. To test for either increasing or decreasing monotonic trend at p significance level, the null hypothesis is rejected if the absolute value of Z is greater than $Z_{1-p/2}$, where $Z_{1-p/2}$ is obtained from the standard normal cumulative distribution tables. In this work, the significance level of $p = 0.01$ and 0.05 are applied.

3.4. Sequential Mann-Kendal test

To see change of trend with time, Sneyers (1990) introduced sequential values, $u(t)$ and $u'(t)$, from the progressive analysis of the Mann-Kendall test. Herein, $u(t)$ is a standardized variable that has zero mean and unit SD. Therefore, its sequential behavior fluctuates around zero level. The following steps are applied to calculate $u(t)$ and $u'(t)$:

1. The values of x_j annual mean time series, ($j = 1, \ldots, n$) are compared with x_i, ($i = 1, \ldots, j-1$). At each comparison, the number of cases $x_j > x_i$ is counted and denoted by n_j.
2. The test statistic t is then calculated by equation

$$t_j = \sum_{1}^{j} n_j \quad (8)$$

3. The mean and variance of the test statistic are

$$E(t) = \frac{n(n-1)}{4} \text{ and}$$
$$\mathrm{Var}(t_j) = [j(j-1)(2j+5)]/72 \quad (9)$$

4. The sequential values of the statistic $u(t)$ are then calculated as

$$u(t) = \frac{t_j - E(t)}{\sqrt{\mathrm{Var}(t_j)}} \quad (10)$$

The values of $u'(t)$ are computed similarly backward, starting from the end of the series.

4. Results and discussion

4.1. Test for randomness and homogeneity

This section presents the results of randomness and homogeneity test for selected variables. The test of randomness is done by drawing the autocorrelation functions (ACFs) for the AMDSL and the ANDSP. For an example, the ACF of the AMDSL of Jandagh and Jarghooyeh Stations are presented in Figure 2. In this figure, all autocorrelation coefficients are within 95% confidence levels which provide evidence of the randomness of AMDSL. The same condition is observed in Figure 3 for ANDSP. The ACFs of all stations are checked for testing the randomness of two variables and the results showed that all dry spell time series are random.

The Z values of homogeneity test and their significant levels are summarized in Table II. The significant values are presented in bold italics. From this table, one can see only one significant Z value for AMDSL (Jarghooyeh Station) and two significant Z values for ANDSP (Jarghooyeh and Chahmalek Stations). This may imply the existence of abrupt climate change in these stations (Lazaro *et al.*, 2001). In other words, in these stations, there is a point in dry spell time series where the descriptive statistics of the variables (such as mean and variance) begin to change suddenly afterward. To find the time of this change we can use sequential Mann-Kendall in Section 4.3.

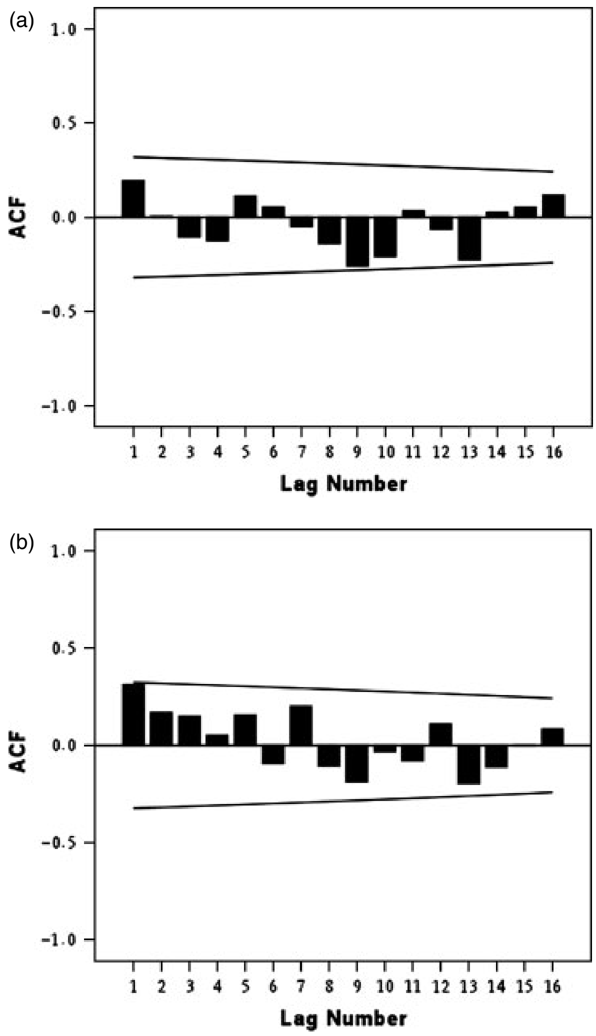

Figure 2. Autocorrelation functions for annual maximum dry spell, (a) Jandagh Station, (b) Jarghooyeh Station. Solid lines are confidence bands at 95% significant level.

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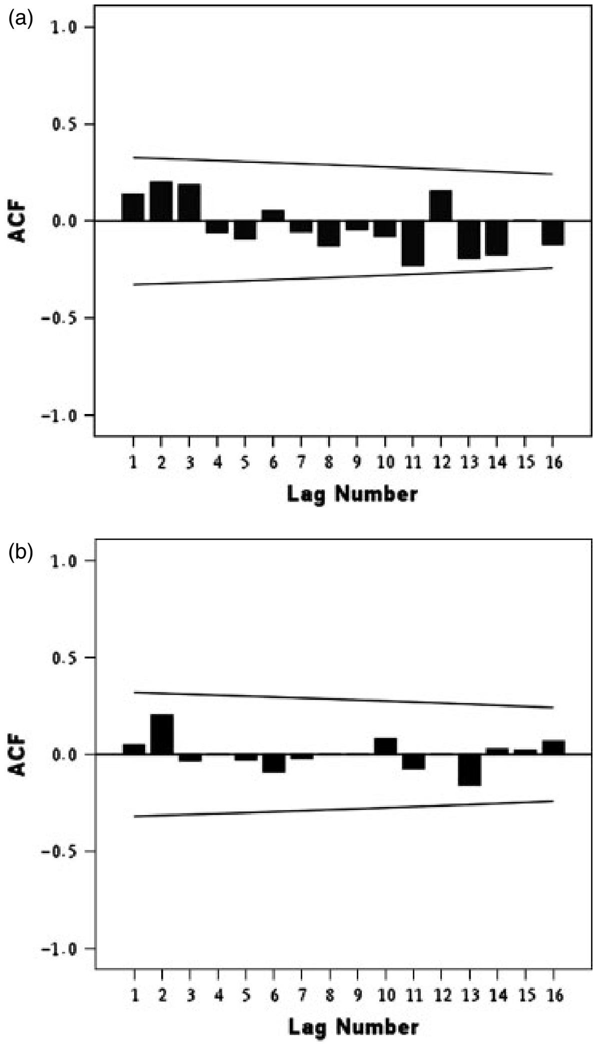

Figure 3. Autocorrelation functions for annual number of dry spells, (a) Choopanan Station, (b) Kuhpayeh Station. Solid lines are confidence bands at 95% significant level.

4.2. Mann-Kendall test for trend

This section presents the results of the nonparametric Mann-Kendall test. Table III shows the Man-Kendall statistics for AMDSL and ANDSP and related p-values. From this table, it is clear that two stations, Jarghooyeh and Kordolia, have a negative trend at 5% significant level. This may show that the AMDSLs have not changed in recent years over Isfahan Province except for two stations. It should also be noted that Jarghooyeh and Kordolia Stations are located in eastern semi-arid region and western humid regions of the province. Thus, we cannot conclude that the climate change has been occurred in the province because climate change does not depend on the local climate variability of the province and climate variability is a local phenomenon rather than a regional phenomenon in the entire province.

In Table III, the results of the nonparametric Mann-Kendall test for ANDSP are also presented. There are four stations with significant trend, among which, one station shows a negative trend at 1% significant level (Chahmalek Station), two stations show positive trend at 5% significant level (Kuhpayeh and Yazdabad Stations), and one station shows positive trend at 1% significant level (Jarghooyeh Station).

Therefore we can say that significant trends are observed only at local scale. In other words, global climate change influences dry spell trends at local level in Isfahan Province.

For graphical illustration, Figures 4 and 5 present the temporal changes of dry spell and the trend line. The linear regression model is used to estimate time trend of data. The regression trend lines are also given in these figures. All trend lines are significant at 5% level. According to the slope of trend lines, AMDSL decreases 26.6

Table II. Statistics of homogeneity test for selected variables.

Station name	AMDSL		ANDSP	
	Z	p-value	Z	p-value
Aznaveleh	−0.34	0.73	−1.03	0.31
Chahmalek	−0.52	0.60	***−2.42***	***0.02***
Choopanan	1.22	0.22	0.17	0.86
Falavarjan	0.18	0.86	−1.96	0.05
Garmeh	0.15	0.85	−0.52	0.60
Jandagh	−0.17	0.87	−0.41	0.68
Klishad	0.89	0.37	1.24	0.21
Khomenishahr	−0.35	0.73	0.86	0.39
Kordolia	−0.35	0.73	1.07	0.29
Kuhpayeh	0.85	0.40	−0.57	0.57
Mahabad	−1.06	0.29	−1.06	0.29
Mahyar	1.42	0.16	0.41	0.69
Karvand	0.74	0.46	1.46	0.14
Mobarakeh	−0.19	0.85	−1.08	0.26
Jarghooyeh	***−2.40***	***0.02***	***−4.80***	***0.00***
Tad	−0.68	0.50	−0.68	0.50
Yazdabad	−0.34	0.73	−1.42	0.16

Table III. Statistics of Mann-Kendall test for selected variables.

Station name	AMDSL		ANDSP	
	Z_{MK}	p-value	Z_{MK}	p-value
Aznaveleh	−0.03	0.78	−0.14	0.25
Chahmalek	0.17	0.15	***−0.37***	***0.00***
Choopanan	0.07	0.56	−0.14	0.26
Falavarjan	−0.23	0.07	0.01	0.94
Garmeh	0.13	0.31	−0.11	0.39
Jandagh	0.02	0.86	0.09	0.48
Klishad	−0.06	0.60	0.18	0.14
Khomenishahr	−0.17	0.15	0.15	0.23
Kordolia	***−0.26***	***0.04***	−0.12	0.32
Kuhpayeh	−0.12	0.31	***0.31***	***0.01***
Mahabad	−0.15	0.23	0.20	0.12
Mahyar	−0.06	0.61	0.09	0.46
Karvand	0.00	0.99	0.03	0.81
Mobarakeh	−0.11	0.41	−0.08	0.55
Jarghooyeh	***−0.31***	***0.01***	***0.42***	***0.00***
Tad	0.16	0.17	0.02	0.86
Yazdabad	−0.18	0.14	***0.31***	***0.01***

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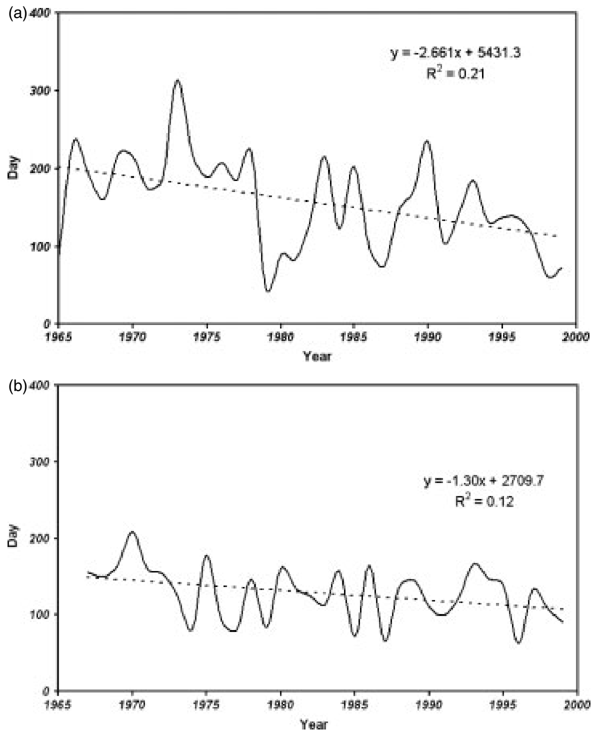

Figure 4. Time series of AMDSL for (a) Jarghooyeh Station and (b) Kordolia Station. Dashed line are linear trends estimated using ordinary least squares technique.

and 13 days per 10 years in Jarghooyeh and Kordolia Stations, respectively. The ANDSP increases 5, 1.5, and 3 dry spell periods per 10 years at Jargooyeh, Kuhpayeh, and Yazdabad Stations, whereas it decreases three dry spell periods per 10 years at Chahmalek Station, respectively.

4.3. Sequential Mann-Kendal test

In this section, we present the results of sequential Mann-Kendall test for the stations with significant trend. Figure 6 shows sequential values of $u(t)$ and $u'(t)$ statistics for AMDSL of Jarghooyeh and Kordolia Stations. Horizontal dashed lines are corresponding to confidence limits at 5% significance level.

Inspecting the plot of $u(t)$ of Jarghooyeh Station, an apparent decreasing trend is identified from 1978 to 2000. Although $u(t)$ and $u'(t)$ do not clearly cut each other but two functions begin to diverge in 1985, indicating the starting point of abrupt change (Lazaro *et al*., 2001; Partal and Kahya, 2006). For Kordolia Station (Figure 6(b)), it is clear that two $u(t)$ and $u'(t)$ plots do not diverge but $u(t)$ plot shows a decreasing trend. In other words, a decreasing trend is obvious in AMDSL of Kordolia Station, but no abrupt change has occurred because $u(t)$ and $u'(t)$ do not cut each other in recent years.

The sequential Mann-Kendall plots for ANDSP are given in Figure 7. In this figure, the $u(t)$ statistics show increasing trend for Jarghooyeh, Kuhpayeh, and Yazdabad Stations (Figure 7(a)–(c)), and decreasing trend for Chahmalek Station (Figure 7(d)). An abrupt climate change is also apparent for the first three stations,

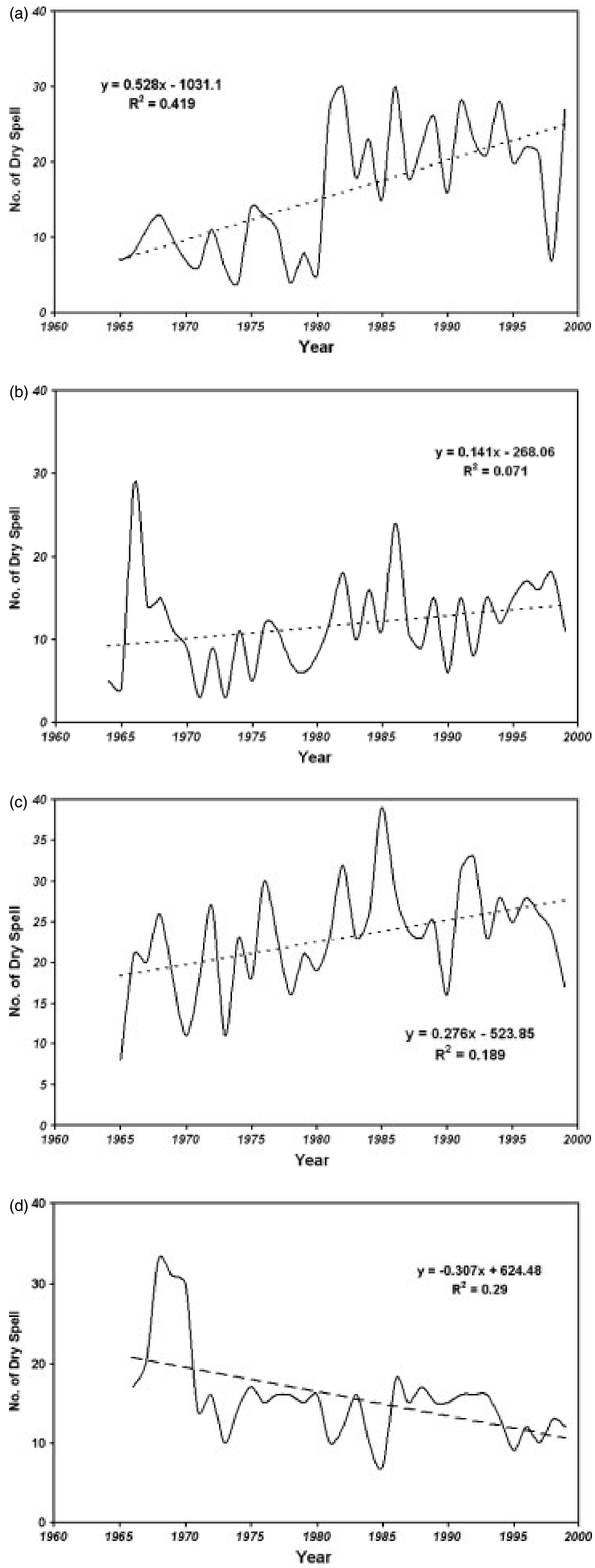

Figure 5. Time series of ANDSP for (a) Jarghooyeh Station, (b) Kuhpayeh Station, (c) Yazdabad Station, and (d) Chahmalek Station. Dashed lines are linear trends estimated using ordinary least squares technique.

Jarghooyeh, Kuhpayeh, and Yazdabad, as $u(t)$ and $u'(t)$ statistics cut each other. For these stations, two statistics diverge at early 1980s. In other words, an abrupt increase of ANDSP is apparent in the last 15 years in

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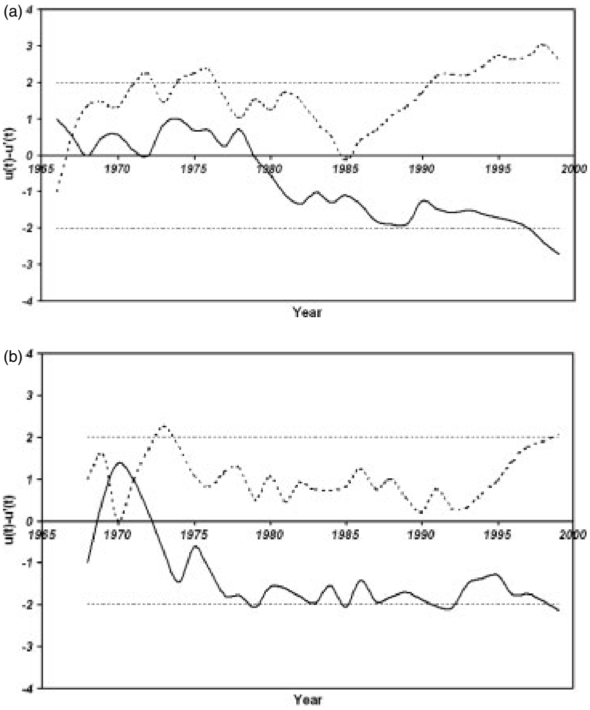

Figure 6. Sequential values of the statistics $u(t)$ (solid line) and $u'(t)$ (dashed line) from the Mann-Kedall test for AMDSL of (a) Jarghooyeh Station, (b) Kordolia Station.

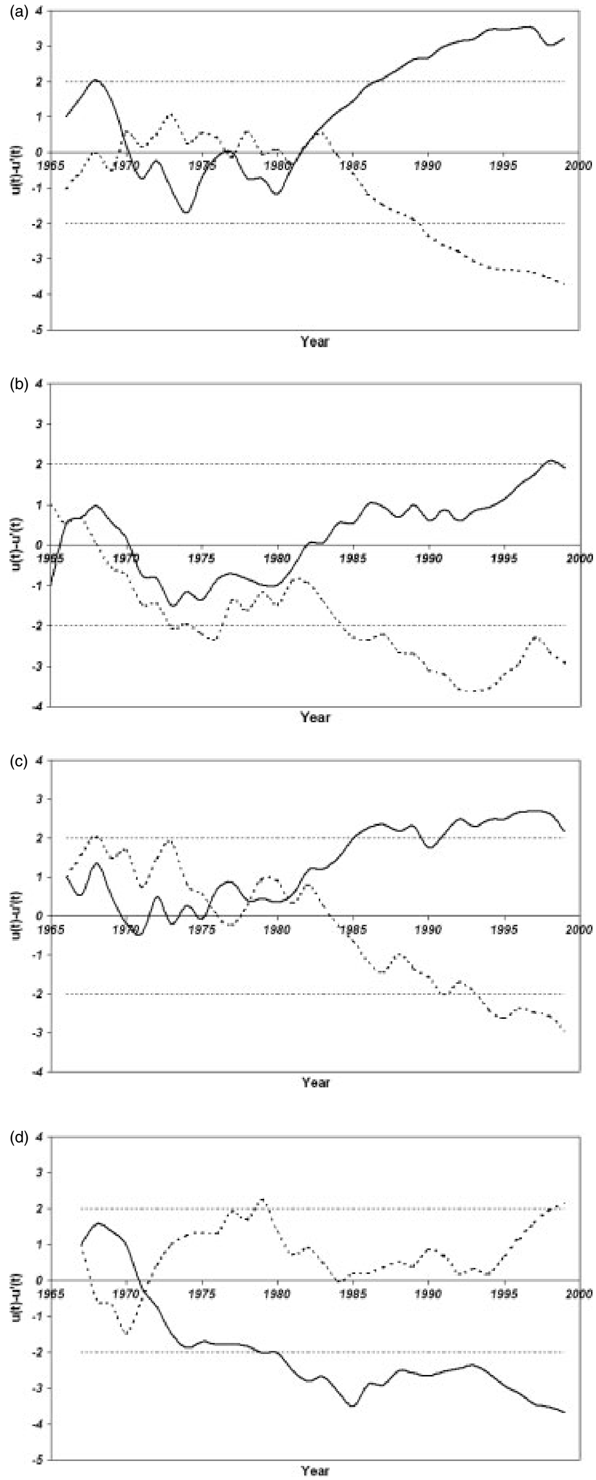

Figure 7. Sequential values of the statistics $u(t)$ (solid line) and $u'(t)$ (dashed line) from the Mann-Kendall test for ANDSP of (a) Jarghooyeh Station, (b) Kuhpayeh Station, (c) Yazdabad Station and (d) Chahmalek Station.

these three stations that are generally located in the arid and semi-arid regions of eastern and southeastern Isfahan Province. For Chahmalek Station (Figure 7(d)), that is located at western subhumid region of Isfahan Province, a decreasing trend is observed for $u(t)$ statistics and the two statistics reach each other in the early 1970s which may imply an abrupt change in ANDSP after early 1970s.

4.4. The standard normal homogeneity test (SNHT)

In this last section of results, we apply standard normal homogeneity test (SNHT) suggested by Alexandersson (1986) and Alexandersson and Moberg (1997) to detect whether or not the observed non-homogeneity may influence the result of trend for non-homogeneous AMDSL and ANDSP time series. Table IV illustrates the results of homogeneity and trend test for standardized AMDSL and ANDSP time series of the stations for which non-homogeneity and trend have been detected. It is clear that the standardized time series are homogeneous after standardization, but the trend is still significant for AMDSL and ANDSP time series. In other words, the results of trend assessment for selected time series are valid.

4.5. Test for regional trend

As only a few gauging stations are affected by statistically significant trend, here we examine if the effects of climate change on the dry spell regime of Isfahan Province seem to be null. The binomial distribution (Pettitt, 1979) is fitted to the signs of local time trends. The null hypothesis would be the lack of positive (negative) field trends. This hypothesis would imply a probability of local positive (negative) time trends of $p = 0.5$ ($Q = 0.5$). The results show that the null hypothesis of no trend in regional scale could not be rejected as the p-values of test are larger that 0.05 for both AMDSL and ANDSP time series. In addition to binomial test, the quantile–quantile plot (qq plot) of the uniform distribution of signs is

Table IV. Statistics of homogeneity test and Mann-Kendall test for standardized selected variables.

Station name	Homogeneity test			
	AMDSL		ANDSP	
	Z_{MK}	p-value	Z_{MK}	p-value
Chahmalek	–	–	***−0.42***	***0.11***
Kordolia	***−0.35***	***0.73***	–	–
Kuhpayeh	–	–	***−0.58***	***0.57***
Jarghooyeh	***−0.4***	***0.81***	***−0.80***	***0.12***
Yazdabad	–	–	***−1.41***	***0.16***
	Trend test			
	AMDSL		ANDSP	
	Z_{MK}	p-value	Z_{MK}	p-value
Chahmalek	–	–	***−0.37***	***0.001***
Kordolia	***−0.25***	***0.03***	–	–
Kuhpayeh	–	–	***0.30***	***0.011***
Jarghooyeh	***−0.23***	***0.03***	***0.41***	***0.001***
Yazdabad	–	–	***0.31***	***0.010***

also presented in Figure 8. Departures from the uniform distribution indicate that the null hypothesis of no trend must be rejected (Small *et al*., 2006). It is clear that the AMDSL and ANDSP do not deviate from linearity, but the departure is clearly larger for ANDSP. In other words, the effect of climate change on dry spells characteristics of Isfahan Province, i.e. AMDSL and ANDSP, is not significant for the region.

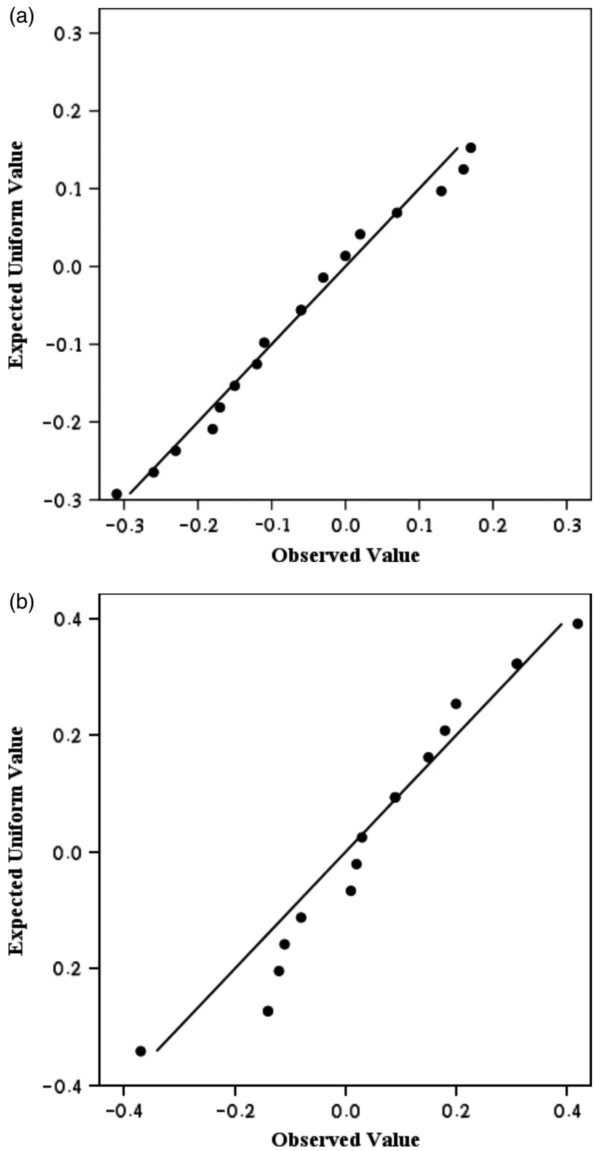

Figure 8. Quantile–quantile plot of uniform distribution for the trend test of (a) AMDSL and (b)ANDSP time series of ISfahan Province.

5. Conclusions

A set of 17 rain gauges in Isfahan Province in the center of Iran with daily rainfall recording for at least 30 years has facilitated a detailed analysis of the spatial patterns of trends of two dry spell magnitudes, the AMDSL and the ANDSP. Focusing on the annual maximum dry spell has allowed us to reveal two stations, in east and west of the province, with significant decreasing trend at the rates of 26 and 13 days/10 years. However, the ANDSP showed an upward trend in three stations in arid and semi-arid region and downward trend in one station in wet region of the province. In addition, the sequential Mann-Kendall test confirms an abrupt change in the ANDSPs in these three stations too in recent 15 years.

The increasing trend and sequential Mann-Kendall trend analysis of the number of dry spells may imply the local effects on trend characteristics in Isfahan Province rather than general trend for the entire region and it could not be considered as a strong evidence of climate change in arid and semi-arid regions of Iran because of binomial and uniform distribution of Mann-Kendall statistics.

This local effect of climate change was also found by Modarres and Silva (2007) on the annual rainfall in arid and semi-arid regions of Iran. Thus, it is worthwhile emphasizing that the results of the present study are not sufficient to approve climate change in Isfahan Province and arid and semi-arid regions of Iran. Future studies with longer data record are essential to check climate change and its attributes in Iran, especially in arid and semi-arid regions of Iran.

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