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Rainfall and rainy days trend in Iran

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Abstract In this study, long-term annual and monthly trends in rainfall amount, number of rainy days and maximum precipitation in 24 h are investigated based on the data collected at 33 synoptic stations in Iran. The statistical significance of trend and climate variability is assessed by the Mann-Kendall test. The Linear trend analysis and the Mann-Kendall test indicate that there are no significant linear trends in monthly rainfall at most of the synoptic stations in Iran. However, the maximum number of stations with negative trends have been observed in April (29 station), and then in May (21 stations) and February (21 stations) and with positive trends in December (26 stations) and July (24 stations). The significant linear trends, with a significant level of 0.05, in annual rainfall have been noticed only at five stations. The monthly number of rainy days does not show any significant linear trend for most areas in Iran. The maximum number of stations with monthly negative trends in rainy days has also been observed in April with the minimum in December. In April, out of 24 stations with negative trends, 12 stations have a significant negative trend. Contrary to that, in October there is no significant linear trend. Most stations have positive trends in annual number of rainy days. Also, the monthly maximum precipitation in 24 h does not show any significant linear trend for most areas in Iran. The maximum number of stations with monthly negative trends in maximum precipitation has also been observed in February with the minimum in December. In spite of that, there are almost no significant precipitation variations in Iran during the last 50-odd years, the tendency of decreasing rainfall amount in April and increasing rainfall amount in December and July could indicate an eventual climate change in this area in the future.

1 Introduction

Climate change is a hot topic and these days everyone is talking about it. Dealing with climate change and climate variability is generally considered to be one of the biggest

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challenges of the coming decades, on all geographical scales, across all economic sectors (Aerts and Droogers 2004). Climate is defined as the mean meteorological conditions in a specific area (Mander 1994). There is much evidence regarding the long-term trends and the climate variability that is impacted by human activities, industries and natural specifications of climate systems. Although the major phenomena related to changes in the composition of atmosphere such as greenhouse gas emissions have major impacts on climate variability. Nowadays human activities have the most effects on climate variability and have made greenhouse gases, CO_2, CH_4, N_2O to be composite together (Domroes and El-Tantawi 2005; Hunt 2000; Raziei et al. 2005).

Studies on climate change have shown an increase of 0.5–1% in rainfalls per decade in much of the Northern Hemisphere's mid and high latitude. Annual average of regional precipitation has increased between 7% and 12% for the areas in 30–85° N latitude and by about 2% for the areas in 0–55° S over the 20th century (Mosmann et al. 2004; Xu et al. 2003; Xu et al. 2005; Yu et al. 2006). Such climate changes have a major impact on hydrological cycles and consequently on available water resources, flooding, drought frequencies and natural ecosystems. (Raziei et al. 2005). Much of the research shows that there are decreasing or increasing trends in annual, seasonal and monthly rainfall but most of them are not significant trends.

For example in Turkey, most regional mean, normalized, annual rainfalls have negative trends which are not significant at 5% level (Kahya and Kalayc 2004; Raziei et al. 2005).

Ramos (2001) did not find a clear and significant trend in annual rainfall of Mediterranean area while González-Hidalgo et al. (2001) found a significant decrease in rainfall amount associated with a significant increase in variability in more humid areas of Valencia.

Piccareta et al. (2004) concluded that annual rainfall in most Basilica stations show a negative trend with mean annual precipitation decrease about 156 mm in recent 30 years.

IPCC report (2007) showed that significant trends have been observed in precipitation amounts in many regions from 1900 to 2005. Over this period, precipitation increased significantly in eastern parts of North and South America, northern Europe and northern and central Asia whereas precipitation declined in the Mediterranean coast, southern Africa and parts of southern Asia.

Yu et al. (2006) showed that annual rainfall has increased in northern Taiwan, declined in central and southern Taiwan, and exhibited no clear tendency in Eastern Taiwan. Almost all of these rainfall series changed significantly around 1960.

Jiang et al. (2006) described a significant positive trend in summer precipitation at many stations of Yangtze, especially for June and July.

The present study focuses on Iran and attempts to investigate climate changes by analyzing trends of rainfall amount, number of rainy days on monthly and annual time scale as well as variability of these parameters.

2 Study area

Iran with an area of about 1,648,000 km^2, is located in the southwest of Asia. Iran lies between 25° 3′ and 39° 47′ N in latitude and between 44° 5′ and 63° 18′ E in longitude. From the latitude point of view, the southern region of Iran is located in a tropical region and northern region is located in a subtropical region. Geographical position of Iran is presented in Fig 1.

Iran is surrounded by two mountain ranges, namely Alborz to the north and Zagros to the west. Alborz and Zagros mountain ranges have stretched in northwest-northeast

Fig. 1 Geographical positions of synoptic stations and topographic features of Iran

and northwest-southeast directions, respectively. Both of them have an important role in the spatial and temporal distribution of precipitation over the country. All of the meteorological systems, which affect Iran, may get stronger or weaker by these two mountain ranges. They will also affect on the direction of climate systems. In other word, these mountains create completely different local climates in Iran. The country's climate is mainly arid and semi-arid, except in the northern coastal areas and parts of western Iran. The arid and semi arid regions have an extremely continental climate with warm and dry summer and very cold winter especially in the central regions. The wet and dry seasons generally occur from November to May and June to October, respectively (Raziei et al. 2005).

The mean annual rainfall over Iran is about 240 mm. Maximum of it is about 1,800 mm on the Caspian seashore and about 400 mm in the sloping region of Alborz and Zagros mountains. The ranges of rainfall decrease to less than 100 mm annually depending on the location in the central and eastern parts of Iran. Cause of high variability in annual rainfall in Iran can be synoptic systems and year-to-year variation in the different number of passing cyclones.

3 Materials and methods

In this study all the synoptic stations with at least 30-year records were selected. The stations under study are scattered across the country. Trend analysis is based on monthly and annual rainfall variables and number of rainy days (Table 1). At first, for reconstruction of missing values, an auto-correlation test was performed with lag $K=1$, otherwise Pearson

Table 1 Spatial location of synoptic meteorological stations of Iran

Station	Elevation (m)	Longitude	Latitude	Period	Mean annual rainfall (mm)	Mean annual number of rainy days
Abadan	7	15° 48′	22° 30′	2005–1951	154.4	37.7
Ahvaz	23	40° 48′	20° 31′	2005– 1957	229.4	39.7
Anzali	−26	28° 49′	28° 37′	2005–1953	1855.8	147.5
Arak	1708	46° 49′	06° 34′	2005–1956	368.2	69.8
Ardebil	1332	17° 48′	15° 38′	2005–1977	313.7	96.9
Babolsar	−21	39° 52′	43° 36′	2005–1951	891.3	106.7
Bam	1,067	21° 58′	06° 26′	2005–1957	61.4	21.9
Bandar Abbas	10	22° 56′	13° 27′	2005–1957	182.5	22.5
Bandar Lenge	23	50° 54′	32° 26′	2005–1966	143.1	20
Birjand	1,491	12° 59′	52° 32′	2005–1956	170.6	49.9
Bushehr	20	50° 50′	59° 28′	2005–1953	279.9	37.9
Esfahan	1,550	40° 51′	37° 32′	2005–1951	122.9	44.6
Qazvin	1,279	3° 50′	15° 36′	2005–1959	316	92.9
Gorgan	13	16° 54′	51° 36′	2005–1953	602.7	103.9
Hamedan	1,680	43° 48′	12° 35′	2005–1951	332.6	82.7
Kashan	982	27° 51′	59° 33′	2005–1967	138.4	41.2
Kerman	1,754	58° 56′	21° 30′	2005–1951	153.3	41.4
Kermanshah	1,319	09° 47′	19° 34′	2005–1951	444.7	76.9
Khoramabad	1,148	17° 48′	26° 33′	2005–1951	508.6	76.5
Mashhad	999	38° 59′	16° 36′	2005–1951	225.1	75.9
Oroomieh	1,316	05° 45′	32° 37′	2005–1951	340.6	89.7
Ramsar	−20	40° 50′	54° 36′	2005–1956	1224.2	133.5
Rasht	37	39° 49′	12° 37′	2005–1956	188.8	52.5
Sabzevar	978	43° 57′	12° 36′	2005–1955	460.3	85.8
Sanandaj	1,373	00° 47′	20° 35′	2005–1960	140.8	48.4
Semnan	1,131	33° 53′	35° 35′	2005–1966	323.3	55.16
Shahrekord	2,049	51° 50′	17° 32′	2005–1956	156.5	63
Shahroud	1,345	57° 54′	25° 36′	2005–1953	346.1	48.1
Shiraz	1,484	36° 52′	32° 29′	2005–1951	232.9	76.5
Tabriz	1,361	17° 46′	05° 38′	2005–1951	60.6	26.8
Tehran	1,191	19° 51′	41° 5′	2005–1951	61.28	21.9
Yazd	1,237	17° 54′	54° 31′	2005–1953	91	27.4
Zabol	489	29° 61′	02° 31′	2005–1963	154.4	37.7
Zahedan	1,370	53° 60′	28° 29′	2005–1951	229.4	39.7
Zanjan	1663	29° 48′	41° 36′	2005–1956	1855.8	147.5

correlation was applied. Non-parametric Mann-Kendall (Hirsch et al. 1982: Modarres and Silva 2007) and Spearman test analyzed the trends in this research.

The Mann-Kendall test is used for determining monotonic trends and is based on ranks (Helsel and Hirsch 2002). This test also is used for determining the existence of statistically significant trends in climate and hydrologic time series (Burn 1994; Pasquini et al. 2006; Robert et al. 1984). This is a test for correlation between a sequence of pairs of values. Using ranks eliminates the sensitivity of the correlation test to the function linking the pairs of values. In particular, the standard correlation test is used to find linear relations between test pairs, but the rank correlation test is not restricted in this way.

The Monte Carlo simulation experiments demonstrated that the existence of serial correlation alters the variance of the MK statistic, whereas it does not alter the central tendency or mean and the distribution type of the MK statistic. It was found that positive serial correlation increases the variance of the MK statistic; this increases the probability of detecting a significant trend, whereas in fact none may exist. To avoid this problem, we check the autocorrelation structure of all 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:

$$CI = \frac{z_\alpha - \alpha/2}{\sqrt{n}} \tag{1}$$

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

The homogeneity of the rainfall's time series was determined by Mann–Whitney test at the 90% significance level. This test assesses shifts in statistical properties of time series.

4 Results and discussion

4.1 Test for randomness and homogeneity

The test of randomness is done by drawing the autocorrelation functions (ACFs) for all time series. For an example, the ACF of the rainfall of Abadan and Babolsar stations are presented in Fig. 2. In this figure, all autocorrelation coefficients are within 95% confidence levels which provide evidence of the randomness of rainfall. The same condition is observed in Fig. 3 for number of rainy days and Fig. 4 for maximum precipitation in 24 h. The ACFs of all stations are checked for testing the randomness of three variables and the results showed that all time series are random.

4.2 Annual and monthly rainfall

The homogeneity of rainfall time series may be damaged by relocation of observation stations. There was relocation of some important stations such as Khoramabad and Kerman. Therefore, in the final analysis the data series of mentioned stations were omitted. The results of non-parametric Mann–Whitney test indicated that the relocation of other stations has not significantly affected the homogeneity of the data series. So the data series of other stations are homogeneous at 10% significance level.

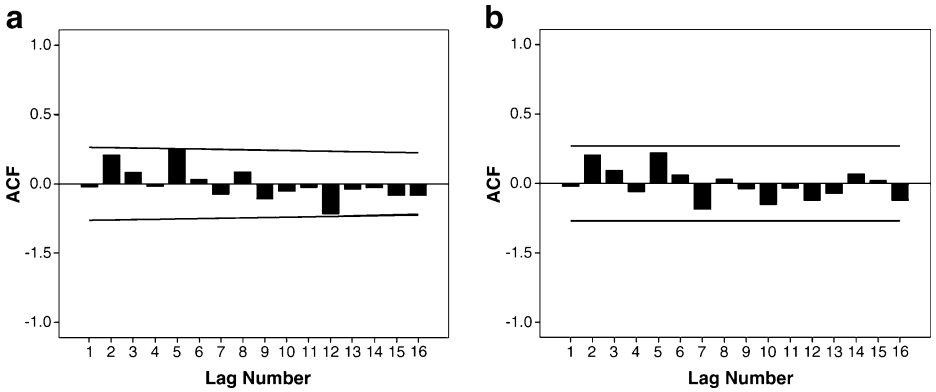

Fig. 2 Autocorrelation functions for annual rainfall, **a** Abadan station, **b** Babolsar station. Solid lines are confidence bands at 95% significant level

The non-parametric Mann-Kendall test was also applied to detect monthly and annual rainfall trends for all selected stations. The results showed eighteen stations have no statistically significant trends. Distribution of these stations is similar to two belts. One of them stretches from west to north and northeast and another stretches from southwest to south and also a part of them located in the southeast (Table 2). The results have clearly shown few stations with statistically significant trends at 1% and 5% significance levels.

In all spring months, Isfahan station showed significant positive linear trend in March (Fig. 5(a, b)).

In all summer months the negative linear trend is observed on the stations of Oroomieh, Gorgan and Yazd. Among these stations the statistically significant trend is noticed in Oroomieh in June, Gorgan in July and Yazd in August (Fig. 5(c)).

In all autumn months, none of the stations had any statistically significant trends (Tables 2, 3 and 4).

In all winter months the positive linear trend is detected in two stations; Tehran and Shahroud. In both stations the statistically significant trend is noticed in December (Fig. 5(e)).

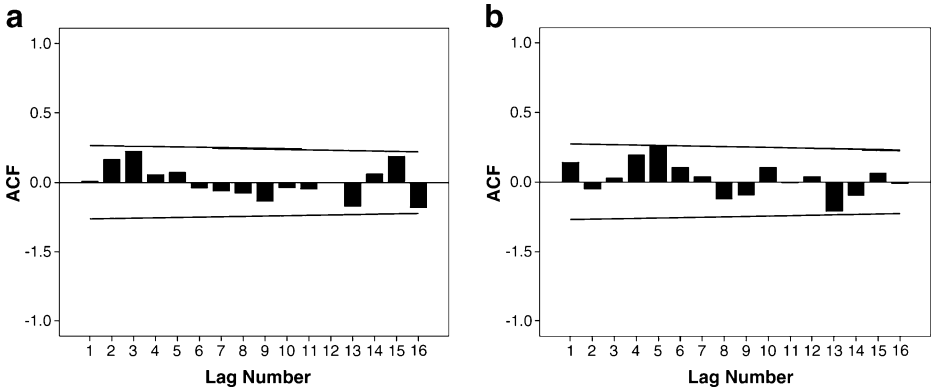

Fig. 3 Autocorrelation functions for annual rainy days, **a** Esfahan station, **b** Sabzevar station. Solid lines are confidence bands at 95% significant level

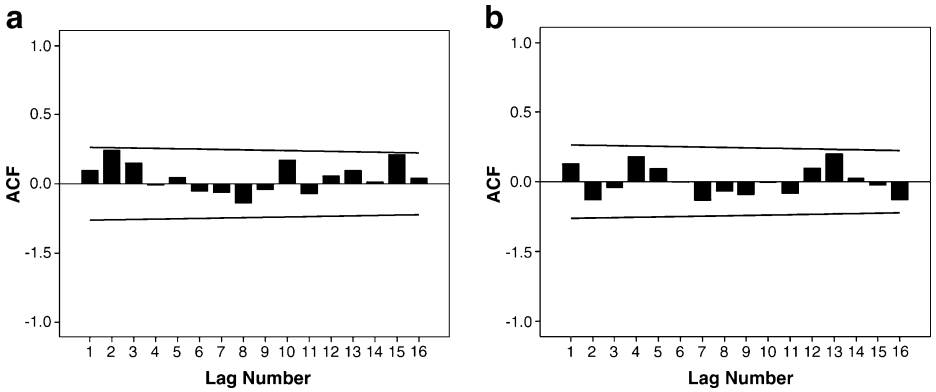

Fig. 4 Autocorrelation functions for annual rainy days, **a** Anzali station, **b** Tabriz station. Solid lines are confidence bands at 95% significant level

Generally, in all spring months, stations located in the south and near to the north-northwest of Iran showed no significant negative trend. In all summer months most of the stations in Iran were without any statistically significant trends and only a few of them, which were mostly located along Zagros mountain ranges, had statistically significant trends in some months. During autumn months, except Abadan station, which had significant positive trend in October, we did not observe statistically significant trends in Iran. Winter and autumn seasons had approximately similar trends. In winter most of the stations are without any statistical significant trends. Only Tehran and Shahroud have significant positive trend in December and Arak and Tabriz have significant negative trend in January and February, respectively. Results of annual rainfall analysis show significant negative trend on the stations: Tabriz, Oroomieh and Zahedan but significant positive trend only in Babolsar and Abadan (Fig. 5(f), and 8). 84% of stations (28 stations) are without any statistical significant. Therefore, most of the stations in western part of Alborz and alongside Zagros to southeast of Iran had negative trends (significant and no significant), central Alborz to northeast of country and also southern parts have positive trends (significant and not significant).

The major number of positive trends occurs more frequently in December while the major number of negative trends occurs in April. Results of Spearman test are approximately similar to Mann-Kendall test but there is a difference between the results of two tests. For example, Ahvaz and Tehran stations had significantly positive trends in March. Also, Sanadaj station shows a significantly negative trend in August and Babolsar station has a significantly positive trend in November (Table 5).

Rahimzadeh et al. (2005) in Iran showed significant positive trends in Abadan station and significant negative trends in Oroomieh and Tabriz in regard to annual rainfall amount, while Raziei et al. (2005) showed in the southern Iran annual precipitation increased insignificantly and a dipole precipitation variability and trend were observed in western Iran.

Although some climatic parameters have been shown to have a distinct trend globally (a positive trend for temperature, for example), rainfall behavior varies depending on the location. Forland et al. (1996) showed a positive precipitation trend for Northern Europe. Both Hess et al. (1995) for the North East arid zone of Nigeria (over the period 1961–1990) and Manton et al. (2001) for South East Asia and the South Pacific (over the period 1961–1998) identified a decrease in annual rainfall. Schonwiese and

Table 2 Linear trends (mm/year) of monthly and annual rainfall for synoptic stations of Iran by Mann-Kendall test. The analyzed periods are given in Table 1

Station/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Abadan	1.73	−0.07	1.77	−1.05	−1.19	1.06		0.7	−0.39	2.23*	0.26	1.12	2.01*
Ahvaz	−0.02	−0.62	1.53	−0.87	−1.78	0.8	0.42	−0.14	0.21	−0.03	0.42	0.2	0.98
Anzali	1.05	−1.03	−1.05	−1.34	−0.96	−1.58	−1.5	−1.23	0.09	−0.63	−1.4	0.67	−1.76
Arak	−2.19*	−1.15	0.95	−1.59	0.2	1.18	1.68	1.23	0.96	1.85	0.66	0.64	−1.3
Ardebil	−0.26	−0.47	0.56	0.6	−0.9	−1.95	1.91	0.36	−0.04	−1.14	0.38	−1.65	−0.98
Babolsar	1.48	−0.13	−1.5	−0.41	0.33	−0.12	−0.85	0.43	0.44	0.76	1.94	1.13	2.46*
Bam	−0.39	0	−0.47	−1.76	−0.86	0.79	0.46	1.09	0.02	0.99	−1.43	−1.06	−0.77
Bandar Abbas	0.02	0.42	0.76	−0.92*	0.78	1.42	0.18	2.64**	0.13	0.24	−0.87	0.83	0.23
Bandar Lenge	0.58	−1.11	0.89	−1.14	−0.02	0.04	−0.16	−1.38	0.53	0.09	1.21	0.12	0.16
Birjand	−0.53	0.91	1.06	−2.68**	−0.02	0.26	0.34	−0.49	1.13	−0.18	0.05	0.82	−0.16
Bushehr	1.65	−0.05	0.36	−0.38	0.14	0	1.19	1.24	0	0.25	0.04	0.4	1.11
Esfahan	1.01	−0.7	2.09*	−0.89	−1.06	1	1.16	0.24	−1.23	−0.08	0.76	0.65	1.02
Gorgan	0.76	0.66	−1.7	−1.68	0.33	−0.37	−2.10*	−0.54	0.87	−0.56	0.75	0.14	−1.17
Hamedan	0.34	−1.07	0.28	−1.98*	−0.83	0.98	2.10*	0.79	0.84	1	−0.17	0.16	−1.44
Kashan	0.09	−0.94	−0.11	0.31	0.29	−1.33	−0.05	−1.43	1.28	−0.7	0.32	−0.11	0.17
Kermanshah	1.85	−0.09	1.33	−2.82**	−0.67	−1.07	2.85**	−1.57	−0.25	0.87	0.07	0.83	0.54
Mashhad	1.14	0.23	0.22	−1.52	−0.3	0.82	1.43	1.48	0.7	−0.26	0.68	0.94	0.46
Oroomieh	−1.19	−1.88	−1.12	−1.76	−0.17	−2.26*	−0.35	−0.9	−1.64	−0.13	0.21	−0.38	−2.58**
Qazvin	0.01	0.33	1.73	−0.27	−0.02	−1.81	1.88	−0.45	−0.13	0.77	1.37	1.49	1.22
Ramsar	0.01	0.03	−0.23	−1.11	0.33	−0.58	0.02	−1.61	−0.18	0.43	−0.31	−0.31	−0.73
Rasht	−0.02	0.27	−0.64	0.13	0.65	−0.36	−0.26	0.15	−0.28	−0.86	0.44	0.43	0.08
Sabzevar	1.24	1.29	0.89	−0.72	−0.46	−0.06	0.46	1.72	1.4	0.78	0.87	1.04	1.67
Sanandaj	−1.74	−1.35	−0.66	−1.54	−0.91	−0.08	1.66	−1.94	−0.76	−0.24	0.11	0.35	−1.56
Semnan	0.44	−1.75	0.7	0.7	−0.74	−0.83	1.37	1.48	0.67	−1.04	0.82	1.01	0.92
Shahrekord	0.3	−0.07	1.15	−1.14	0.07	1.6	2.28*	0.35	1.96	0.97	1.38	1.67	1.05

Table 2 (continued)

Station/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Shahroud	0.6	0.31	0.78	−0.4	−0.25	1.42	0.22	1.22	0.61	0.73	0.15	2.19*	1.27
Shiraz	1.15	0.11	0.44	−1.13	−0.26	2.16*	0.23	0.63	1.35	1.49	−0.27	−0.01	0.27
Tabriz	−1.14	−3.45**	−2.42*	−0.71	0.35	−1.75	0.73	−0.13	−1.05	−0.49	−0.06	0.38	−2.62**
Tehran	0.95	0.28	1.82	−0.3	0.59	−0.7	0.99	−0.07	−0.48	0.64	−0.56	2.00*	1.51
Yazd	1.26	−0.19	0.89	−2.36*	−0.07	0.86	0.94	−2.14*	−1.18	−0.58	0.61	0.69	−0.15
Zabol	0.93	−0.79	0.72	−1.76	−0.53	−0.97	−0.64	−0.56		−0.2	−0.1	1.31	0.41
Zahedan	−1.37	−1.24	−1.82	−2.14*	−0.99	0.8	0.31	0.87	−0.09	1.1	−0.11	−1.24	−3.17**
Zanjan	0	−0.76	−0.62	−1.89	0.42	−1.08	1.81	0.38	−0.83	0.02	0.59	0.75	−1.57

*Trend statistically significant at $p<0.05$

**Trend statistically significant at $p<0.01$

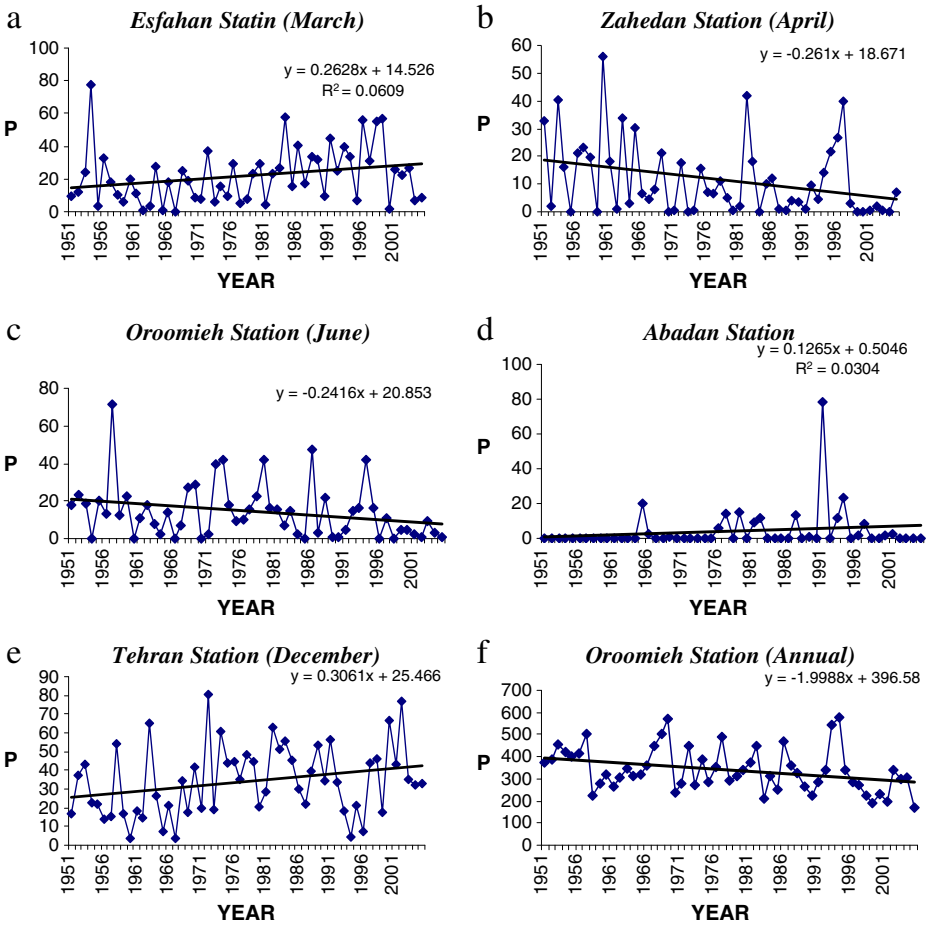

Fig. 5 Linear trends (mm/year) of monthly and annual rainfall for selected synoptic stations in Iran during the period 1951–2005

Rapp (1997) found a positive trend in the North and a negative trend in the South of Europe. Herath and Ratnayake (2004) reported a decrease in the annual rainfall in the Sri Lanka for 1964 to 1993. One third of stations considered by Ceballos et al. (2004) in Spain, possessed negative trend. Khalili and Bazrafshan (2004) observed no trends in annual rainfall of 4 major stations of Iran for a 108 year period.

This result revealed a seasonal movement toward concentrated rainfall in the winter. Statistically significant trends occur in all months except for September and November. Also, our results have indicated the decreasing trend in mean annual rainfall and the intensification of its severity during recent years.

4.3 Number of rainy days

As mentioned in the previous section, all stations except Khoramabad and Kerman, which are omitted, are homogeneous as shown by Mann–Whitney test.

Table 3 Linear trends (day/year) of monthly and annual rainy days for synoptic stations of Iran by Mann-Kendall test. The analyzed periods are given in Table 1

Station/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Abadan	−0.24	−0.46	−0.68	−2.58**	−2.06*	0.26		0.72	−0.71	1.09	−0.8	−0.56**	−1.98*
Ahvaz	3.22**	2.91**	3.36**	1.71	1.13	1.13	1.67	0.13	0.68	0.92	1.73	3.43	4.78**
Anzali	0.73	1.17	−0.13	0.34	2.87**	2.07*	2.05*	2.46*	−0.51	−0.09	1.57	0.99	3.68**
Arak	0.73	0.73	1.34	−0.5	0.22	0.86	1.08	1.48	0.2	0.98	1.17	1.39	1.48
Ardebil	0.99	0.21	−0.61	1.3	−0.06	−0.9	3.70**	1.1	1.57	0.04	0.36	0.55	1.56
Babolsar	0.02	0.77	−0.58	−2.78**	0.64	0.04	0.16	1.52	−0.92	0.22	0.48	1.78	0.08
Bam	−0.1	−0.76	−0.68	−2.78**	−1.5	−0.06	0.01	0.44	0.1	0.77	−1.11	−0.88	−1.89
Bandar Abbas	0.46	1.71	2.60**	−0.99	1.86	1.46	1.55	3.12**	0.93	0.26	−0.3	1.32	2.62**
Bandar Lenge	0.06	−1.26	1.47	−2.12*	0.33	0.04	−1.68	−1.82	0.56	0.55	0.37	−0.12	−0.53
Birjand	0.48	1.63	0.66	−2.08*	0.05	0.28	−0.31	−0.42	1.29	−0.16	0.08	1.12	0.28
Bushehr	3.00**	2.59**	2.71**	1.18	0.74	0.84	0.88	1.24	0	0.37	0.54	0.71	3.22**
Esfahan	0.99	0.11	−0.69	−2.15*	−2.91**	0.25	−0.22	−0.39	−1.69	0	−0.71	−0.6	−2.41*
Gorgan	1.31	1.48	0.96	0.22	3.11**	2.01*	0.39	2.19*	1.38	0.9	1.54	3.12**	3.85**
Hamedan	1.54	0.28	−0.69	−0.42	0.62	1.26	1.9	0.15	0.1	1.1	0.63	1.08	1.14
Kashan	0.15	−1.99*	−1	−0.01	−1.2	−1.2	0.09	−1.32	1.25	−0.29	0.15	0.13	−1.19
Kermanshah	2.78**	0.42	0.02	−1.96	0.91	−0.66	2.65**	−0.64	−0.06	1.01	0.47	1.25	1.37
Mashhad	0.93	2.17*	−1.37	−2.01*	−0.05	0.74	0.07	1.46	−0.16	0.32	−0.02	0.84	0.25
Oroomieh	−0.33	0.53	−0.81	−2.32*	0.39	−0.83	0.41	−0.25	−1.14	−0.04	0.07	0.52	−0.29
Qazvin	0.19	0.27	−1.23	−2.10*	−0.91	−1.67	1.33	−0.88	−0.32	−0.29	1.39	1.64	−0.85
Ramsar	0.63	0.52	−1.24	−0.74	1.14	0.11	−0.02	−0.31	−1.07	−1.86	1.33	0.63	−0.49
Rasht	0.86	0.93	−0.35	−0.72	2.15*	1.34	0.96	1.16	−0.95	−0.52	1.42	0.74	1.44
Sabzevar	1.13	1.38	0.66	0.55	0.88	0.31	−0.18	1.78	1.66	0.81	1.39	1.64	2.85**
Sanandaj	−0.53	−0.69	−1.34	−2.43*	−0.37	1.19	2.25*	−1.14	0.01	0.54	0.83	0.44	−1
Semnan	−0.45	0.2	0.1	−0.43	−1.61	−1.26	0.73	0.47	0.15	−0.31	0.85	1.45	−0.82
Shahrekord	2.72**	3.82**	2.88**	1.1	1.04	2.27*	2.54*	1.15	3.44**	1.33	1.99*	3.15**	4.87**

Table 3 (continued)

Station/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Shahroud	−0.66	−0.81	−1.91	−1.5	−1.46	−0.55	−1.49	0.48	−0.68	0.5	−0.15	0.77	−1.87
Shiraz	1.79	1.85	1.2	0.34	0.75	2.22*	1.56	1.91	1.03	1.38	1.47	0.31	2.43*
Tabriz	1.89	0.66	−0.77	−1.26	1.01	−0.57	1.63	−0.35	0.21	0.95	0.79	1.3	1.53
Tehran	1.33	0.77	0.53	−1.97*	0.79	−0.39	0.94	0.64	−0.25	0.88	1.03	2.04*	1.57
Yazd	2.28*	0.88	1.41	−0.13	2.18*	2.50*	0.54	−0.84	1.45	−0.39	1.04	2.03*	3.00**
Zabol	2.36*	0.1	1.41	−2.10*	−0.73	−0.09	−0.64	−0.56	−2.19*	−0.89	−0.1	0.56	0.72
Zahedan	−0.01Z	0.6	0.74	−0.06	−1.07	0.62	0.8	0.85	1	0.26	0.96	0.18	0.3
Zanjan	1.85	3.51**	0.14	0.54	1.12	0.15	3.08**	0.95	−0.33	0.75	2.82**	3.54**	3.72**

*Trend statistically significant at $p<0.05$

**Trend statistically significant at $p<0.01$

Table 4 Linear trends (mm/year) of monthly and annual maximum precipitation in 24 h for synoptic stations of Iran by Mann-Kendall test. The analyzed periods are given in Table 1

Station/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Abadan	2.18*	−0.53	1.32	−1.15	−1.02	1.06	0.00	0.70	−0.39	2.25*	0.65	1.45	2.36*
Ahvaz	1.47	−0.41	2.09*	−0.55	−1.86	0.80	0.42	−0.14	0.21	−0.30	1.26	0.71	0.94
Anzali	1.05	−1.03	−1.05	−1.34	−0.96	−1.58	−1.50	−1.23	0.09	−0.63	−1.40	0.67	−1.98*
Arak	−1.98*	−0.80	0.90	−1.66	0.75	1.18	1.59	1.08	0.98	1.94	1.20	0.65	−0.83
Ardebil	0.41	−0.64	1.13	−0.24	−1.13	−1.11	1.79	0.32	0.06	−0.39	−0.17	−2.01*	−0.08
Babolsar	1.70	2.15*	1.80	1.19	1.02	0.99	3.04**	2.23*	1.39	2.40*	2.09*	2.72**	1.81
Bam	−0.45	−0.06	−0.31	−0.95	−0.72	0.79	0.47	1.09	0.02	0.88	−1.56	−1.06	−0.27
Bandar Abbas	0.13	0.22	0.43	−0.86	0.78	1.42	0.18	2.65**	0.13	0.20	−0.74	1.11	0.57
Bandar lenge	−0.90	−0.04	−1.18	0.57	−1.65	−2.75**	−1.39	−0.06	−0.02	−1.22	0.45	−0.26	0.15
Birjand	−0.95	−1.49	−1.52	−1.15	−1.94	−0.65	−1.98*	−1.54	−0.63	−1.47	0.91	1.20	0.00
Bushehr	−0.32	−0.10	−0.64	0.59	1.17	0.15	0.45	−0.96	−0.13	1.34	0.04	0.24	0.16
Esfahan	0.03	−0.26	−0.50	0.80	−0.17	0.94	0.01	1.02	0.11	0.18	0.89	1.21	0.87
Gorgan	0.96	0.70	−0.13	−0.74	0.61	0.09	−2.11*	−0.64	1.80	0.35	0.18	0.23	1.26
Hamedan	−0.93	−0.04	0.80	−2.41*	−0.56	0.87	2.08*	0.74	0.74	1.07	−0.41	0.26	−0.66
Kashan	0.40	−0.61	1.03	0.13	1.32	−1.39	−0.06	−1.33	1.28	−0.90	0.17	−0.19	−0.30
Kermanshah	1.16	0.05	2.27*	−1.55	−1.02	−1.08	2.85**	−1.57	−0.21	0.98	−0.23	1.88	0.02
Mashhad	0.58	−0.57	0.35	−1.06	−0.14	0.73	1.47	1.50	0.63	−0.11	1.03	0.48	−0.90
Oroomieh	−1.86	−0.32	−1.07	−0.45	−0.72	−2.18*	−0.56	−1.21	−1.68	0.30	0.87	−0.25	0.10
Qazvin	−1.76	0.45	2.06*	1.17	−0.65	−1.51	1.92	−0.41	0.12	1.53	0.88	0.61	0.40
Ramsar	0.97	−0.92	−0.03	−1.05	−0.18	−0.27	0.11	−1.30	−0.13	0.54	−1.80	−0.25	1.22
Rasht	−0.16	1.44	−0.24	0.92	0.17	−2.29*	−0.60	1.07	0.63	2.15*	0.49	0.01	0.76
Sabzevar	0.75	0.73	0.50	−1.15	−0.62	−0.03	0.44	1.25	1.33	0.88	1.11	0.46	0.28
Sanandaj	−2.87**	−2.27*	−0.04	−0.92	−0.59	−0.05	1.62	−1.93	−0.74	0.07	−0.63	0.27	−0.77
Semnan	0.82	−2.48*	0.27	0.61	−0.55	−0.70	1.51	1.53	0.76	−0.87	0.69	1.02	0.39
Shahrekord	0.09	−1.14	1.21	−1.68	0.60	1.63	2.29*	0.32	1.96	0.91	1.40	0.70	−0.34

Table 4 (continued)

Station/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Shahroud	0.66	0.59	0.17	−0.81	−0.35	1.41	0.03	1.05	0.69	1.06	−0.01	1.75	1.64
Shiraz	0.70	−1.02	−0.29	−0.62	−0.21	2.16*	0.22	0.63	1.35	1.42	−0.35	0.11	−1.18
Tabriz	−1.82	−3.06**	−1.73	0.39	−0.60	−1.80	0.87	0.01	−1.06	0.05	−0.13	0.39	−2.49*
Tehran	1.52	−0.57	1.26	0.73	1.06	−0.60	0.96	−0.17	−0.57	0.68	−0.86	2.49*	1.72
Yazd	1.26	0.16	0.53	−2.79**	−0.23	0.84	0.92	−2.14*	−1.18	−0.57	0.86	0.55	−0.18
Zabol	1.02	−0.18	0.42	−1.78	−0.58	−0.97	−0.64	−0.56	0.00	−0.23	−0.08	1.19	−0.25
Zahedan	−1.37	−1.61	−1.95	−2.02*	−1.08	0.75	0.34	0.87	−0.10	1.14	−0.10	−1.04	−2.60
Zanjan	0.88	−0.71	0.81	−0.27	0.74	−1.10	1.40	0.43	−0.83	0.14	−0.06	0.80	−0.88

*Trend statistically significant at $p<0.05$

**Trend statistically significant at $p<0.01$

Table 5 Linear trends (mm/year) of monthly and annual rainfall for synoptic stations of Iran by Spearman test. The analyzed periods are given in Table 1

Station/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Abadan	0.25	−0.01	0.23	−0.14	−0.16	0.14		0.1	−0.05	0.32*	0.041	0.16	0.29*
Ahvaz	0.17	0.01	0.29*	−0.09	−0.2	0.11	0.06	−0.02	0.03	−0.02	0.15	0.15	0.17
Anzali	−0.05	−0.13	0.07	0.1	−0.19	−0.37	0.36	0.05	−0.01	−0.22	0.04	−0.32	−0.22
Arak	−0.34*	−0.18	0.11	−0.23	0.2	0.16	0.22	0.16	0.14	0.27	0.09	0.1	−0.17
Ardebil	−0.05	−0.47	0.56	0.6	−0.9	−1.95	1.91	0.36	−0.04	−1.14	0.38	−1.65	−0.98
Babolsar	0.22	−0.01	−0.18	−0.05	0.05	0	−0.11	0.05	0.06	0.12	0.28*	0.15	0.33*
Bam	−0.07	−0.01	−0.05	−0.26	−0.11	0.11	0.06	0.16	0.04	0.13	−0.21	−0.17	−0.11
Bandar Abbas	0	0.05	0.1	−0.14	0.02	0.21	0.03	0.39**	0.02	0.03	−0.14	0.12	0.04
Bandar Lenge	0.09	−0.18	0.15	−0.19	−0.01	0.01	0.02	−0.22	0.09	0.01	0.22	0.01	0
Birjand	−0.06	0.14	0.14	−0.38**	0	0.04	0.05	−0.06	0.15	−0.01	0	0.11	−0.01
Bushehr	0.23	0	0.05	−0.06	0.03	0	0.16	0.17		0.04	0	0.02	0.13
Esfahan	0.12	−0.08	0.28*	−0.12	−0.14	0.14	0.17	0.03	−0.17	−0.01	0.11	0.09	0.13
Gorgan	0.12	0.07	−0.23	−0.21	0.05	−0.04	−0.28*	−0.09	0.12	−0.04	0.11	0.02	−0.15
Hamedan	0.06	−0.14	0.02	−0.32*	−0.1	0.13	0.28*	0.11	0.1	0.15	−0.04	0.04	−0.2
Kashan	0.04	−0.18	−0.03	0.07	0.04	−0.21	0	−0.24	0.2	−0.12	0.04	−0.01	−0.07
Mashhad	0.17	0.02	0.04	−0.19	−0.02	0.12	0.2	0.2	0.09	−0.04	0.09	0.13	0.06
Oroomieh	−0.16	−0.26*	−0.16	−0.24	−0.01	−0.30*	−0.04	−0.13	−0.2	0	0.03	−0.05	−0.37**
Qazvin	0.02	0.06	0.27	−0.05	0	−0.26	0.26	−0.06	−0.02	0.13	0.2	0.23	0.18
Ramsar	0.01	0	−0.06	−0.16	0.05	−0.08	0.01	−0.26	−0.03	0.05	−0.05	−0.04	−0.1
Rasht	0.02	0.03	−0.09	0	0.12	−0.05	−0.06	0.03	−0.04	−0.11	0.06	0.09	0
Sabzevar	0.16	0.19	0.14	−0.1	−0.05	0	0.07	0.24	0.2	0.11	0.13	0.015	0.25
Sanandaj	−0.25	−0.21	−0.08	−0.24	−0.14	−0.02	0.24	−0.30*	−0.1	0	0.01	0.04	−0.24
Semnan	0.07	−0.27	0.1	0.12	−0.12	−0.1	0.21	0.23	0.11	−0.16	0.13	0.16	0.15
Shahrekord	0.04	0	0.15	−0.15	0.01	0.22	0.33*	0.06	0.28*	0.15	0.19	0.22	0.16
Shahroud	0.09	0.03	0.11	−0.05	−0.02	0.2	0.03	0.17	0.09	0.13	0.01	0.30*	0.19

Table 5 (continued)

Station/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Shiraz	0.16	0.03	0.05	−0.15	−0.02	0.31*	0.03	0.07	0.18	0.2	−0.03	−0.02	0.01
Tabriz	−0.14	−0.47**	−0.33*	−0.09	0.04	−0.23	0.09	−0.01	−0.15	−0.04	−0.01	0.08	−0.36**
Tehran	0.15	0.02	0.27*	−0.04	0.08	−0.1	0.13	−0.02	−0.06	0.08	−0.07	0.28*	0.2
Yazd	0.18	0.02	0.12	−0.33*	−0.01	0.12	0.12	−0.30*	−0.16	−0.08	0.07	0.08	−0.03
Zabol	0.16	−0.12	0.11	−0.27	−0.09	−0.14	−0.09	−0.09		−0.03	−0.01	0.17	0.06
Zahedan	−0.19	−0.17	−0.23	−0.29*	−0.13	0.11	0.04	0.12	−0.01	0.15	−0.02	−0.16	−0.43**
Zanjan	0	−0.09	−0.09	−0.24	0.07	−0.17	0.25	0.04	−0.18	0.01	0.07	0.1	−0.2

*Trend statistically significant at $p<0.05$

**Trend statistically significant at $p<0.01$

The Mann-Kendall test was applied to detect monthly and annual number of rainy day trends for all the selected stations. The results showed nine stations have no statistically significant trends. Most of these stations are west of the central regions of Iran (Table 3).

In all spring months the negative linear trend is observed on the stations: Abadan, Babolsar, Esfahan, Bam, Sanandaj, Qazvin, Bandar Lenge, Birjand, Tehran, Zabol, Oroomieh and Mashhad but positive on the stations Ahvaz, Anzali, Bandar Abbas, Bushehr, Rasht, Shahrekord, Yazd and Gorgan. Out of these stations the statistical significant trend is noticed in Abadan and Esfahan in April and May, Babolsar, Bam, Oroomieh, Bandar Lenge, Birjand, Qazvin, Sanandaj, Tehran, Zabol and Mashhad in April and Anzali, Rasht, Yazd and Gorgan in May and Shahrekord, Bandar Abbas, Ahvaz and Bushehr stations in Mar (Fig. 6(a,b) and 7).

In all summer months the positive linear trend is observed on the stations: Anzali, Bandar Abbas, Zanjan, Shahrekord, Shiraz and Gorgan stations. Out of these stations the

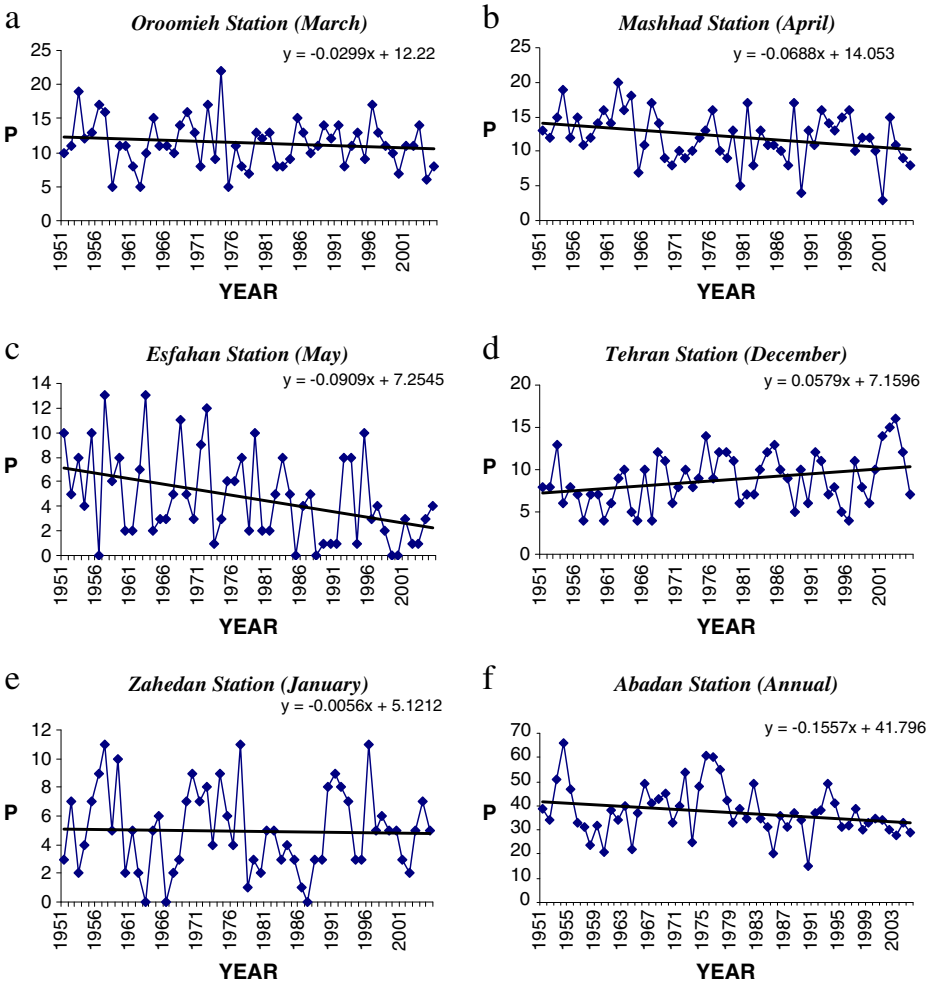

Fig. 6 Linear trends (day/year) of monthly and annual rainy days for selected synoptic stations in Iran during the period 1951–2005

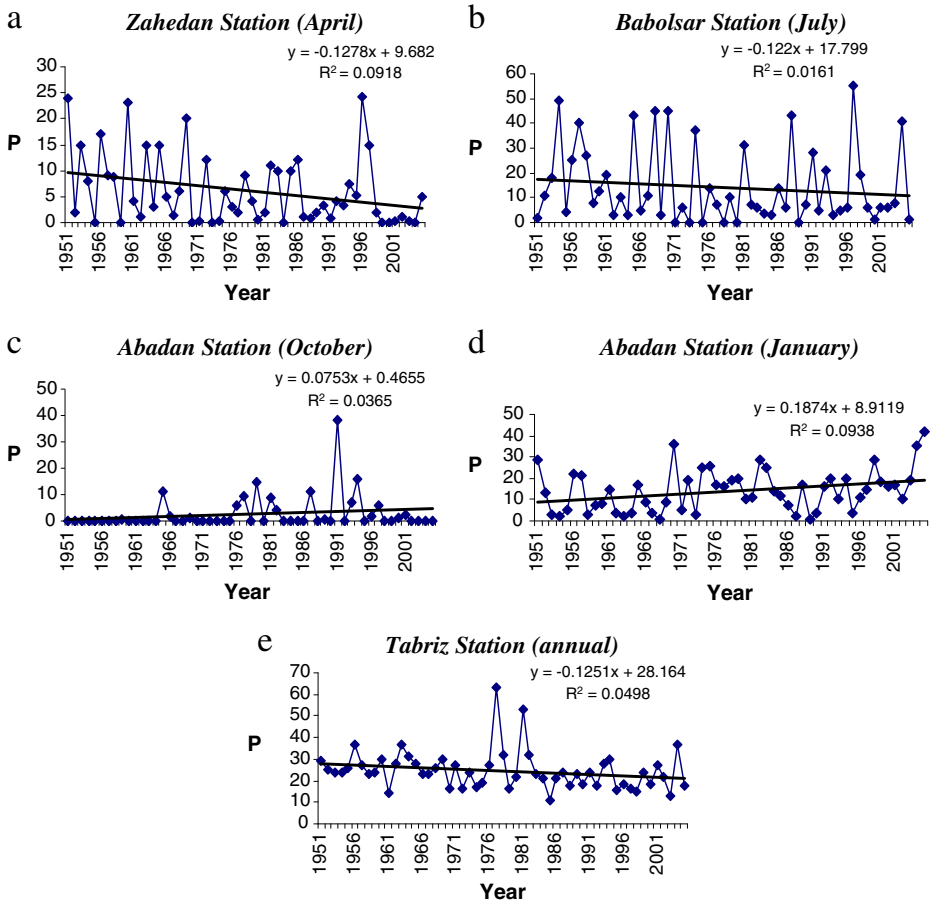

Fig. 7 Linear trends (day/year) of monthly and annual maximum precipitation of 24 h for selected synoptic stations in Iran during the period 1951–2005

statistically significant trend is noticed in Anzali in all of the months, Shahrekord in June and July, Gorgan in June and August, Shiraz in June, Zanjan in July and Bandar Abbas in August (Fig. 6(c)).

In all autumn months, Zabol showed a negative trend and Shahrekord has a positive trend. Both of them showed statistically significant trends in September. In addition, Shahrekord station had a statistically significant trend in November.

In all winter months the positive linear trend is detected on the stations: Ahvaz, Bushehr, Tehran, Shahrekord, Kermanshah, Gorgan, Mashhad and Yazd stations. Among these stations the statistically significant trend is notice in Ahvaz and Shahrekord stations in all of the month, Zabol and Kermanshah in January, Mashhad in February, Bushehr in January and February, Zanjan in February and December, Yazd in January and December and Gorgan in December (Fig. 6(d, e)).

This data shows the greatest trends in spring and winter and the least change in autumn.

In all spring months and especially in March, except the several stations located in south of Iran, which had significant positive trends, other stations had no statistically significant trends. In April approximately one third of Iran had significant negative trends that

stretched from northwest to northeast and from southwest to southeast. Most of the stations had no statistically significant trend in all autumn and winter months, only Shahrekord station in November and September, and Zanjan station in November, had significant positive trends and Zabol station had significant negative trend in September.

According to the Mann-Kendall test for trend, trends of the number of rainy days were significantly negative in Abadan and Ahvaz stations, and significantly positive in ten stations, with others showing no statistically significant trend (Fig. 6(F), and 8). On the whole, distribution of positive trend (significant and no significant) is like two belts. One of them stretched from northwest to northeast and another stretched from northwest to southeast and central regions of Iran mostly had negative trend (significant and not significant).

Regarding the issue that trend variability was minimal in autumn and winter (precipitation time in Iran) there has not been any noticeably significant change in the rainfall regime. Change in the number of rainy days was increased in spring and summer, scattered cloudbursts happen in these seasons and this phenomenon could cause spring and summer flooding.

The major number of positive trends occurs more frequently in December, while the major number of negative trends occurs in April so it is compatible with monthly and annual rainfall. Results of the Spearman test are approximately similar to Mann-Kendall test and there is a small difference between the results of the two tests. For example, Birjand and Bushehr stations had significantly positive trends in February. Also, Ahvaz station shows significantly positive trend in December (Table 6). Yue et al. (2002) showed that the results of Spearman and Mann-Kendall are similar to each other.

Modarres and Silva (2007) in Iran showed increasing trends in Shiraz station and decreasing trend in Isfahan in regard to annual number of rainy days. Statistically significant trends occur in all of the months except October.

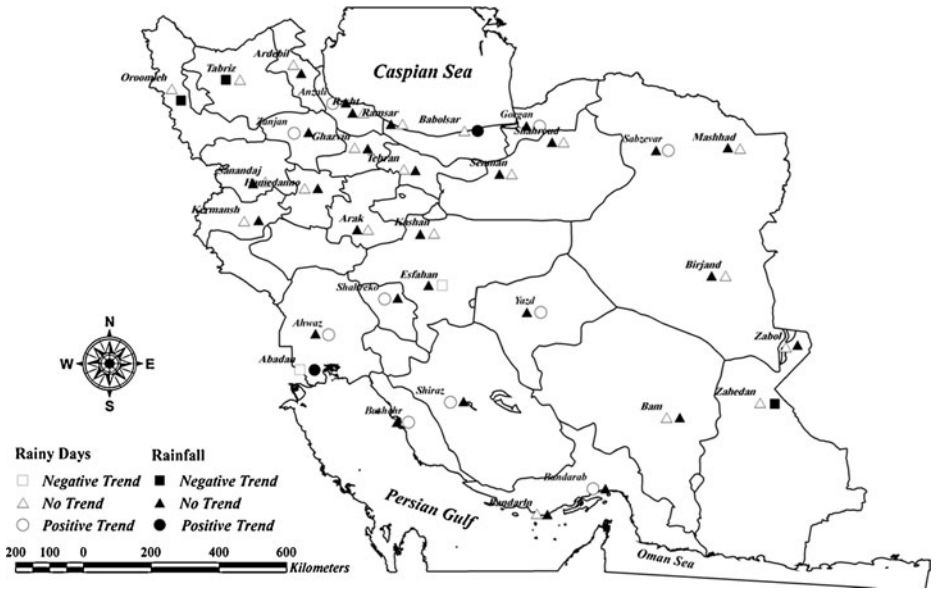

Fig. 8 Map of linear trends (mm/year) of annual rainfall and rainy days for synoptic stations of Iran. The analyzed periods are given in Table 1

Table 6 Linear trends (day/year) of monthly and annual rainy days for synoptic stations of Iran by Spearman test. The analyzed periods are given in Table 1

Station/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Abadan	−0.03	−0.07	−0.09	−0.34**	−0.27*	0.03		0.09	−0.09	0.15	−0.13	−0.08	−0.24
Ahvaz	0.47**	0.47**	0.47**	0.25	0.17	0.16	0.24	0.01	0.09	0.13	0.26	0.47**	0.71**
Anzali	0.11	0.14	−0.01	0.04	0.37**	0.27*	0.27*	0.34*	−0.08	0	0.23	0.14	0.48**
Arak	0.09	0.13	0.17	−0.06	0.05	0.12	0.15	0.21	0.04	0.12	0.15	0.23	0.22
Ardebil	0.22	0.09	−0.07	0.27	−0.03	−0.18	0.67**	0.23	0.28	0	0.05	0.13	0.33
Babolsar	0.01	−0.11	−0.06	−0.35**	0.07	0.01	0.02	0.2	−0.15	0.03	0.07	0.24	−0.01
Bam	−0.01	0.25	−0.08	−0.40**	−0.21	−0.01	0	0.06	0.01	0.1	−0.16	−0.15	−0.24
Bandar Abbas	0.06	−0.21	0.39**	−0.15	0.27	0.21	0.22	0.45**	0.14	0.03	−0.04	0.18	0.37**
Bandar Lenge	−0.03	0.21	0.23	−0.36*	0.05	0.01	−0.27	−0.28	0.09	0.09	0.07	−0.02	−0.09
Birjand	0.07	0.35**	0.09	−0.29*	0.02	0.03	−0.04	−0.06	0.18	−0.02	0.01	0.16	0.04
Bushehr	0.42**	0.35**	0.39**	0.14	0.09	0.11	0.12	0.17		0.05	0.07	0.11	0.45**
Esfahan	0.13	0.01	0.05	−0.18	−0.27**	0.05	−0.01	−0.19	−0.25	−0.15	0.07	−0.04	−0.28*
Gorgan	0.22	0.18	0.14	0.04	0.40**	0.27*	0.05	0.29*	0.17	0.13	0.22	0.45**	0.53**
Hamedan	0.21	0.04	−0.11	−0.07	0.09	0.17	0.25	0.02	0	0.17	0.08	0.16	0.21
Kashan	0.01	−0.31	−0.19	0.01	−0.19	−0.21	0.02	−0.21	0.2	−0.04	0.01	0.02	−0.19
Kermanshah	0.37**	0.06	−0.01	−0.26	0.13	−0.08	0.36**	−0.08	−0.01	0.15	0.07	0.18	0.23
Mashhad	0.15	0.29*	−0.18	−0.28*	−0.02	0.09	0.01	0.2	−0.02	0.04	−0.02	0.1	0.05
Oroomieh	−0.04	0.09	−0.11	−0.35*	0.07	−0.11	0.06	−0.03	−0.14	−0.01	0.01	0.06	−0.04
Qazvin	0.05	0.01	−0.16	−0.33*	−0.11	−0.26	0.19	−0.12	−0.04	−0.03	0.23	0.24	−0.12
Ramsar	0.09	0.05	−0.18	−0.09	0.14	0	0.02	−0.05	−0.17	−0.26	0.22	0.11	−0.06
Rasht	0.13	0.12	−0.06	−0.09	0.30*	0.2	0.12	0.17	−0.12	−0.07	0.2	0.11	0.18
Sabzevar	0.17	0.18	0.09	0.08	0.11	0.05	−0.02	0.25	0.23	0.11	0.19	0.23	0.38**
Sanandaj	−0.08	−0.08	−0.19	−0.36*	−0.05	0.17	0.32*	−0.17	0	0.08	0.14	0.05	0.14
Semnan	−0.45	0.2	0.1	−0.43	−1.61	−1.26	0.73	0.47	0.15	−0.31	0.85	1.45	−0.82
Shahrekord	0.38**	0.51**	0.41**	0.14	0.14	0.32*	0.40*	0.16	0.49**	0.19	0.29*	0.43**	0.66**

Table 6 (continued)

Station/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Shahroud	−0.09	−0.12	−0.27	−0.21	−0.19	−0.07	−0.21	0.07	−0.09	0.09	−0.02	0.11	−0.27
Shiraz	0.25	0.26	0.16	0.04	0.08	0.31*	0.21	0.25	0.15	0.18	0.19	0.05	0.35*
Tabriz	0.26	0.1	−0.11	−0.16	0.16	−0.08	0.21	−0.05	0.04	0.14	0.09	0.18	0.2
Tehran	0.2	0.11	0.07	−0.25	0.1	−0.05	0.12	0.09	−0.03	0.13	0.15	0.27*	0.22
Yazd	0.31*	0.13	0.21	−0.01	0.27*	0.34*	0.08	−0.12	0.2	−0.05	0.14	0.28*	0.42**
Zabol	0.33*	0.01	0.21	−0.33*	−0.12	−0.01	−0.09	−0.09	−0.33*	−0.14	−0.01	0.07	0.06
Zahedan	−0.01	0.08	0.1	−0.01	−0.12	0.08	0.1	0.11	0.14	0.03	0.12	0.01	−0.03
Zanjan	0.25	0.49**	0.01	0.07	0.15	0.01	0.43**	0.14	−0.05	0.11	0.39**	0.51**	0.51**

*Trend statistically significant at $p<0.05$

**Trend statistically significant at $p<0.01$

Regard to arid and semi-arid regions of Iran cover more than 60% of the country climatically, water resource management, especially in the summer seasons, are one of the most important problems in Iran. It is because of the fact that most of the agricultural activates are done in the warm season while precipitation occurs in the cold season. On the other hand, especially in the four last decades, the basins and natural resources of Iran have faced some serious degradation problems such as land use changes, soil degradation and erosion, overgrazing in the rangelands, over-harvesting of groundwater by the construction of wells, etc. These problems have been created at the national scale during the last decades, but the other problem, which has occurred at the global scale, is climatic change, especially since the decade of 1980. These events have made water resource management and soil resources programming more problematic.

4.4 Maximum precipitation in 24 h

As mentioned in the previous section, all stations except Khoramabad and Kerman, which are omitted, are homogeneous as shown by Mann–Whitney test.

The Mann- Kendall test was applied to detect monthly and annual maximum precipitation in 24 h trends for all the selected stations. The results showed ten stations have no statistically significant trends. Most of these stations are west of the central regions of Iran (Table 4).

In all spring months the positive linear trend is observed on the stations: Ahvaz, Qazvin and Kermanshah, but negative on the stations Hamedan, Yazd and Zahedan. Out of these stations the statistical significant trend is noticed in Ahvaz, Qazvin and Kermanshah in Mar and Hamedan, Yazd and Zahedan in April (Fig. 7(a)).

In all summer months the positive linear trend is observed on the stations: Shiraz, Babolsar, Bandar Abbas, Hamedan, Kermanshah and Shahrekord stations. Out of these stations the statistically significant trend is noticed in Shiraz in Jun, Babolsar in July and August, Bandar Abbas in August, Hamedan, Kermanshah and Shahrekord in July (Fig. 7(b)).

In all autumn months the positive linear trend is detected on the stations: Abadan, Babolsar and Rasht stations. Among these stations the statistically significant trend is notice in Abadan and Rasht in October and Babolsar in October and November (Fig. 7(c)).

In all winter months the positive linear trend is detected on the stations: Abadan, Babolsar and Tehran. Among these stations the statistically significant trend is notice in Abadan station in January, Babolsar in February and December and Tehran in December (Fig. 7(d)).

Generally, in all spring months, stations located in the west and the northwest of central Iran showed statistically significant trend. In all summer months, two belts had statistically significant trends. One of them stretched from northwest to north and another stretched from northwest to south. During autumn months, most of the stations in Iran were without any statistically significant trends and only a few of them (2 stations in north and 1 station in southwest of Iran) had statistically significant trends in some months. In all winter months, the stations with statistically significant trend are located in north and northwest of Iran mostly. Results of annual Maximum Precipitation in 24 h analysis show significant negative trend on the stations: Anzali and Tabriz but significant positive trend only in Abadan (Fig. 7(e), and 9). Therefore, most of the stations in northern parts of Iran had positive trends (significant and no significant), so the probability of flood occurrence increases in these areas. Regarding to the maximum precipitation and rainy days increase in

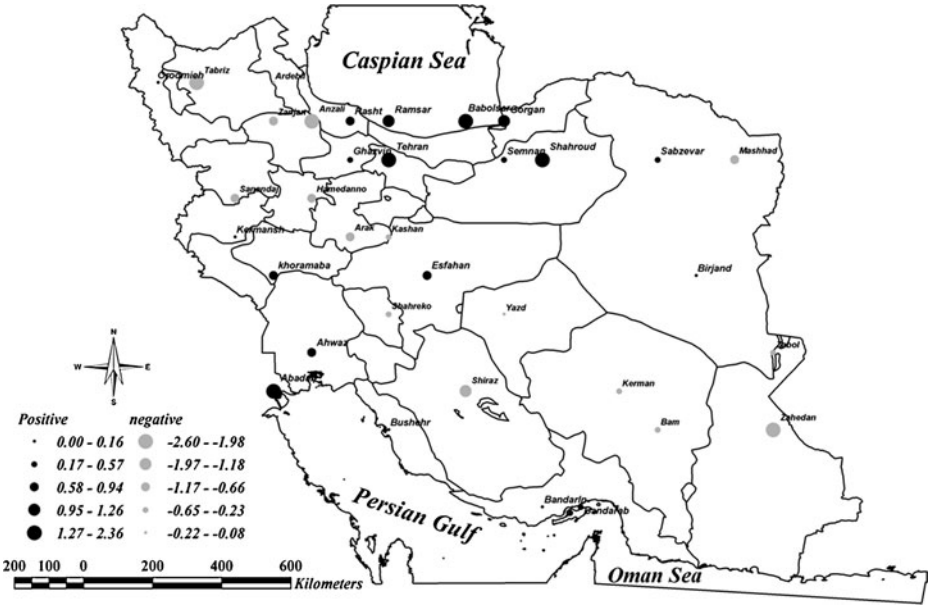

Fig. 9 Map of linear trends (mm/year) of annual maximum of precipitation in 24 h for synoptic stations of Iran. The analyzed periods are given in Table 1

Babolsar station, the probability of flood occurrence is probable, spatially in autumn and summer months.

Results of the Spearman test are approximately similar to Mann-Kendall test and there is a small difference between the results of the two tests. For example, Babolsar station had significantly positive trends in January, Esfahan in March, Shahrekord in September, Arak in October but Birjand and Sanandaj stations in April and August had significantly negative trends, respectively (Table 7).

Modarres and Sarhadi (2009) in Iran showed that the annual rainfall is decreasing at 67% of the stations while the 24-h maximum rainfall is increasing at 50% of the stations. The positive trends of 24-h maximum rainfall are mostly located in arid and semiarid regions of Iran.

5 Conclusion

This study investigated rainfall variability all over Iran by analyzing data for annual and monthly rainfall and number of rainy days, which have been collected at 33 stations. Results showed that all analyzed time-series, except Khoramabad and Kerman, were homogeneous at 10% significance level according to the Mann–Whitney test.

The Mann-Kendall test applied to the annual and monthly rainfall time-series showed most of the stations of Iran had no statistically significant trends in all seasons. Only local and isolated trends in the rainfall data were found. For instance, some stations which are mostly located along Zagros mountain ranges had statistically significant trends in all summer months. Analyzing annual rainfall showed 84% of stations had no statistically significant trends. Just some parts of western Alborz and along Zagros to southeast had

Table 7 Linear trends (day/year) of monthly and annual maximum precipitation in 24 h for synoptic stations of Iran by Spearman test. The analyzed periods are given in Table 1

Station/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Abadan	0.29*	−0.07	0.19	−0.16	−0.15	0.15	0.00	0.10	−0.05	0.32*	0.09	0.22	0.31*
Ahvaz	0.23	−0.05	0.30*	−0.10	−0.22	0.11	0.06	−0.02	0.03	−0.03	0.20	0.10	0.13
Anzali	0.16	−0.14	−0.15	−0.17	−0.13	−0.22	−0.22	−0.15	0.01	−0.08	−0.18	0.10	−0.26*
Arak	−0.32*	−0.10	0.13	−0.24	0.12	0.17	0.21	0.15	0.14	0.28*	0.16	0.09	−0.10
Ardebil	0.07	−0.15	0.23	−0.04	−0.24	−0.21	0.32	0.03	0.04	−0.10	−0.02	−0.38*	−0.02
Babolsar	0.37**	−0.01	−0.11	−0.01	0.02	0.04	−0.15	−0.09	0.08	0.13	0.29*	0.16	0.25
Bam	−0.07	−0.02	−0.05	−0.14	−0.09	0.11	0.06	0.16	0.00	0.13	−0.24	−0.16	−0.03
Bandar Abbas	0.00	0.02	0.06	−0.13	0.12	0.21	0.03	0.39**	0.02	0.02	−0.12	0.16	0.09
Bandar Lenge	0.08	−0.12	0.09	−0.19	−0.01	0.01	−0.02	−0.22	0.09	0.01	0.24	0.00	0.03
Birjand	−0.09	0.11	0.05	−0.38**	−0.02	0.04	0.05	−0.07	0.16	0.00	0.07	0.05	0.01
Bushehr	0.16	−0.05	−0.01	−0.03	0.02	0.00	0.16	0.17	0.00	0.03	−0.01	0.01	0.00
Esfahan	0.06	−0.16	0.33*	−0.09	−0.07	0.15	0.17	0.03	−0.17	−0.02	0.10	0.10	0.12
Gorgan	0.13	0.09	0.00	−0.09	0.08	0.00	−0.28*	−0.11	0.24	0.05	0.02	0.02	0.17
Hamedan	−0.13	−0.02	0.11	−0.31*	−0.08	0.13	0.28*	0.10	0.10	0.16	−0.08	0.04	−0.10
Kashan	0.05	−0.12	0.14	0.03	0.22	−0.21	−0.01	−0.22	0.20	−0.15	0.01	−0.03	−0.07
Kermanshah	0.16	0.01	0.29*	−0.22	−0.11	−0.14	0.39**	−0.22	−0.02	0.15	−0.04	0.23	−0.01
Mashhad	0.09	−0.07	0.05	−0.13	−0.02	0.10	0.21	0.20	0.09	−0.03	0.13	0.09	−0.12
Oroomieh	−0.26	−0.02	−0.16	−0.06	−0.08	−0.30*	−0.07	−0.16	−0.21	0.05	0.13	−0.04	0.01
Qazvin	−0.23	0.09	0.31*	0.17	−0.09	−0.24	0.28	−0.05	0.02	0.23	0.13	0.09	0.06
Ramsar	0.13	−0.17	0.00	−0.16	−0.03	−0.04	0.03	−0.19	0.00	0.08	−0.27	−0.04	0.16
Rasht	0.15	0.13	0.01	0.15	−0.02	−0.14	−0.07	0.00	−0.05	0.09	−0.04	0.14	0.12
Sabzevar	0.10	0.14	0.06	−0.16	−0.09	−0.01	0.07	0.18	0.19	0.13	0.17	0.07	0.04
Sanandaj	−0.42**	−0.31*	0.01	−0.13	−0.09	−0.02	0.24	−0.30*	−0.10	0.01	−0.09	0.04	−0.12
Semnan	0.15	−0.37*	0.04	0.09	−0.09	−0.09	0.22	0.24	0.12	−0.15	0.12	0.16	0.06
Shahrekord	0.00	−0.15	0.16	−0.22	0.08	0.23	0.34*	0.06	0.28*	0.15	0.19	0.10	−0.06

Table 7 (continued)

Station/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Shahroud	0.09	0.08	0.03	−0.12	−0.03	0.21	0.00	0.14	0.11	0.16	0.00	0.24	0.22
Shiraz	0.09	−0.14	−0.06	−0.10	−0.01	0.31*	0.02	0.08	0.18	0.20	−0.04	−0.02	−0.17
Tabriz	−0.25	−0.43**	−0.24	0.06	−0.08	−0.24	0.12	0.01	−0.15	0.03	−0.01	0.07	−0.35**
Tehran	0.22	−0.07	0.19	0.09	0.14	−0.08	0.13	−0.04	−0.07	0.10	−0.11	0.33*	0.24
Yazd	0.17	0.05	0.08	−0.38**	−0.03	0.11	0.12	−0.30*	−0.16	−0.08	0.12	0.08	0.00
Zabol	0.18	−0.04	0.08	−0.28	−0.10	−0.15	−0.10	−0.09	0.00	−0.03	0.00	0.15	−0.02
Zahedan	−0.19	−0.21	−0.25	−0.28*	−0.15	0.10	0.05	0.12	−0.01	0.16	−0.02	−0.15	−0.35**
Zanjan	0.12	−0.08	0.11	−0.05	0.12	−0.17	0.21	0.06	−0.11	0.03	0.00	0.11	−0.12

*Trend statistically significant at $p<0.05$

**Trend statistically significant at $p<0.01$

negative trends (significant and no significant) and central Alborz to the northeast and also south of the country had positive trends (significant and no significant).

The Mann-Kendall test applied to the annual and monthly number of rainy days time-series indicated most of Iran had no statistically significant trend in March and vice versa. Approximately one third of Iran had significant negative trends in April, which is mostly located from northwest to northeast and southwest to southeast line. In summer and winter except west and north coast and some parts of central Iran, which had statistically significant trends, other parts of the country showed no statistically significant trends. Regarding autumn and winter, which is the main rainfall time in Iran and based on preformed analysis, trend changes were minimum so, there has been no change in rainfall regime. Only because of spatial raining in spring and summer, have there been more rainy days and this phenomenon can cause spring and summer flooding. At about 66% of Iran's stations there are increases the in number of rainy days in annual time scale (22 stations with positive trend), 30% (ten stations with significant positive trend) and 36% (12 stations without significant positive trends). Northwest-northeast parts of Iran and northwest-southeast showed increasing trends in this parameter.

These result also indicated that for the analyzed time-period, there was no significant climate change overall in Iran. In spite of the fact that there are almost no significant precipitation variations in Iran for the last 50-odd years, the tendency in decreasing rainfall amount in April and increasing in December and July could indicate the eventual climate change in this area in the future. The results also suggest the need for further investigation into greenhouse gases in the environment, especially for industrial areas, which could be one of the major causes of climate change in Iran.

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