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Variability in snowfall/total precipitation-day ratio in Iran

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Abstract

Global warming has substantial impacts on the hydrologic cycle and precipitation characteristics. This study aimed to explore variability in the form of precipitation by analysis of trends in the snowfall (SD)/total precipitation-day (PD) ratio across Iran. To this end, the PD and SD records were acquired from 33 synoptic stations during 1965–2014. The Mann-Kendall (MK) test was the main method used for trend detection. Analyzing data exposed that the annual SD/PD ratio was less than 25% in a plethora of the stations. The MK test findings indicated downward tendencies in the SD/PD ratio over most regions of the country; although in many cases, the observed trends were not statically significant. The changes in the annual SD/PD ratio were estimated down to − 2% per decade over ~ 70% of Iran's total area. Further studies are required to ascertain the linkages between the large-scale climate oscillations and the form of precipitation across this region. Also, using remotely sensed data (e.g., obtained from the MODIS) and fine-resolution gridded data (e.g., global and regional reanalysis data) in future research could improve the findings of such studies and dwindle the uncertainties caused by the scanty site-based observations.

Keywords The form of precipitation · Snowfall-day · Mann-Kendall test · Climate change · Iran

1 Introduction

Precipitation characteristics (e.g., amount, duration, intensity, and form) have noticeable spatiotemporal variations, particularly in the midlatitudes (Ahrens 2016; Martin 2006; Trenberth et al. 2003). Various factors influence the precipitation characteristics, such as air temperature, fronts, and topography (Ahrens 2016; Trenberth et al. 2003). Meanwhile, air temperature is one of the most distinguished factors affecting the form of precipitation. If air temperature from the cloud base to the land surface is equal or less than 0 °C, the form of precipitation will be solid.

The form of precipitation has manifold conspicuous roles in hydroclimatology (Karamouz et al. 2013; Maidment 1993; Shelton 2009). For instance, due to the melting process, snow could recharge the surface and groundwater resources more gradually, compared to rain. The liquid (solid) precipitation decreases (increases) the albedo of the land surface and resulted in more (less) absorption of the incoming sunlight, and this accelerates (decelerates) the evaporation rate. Accordingly, if the form of precipitation shifts from solid to liquid, the risk of environmental drought stresses could be increased; and admittedly, the water crisis exacerbates, particularly, in arid and semiarid regions with a dearth of water resources (Araghi et al. 2019a; Chen et al. 2015; Feng and Hu 2007; Karamouz et al. 2013; Lawrence and Slater 2010; Shelton 2009).

The extent to which global warming can play a role in regional climatic variability continues to be an issue of interest to researchers. Despite a large amount of research on the impacts of climate change on the precipitation amount, very few studies have investigated the alterations in the form of precipitation associated with global warming.

For instance, Scherrer et al. (2004) found decreases in snow days (SD) in the late-twentieth century for the stations below 1300 m altitude in Swiss Alpine and expressed that these decrements were mainly related to raises in temperature. Feng and Hu (2007) demonstrated that S/P—the ratio of snowfall to precipitation—has been decreasing in the Pacific Northwest and the central USA during 1949–2005. Analysis of 100-year records from 1908 to 2008 at 76 stations in Switzerland revealed coherent declining trends in SD relative to precipitation days (PD) (Serquet et al. 2011). Similar descending tendencies in S/P were detected in Kraków, Poland, during the second half of the

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twentieth century (Twardosz et al. 2012) and over the Tibetan Plateau through 1961–2013 (Wang et al. 2016). By contrast, Buisan et al. (2015) reported no significant trend in SD and PD records in the Spanish Pyrenees during 1981–2010. Analyzing records at 237 weather stations across Turkey, Özgür and Koçak (2019) exhibited significant decreasing trends in the annual SD/PD ratio only in 65 stations.

Although previous studies exposed the spatiotemporal trends in the amount of precipitation (Raziei et al. 2014) and the effects of geographical factors (i.e., elevation, latitude, and longitude) on precipitation regime in Iran (Sabziparvar et al. 2015), thus far, no research was found exploring the changes in the SD/PD ratio. The main purpose of the current study was the analysis of trends in the SD/PD ratio in Iran over the past five decades. The SD/PD ratio could be a staunch indicator to clarify the long-term variations in the form of precipitation connected to climate change (Özgür and Koçak 2019; Serquet et al. 2011).

2 Materials and methods

2.1 Study area and data

Iran, with nearly 1.65×10^6 km^2 in area, has been located in Southwest Asia, between 25°N–38°39′N latitude and 44°E–63°25′E longitude. With spatiotemporal annual precipitation of ~250 mm, most parts of the country have arid or semiarid climate (Araghi et al. 2018). Solid precipitation frequently occurs through December to March.

For this study, the number of snow-day (SD) and the total number of precipitation-day (PD) were collected from 33 synoptic stations across Iran over a five-decade period, from 1965 to 2014 (Fig. 1 and Table 1). The selected stations had no gap in their data. Using SD and PD, the SD/PD ratio was computed for each station in the months of the year and also annually. The SD/PD ratio was utilized as an authentic indicator for evaluating the alterations in the form of precipitation over the past decades (Özgür and Koçak 2019; Serquet et al. 2011). As a case in point, some of the monthly and annual SD/PD ratio time series in several stations are presented in Fig. 2.

2.2 Mann-Kendall trend test

The Mann-Kendall (MK) test is one of the most widely used nonparametric methods (Kendall 1975; Wilks 2011) for trend estimation in climatology and hydrology (Araghi et al. 2018; Araghi et al. 2015a, 2017a; Raziei et al. 2014; Yue et al. 2002). The MK test is distribution-free and can be exerted on time series with any probability distribution (Wilks 2011). The original version of the MK test has been expressed as follows (Kendall 1975; Mann 1945):

$$S_t = \sum_{c=1}^{n-1} \sum_{d=c+1}^{n} sign(x_d - x_c) \tag{1}$$

$$sign\ (x_d - x_c) = \begin{cases} +1 & if\ \ x_d > x_c \\ 0 & if\ \ x_d = x_c \\ -1 & if\ \ x_d < x_c \end{cases} \tag{2}$$

$$Var(S_t) = \frac{n(n-1)(2n+5) - \sum_{c=1}^{n} t_c(c)(c-1)(2c+5)}{18} \tag{3}$$

$$Z = \begin{cases} \dfrac{S_t - 1}{\sqrt{Var(S_t)}} & if\ S_t > 0 \\ 0 & if\ S_t = 0 \\ \dfrac{S_t + 1}{\sqrt{Var(S_t)}} & if\ S_t < 0 \end{cases} \tag{4}$$

where x_d and x_c are data values in the time series, n is the length of the data, t is the number of duplicates of the extent c, and t_c is the summation of t.

Previous studies explicated that the existence of seasonality patterns (i.e., uniform oscillations) and the significance of lag-1 autocorrelation in a time series had evident unfavorable effects on the MK test results (Hamed and Ramachandra Rao 1998; Hirsch and Slack 1984; Hirsch et al. 1982). Thus, in such cases, the modified versions of the MK test must be applied. Using a plot called *correlogram*—which presents autocorrelation coefficients against different lags—is one of the simplest techniques to check the presence of seasonality patterns and the significance of lag-1 autocorrelation in data (Wilks 2011). Lag-k autocorrelation coefficient (r_k) in a time series can be calculated as (Wilks 2011; Yue et al. 2002):

$$r_k = \frac{\frac{1}{n-k} \sum_{t=1}^{n-k} [x_t - E(x_t)][x_{t+k} - E(x_t)]}{\frac{1}{n} \sum_{t=1}^{n} [x_t - E(x_t)]^2} \tag{5}$$

$$E(x_t) = \frac{1}{n} \sum_{t=1}^{n} x_t \tag{6}$$

where $E(x_t)$ is the mean of the sample data. If r_1 is between the specific bounds (Eq. 7), data are not serially correlated at the significant level of $\alpha = 0.1$ of the two-tailed test (Maidment 1993; Yue et al. 2002):

$$\frac{-1 - 1.645\sqrt{n-2}}{n-1} \le r_1 \le \frac{-1 + 1.645\sqrt{n-2}}{n-1} \tag{7}$$

If data are serially correlated (i.e., the lag-1 autocorrelation coefficient is significant), the modified version of the MK test proposed by Hamed and Ramachandra Rao (1998) has to be applied. Also, if the seasonality pattern exists in data, the modified version of the MK test presented by Hirsch and Slack (1984) must be used. More details about these modified versions of the MK test are given in relevant papers (Araghi et al. 2017a; Hamed and Ramachandra Rao 1998; Hirsch and Slack 1984).

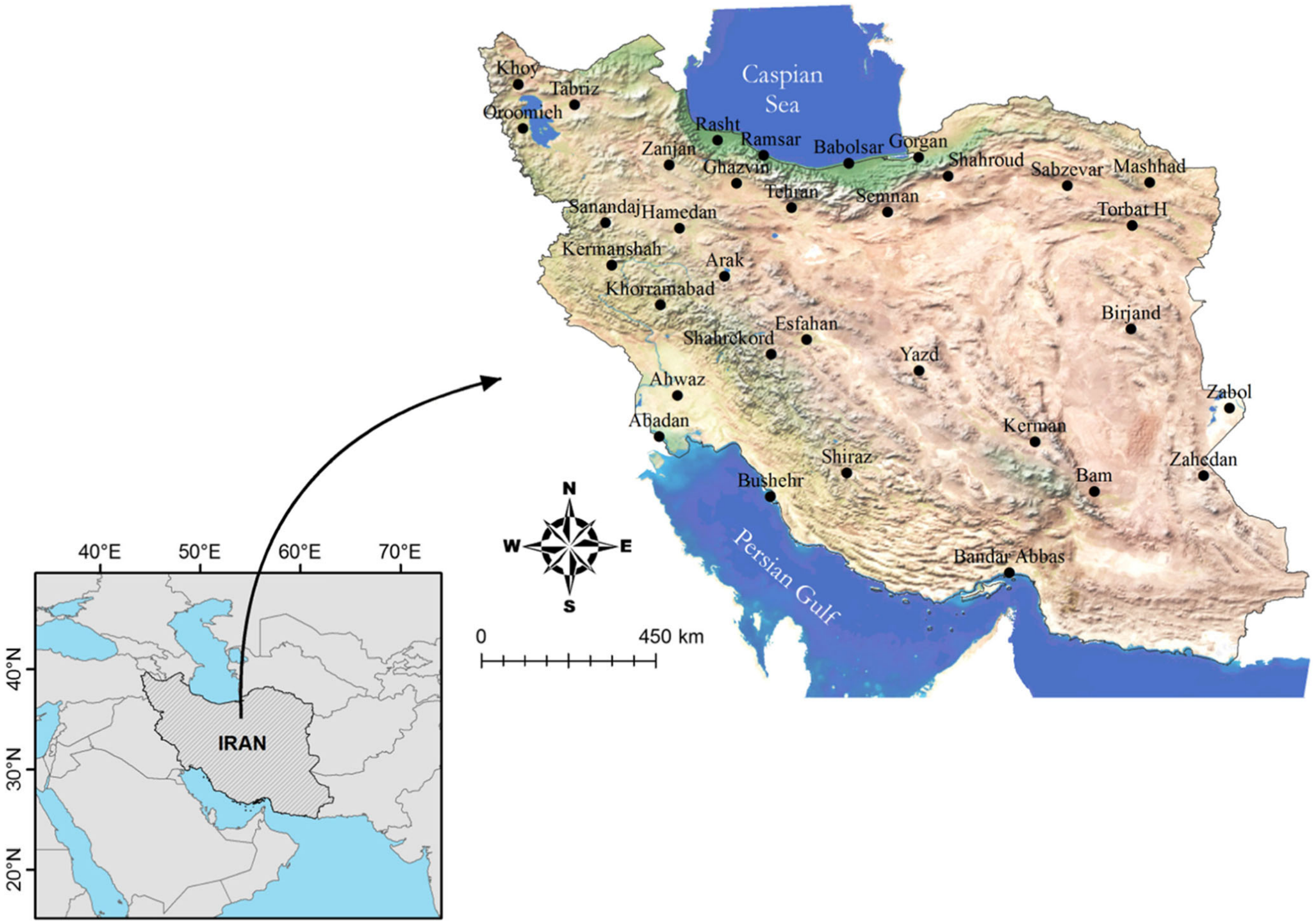


Fig. 1 Study area and the selected synoptic stations

3 Results and discussion

3.1 Variations of PD and SD

The long-term monthly and annual averages of PD over 1965–2014 are presented in Table 2. The annual PD values had remarkable spatial variations, similar to the variability in precipitation amounts across the country (Araghi et al. 2017b; Raziei et al. 2014). The minimum and maximum values of the annual PD were observed as 20 and 137 days, in Bam and Rasht stations, respectively. Considering PD averages for all stations, the minima was from June to September, as ~ 1.7 days to ~ 2.5 days, and the maxima was from October to May, as ~ 4.5 days to ~ 9.5 days. Note that the previous studies indicated no discernible temporal trend in PD in most parts of the country during the last decades (Soltani et al. 2012).

Table 3 shows the long-term monthly and annual averages of the SD in the studied stations. According to this table, the range of the annual SD was coherently shorter (i.e., from 0 to 33 days) than the annual PD. The highest annual SD was detected over northwest Iran, in Zanjan and Tabriz stations, with the values of 33 days and 31 days, respectively. The monthly spatiotemporal average of SD was ~ 0.4 days or less during April to November and from ~ 1.4 to ~ 3.8 days throughout the other months. In Fig. 3, the long-term spatiotemporal averages of PD and SD were depicted in the months of the year. Exploring Tables 2 and 3 beside Fig. 3, it was recognized that most of the stations had a short period with snowfall, mostly from December to March. This might result from the temperature regime and the predominant arid to the semiarid climate in a vast area of Iran (Araghi et al. 2018; Soltani et al. 2012). Therefore, in this research, trend detection of the SD/PD ratio was merely conducted during December to March.

Furthermore, some stations (i.e., Abadan, Ahvaz, Bam, Bandar Abbas, Bushehr, and Zabol) had the monthly SD as zero for the whole year or in some month(s) during December to March (e.g., Babolsar and Ramsar in March). Hence, such stations were eliminated from trend estimation in the relevant months.

3.2 Variations of the SD/PD ratio

Figure 4 illustrates the long-term averages of the SD/PD ratio at the studied stations from December to March and

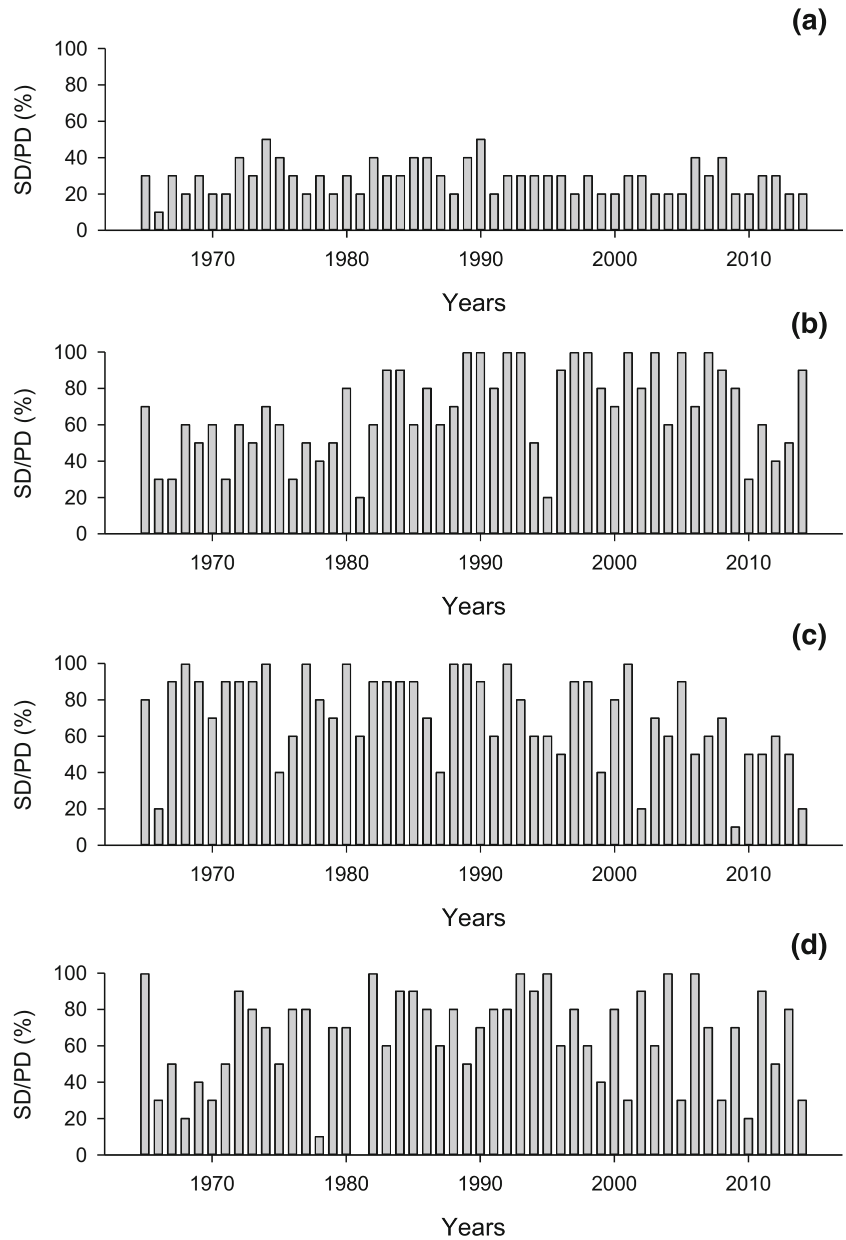
Table 1 Characteristics of the selected weather stations across Iran

No.	Station name	Longitude (°E)	Latitude (°N)	Elevation (m)	Long-term annual temperature (°C)	Long-term annual precipitation (mm)	Climate (de Martonne)
1	Abadan	48.25	30.37	6.6	25.4	156	Arid
2	Ahvaz	48.67	31.33	22.5	26.2	213	Arid
3	Arak	49.77	34.10	1708	13.7	342	Semiarid
4	Babolsar	52.65	36.72	− 21	16.6	894	Humid
5	Bam	58.35	29.10	1066.9	23.1	61	Arid
6	Bandar Abbas	56.37	27.22	98	27.3	183	Arid
7	Birjand	59.20	32.87	1491	16.7	171	Arid
8	Bushehr	50.83	28.98	196	24.6	279	Arid
9	Esfahan	51.67	32.62	1550.4	16.2	123	Arid
10	Qazvin	50.05	36.25	1279.2	14.3	316	Semiarid
11	Gorgan	54.27	36.85	133	17.8	601	Sub-humid
12	Hamedan	48.72	35.20	1679.7	11.1	333	Semiarid
13	Kerman	56.97	30.25	1753	17.0	153	Arid
14	Kermanshah	47.15	34.35	1318.6	14.5	445	Semiarid
15	Khorramabad	48.28	33.43	1147.8	17.3	509	Semiarid
16	Khoy	44.97	38.55	1103	12.5	293	Semiarid
17	Mashhad	59.63	36.27	999.2	14.1	255	Semiarid
18	Orumiyeh	45.08	37.53	1315.9	11.2	341	Semiarid
19	Ramsar	50.67	36.90	− 20	16.0	1218	Very humid
20	Rasht	49.60	37.25	− 6.9	16.2	1359	Very humid
21	Sabzevar	57.72	36.20	977.6	17.6	189	Arid
22	Sanandaj	47.00	35.33	1373.4	14.2	458	Semiarid
23	Semnan	53.55	35.58	1130.8	18.3	141	Arid
24	Shahrekord	50.85	32.28	2048.9	12.5	322	Semiarid
25	Shahroud	54.95	36.42	1345.3	14.5	154	Arid
26	Shiraz	52.60	29.53	1484	17.9	346	Semiarid
27	Tabriz	46.28	38.08	1361	12.0	289	Semiarid
28	Tehran	51.32	35.68	1190.8	17.2	233	Arid
29	Torbat Heydarieh	59.22	35.27	1450.8	14.8	275	Semiarid
30	Yazd	54.28	31.90	1237.2	19.3	60	Arid
31	Zabol	61.48	31.03	489.2	22.7	61	Arid
32	Zahedan	60.88	29.47	1370	18.6	91	Arid
33	Zanjan	48.48	36.68	1663	11.5	313	Semiarid

also annually, throughout 1965–2014. Following this figure, the highest values of the SD/PD ratio were in January, especially over the west and northwest regions of the country (e.g., in Tabriz and Zanjan stations); in which, the SD/PD ratio was greater than or equal to 50%. This finding is consistent with that of Twardosz et al. (2012) who reported the maxima SD/PD ratio greater than 50% in January, in Kraków, Poland. By contrast, the lowest values of SD/PD in the current study were frequently observed through the southwest, south, and southeast zones (e.g., in Shiraz station). This might be owing to the higher temperatures—because of more incoming solar radiation—in the southern half of the country (Araghi et al. 2015a; Araghi et al. 2015b), since air temperature is a foremost factor affecting the form of precipitation (Ahrens 2016).

The SD/PD ratio in the stations located in the southern coastal region of the Caspian Sea (e.g., Rasht, Ramsar,

Fig. 2 The SD/PD ratio at Mashhad station annually (**a**), Shahrekord station in January (**b**), Tabriz station in February (**c**), and Zanjan station in December (**d**) during 1965–2014



Babolsar, and Gorgan) was zero in December and March. This could plausibly result from the high amounts of atmospheric humidity in this zone (as a result of proximity to the Caspian Sea), compared with the other parts of the country (Noshadi and Ahani 2015). The higher atmospheric humidity restrains the extreme high and low temperatures, and thus, PD will be noticeably greater than SD in winter (Ahrens 2016). As shown in Fig. 4, the highest and lowest values of SD/PD were in January and March, respectively. It was not a surprising result, since the temperature in March is generally greater than January, almost over the whole country (Araghi et al. 2018; Araghi et al. 2017b). The findings exhibit that the long-term annual average of SD/PD was less than 25% for most of the studied stations, whereas the reported average values of SD/PD in the contiguous country, Turkey (Özgür and Koçak 2019), were higher. This is probably due to the perceptible discrepancies between the magnitude and regime of temperature and humidity over Iran and Turkey.

Table 2 Monthly and annual averages of PD (total number of days with precipitation) in the studied stations from 1965 to 2014

Station name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Abadan	7	5	6	5	2	0	0	0	0	2	4	6	37
Ahvaz	8	6	6	5	2	0	0	0	0	2	5	7	41
Arak	11	9	11	9	7	2	1	1	1	5	7	9	73
Babolsar	11	10	11	8	7	5	6	8	8	9	10	11	104
Bam	3	3	4	4	2	0	0	0	0	1	1	2	20
Bandar Abbas	5	5	5	2	0	0	0	1	0	0	1	3	22
Birjand	8	9	9	7	4	1	0	0	0	2	4	6	50
Bushehr	9	7	7	4	1	0	0	0	0	1	4	7	40
Esfahan	7	5	7	7	4	1	1	1	0	2	4	6	45
Qazvin	10	10	12	13	12	4	3	2	2	7	9	10	94
Gorgan	10	11	14	11	10	7	6	7	7	8	9	9	109
Hamedan	11	10	11	11	10	2	1	1	1	6	8	10	82
Kerman	7	6	7	6	3	1	0	1	0	1	2	5	39
Kermanshah	12	11	12	11	8	1	1	0	1	5	9	10	81
Khorramabad	12	10	12	11	6	1	0	0	1	5	8	10	76
Khoy	8	8	10	13	15	9	4	4	4	8	7	8	98
Mashhad	9	11	13	11	9	3	1	1	1	4	6	8	77
Orumiyeh	10	9	11	12	12	5	2	2	2	8	8	9	90
Ramsar	11	12	15	13	13	9	7	8	11	13	12	12	136
Rasht	13	13	15	12	11	7	6	8	12	14	13	13	137
Sabzevar	8	8	9	7	6	1	1	0	1	3	5	7	56
Sanandaj	12	12	13	11	9	2	1	1	1	6	9	10	87
Semnan	6	5	7	6	6	2	1	1	1	3	4	5	47
Shahrekord	9	8	9	8	5	1	1	1	0	3	6	8	59
Shahroud	7	7	8	8	8	3	2	2	2	4	5	6	62
Shiraz	9	8	8	6	2	0	1	1	0	1	5	7	48
Tabriz	11	11	13	14	14	7	3	2	3	9	9	10	106
Tehran	10	9	11	10	9	3	2	1	1	6	8	9	79
Torbat H.	9	9	11	8	6	2	1	0	0	2	5	8	61
Yazd	5	4	5	4	3	0	0	0	0	1	2	4	28
Zabol	5	5	4	3	1	0	0	0	0	1	1	3	23
Zahedan	5	5	5	5	3	1	0	0	0	1	2	3	30
Zanjan	11	11	13	13	12	4	3	2	2	7	9	10	97

3.3 Trends in the SD/PD ratio

As displayed in Fig. 5, the SD/PD ratio had no significant trend in most of the stations. A significant positive trend was only found at the Khoy and Shahrekord stations in December and January, respectively. As well, a significant negative trend was merely detected in three stations in December, one station in January, and two stations in February. Also, in March, no station had a significant trend, neither positive nor negative (Fig. 6). It seems that these decreasing tendencies of the SD/PD ratio are associated with a considerable increase in monthly temperatures through most regions of Iran (Araghi et al. 2015b).

Based on the findings, only a few stations (i.e., Esfahan, Tabriz, and Tehran) had a significant negative trend in the annual SD/PD ratio, while no significant positive trend was observed (Fig. 5). Most of the downward and upward tendencies were not statically significant. Note that the number of stations with a decrement in the annual SD/PD ratio was substantially greater than those with increment. These results are in agreement with

Table 3 Monthly and annual averages of SD (number of days with snow) in the studied stations from 1965 to 2014

Station name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Abadan	0	0	0	0	0	0	0	0	0	0	0	0	0
Ahvaz	0	0	0	0	0	0	0	0	0	0	0	0	0
Arak	8	6	3	0	0	0	0	0	0	0	1	4	22
Babolsar	1	1	0	0	0	0	0	0	0	0	0	0	2
Bam	0	0	0	0	0	0	0	0	0	0	0	0	0
Bandar Abbas	0	0	0	0	0	0	0	0	0	0	0	0	0
Birjand	3	2	0	0	0	0	0	0	0	0	0	1	6
Bushehr	0	0	0	0	0	0	0	0	0	0	0	0	0
Esfahan	3	1	0	0	0	0	0	0	0	0	0	1	5
Qazvin	7	5	2	0	0	0	0	0	0	0	1	4	19
Gorgan	2	2	1	0	0	0	0	0	0	0	0	0	5
Hamedan	9	7	4	0	0	0	0	0	0	0	1	6	28
Kerman	2	1	0	0	0	0	0	0	0	0	0	1	5
Kermanshah	6	4	2	0	0	0	0	0	0	0	0	2	15
Khorramabad	2	2	1	0	0	0	0	0	0	0	0	1	6
Khoy	6	6	3	0	0	0	0	0	0	0	2	4	21
Mashhad	6	6	4	0	0	0	0	0	0	0	1	4	22
Orumiyeh	8	7	4	1	0	0	0	0	0	0	1	5	26
Ramsar	1	1	0	0	0	0	0	0	0	0	0	0	3
Rasht	2	3	1	0	0	0	0	0	0	0	0	1	8
Sabzevar	4	2	1	0	0	0	0	0	0	0	0	1	8
Sanandaj	8	6	2	0	0	0	0	0	0	0	1	4	21
Semnan	3	2	1	0	0	0	0	0	0	0	0	1	6
Shahrekord	7	5	3	0	0	0	0	0	0	0	1	4	19
Shahroud	4	3	2	0	0	0	0	0	0	0	0	2	12
Shiraz	2	0	0	0	0	0	0	0	0	0	0	0	2
Tabriz	9	8	4	1	0	0	0	0	0	0	2	6	31
Tehran	5	3	1	0	0	0	0	0	0	0	0	2	12
Torbat H.	6	4	2	0	0	0	0	0	0	0	1	3	15
Yazd	2	1	0	0	0	0	0	0	0	0	0	1	4
Zabol	0	0	0	0	0	0	0	0	0	0	0	0	0
Zahedan	1	0	0	0	0	0	0	0	0	0	0	0	2
Zanjan	10	8	6	1	0	0	0	0	0	0	2	7	33

Özgür and Koçak (2019) which revealed a significant declining trend merely for 65 out of 237 studied stations across Turkey, and no increasing trend was found, as well. As previous studies reported no considerable trend in PD over Iran (Soltani et al. 2012), it seems that the nonsignificant tendencies of the SD/PD ratio in the current study are mainly because of the nonsignificant trends in SD. This finding is consistent with that of Buisan et al. (2015) who showed nonsignificant trends in SD across the Spanish Pyrenees. It should be kept in mind that if the rising trends of temperature during the past decades in Iran (Araghi et al. 2015a; Araghi et al. 2015b) tend to be continued, it is expectable to have more stations with significant increasing trends in the SD/PD ratio in the near future.

Using linear regression, the spatial pattern of decadal changes in the SD/PD ratio was estimated and shown in Fig. 6. Following this figure, reductions in the SD/PD ratio—down to − 6% per decade—were found in December and February, over ~ 70% of Iran's total area, frequently across the west and northwest zones, respectively. These decrements were down to − 4% and − 2% per decade in January and March, throughout 50% and 60% of the country's total

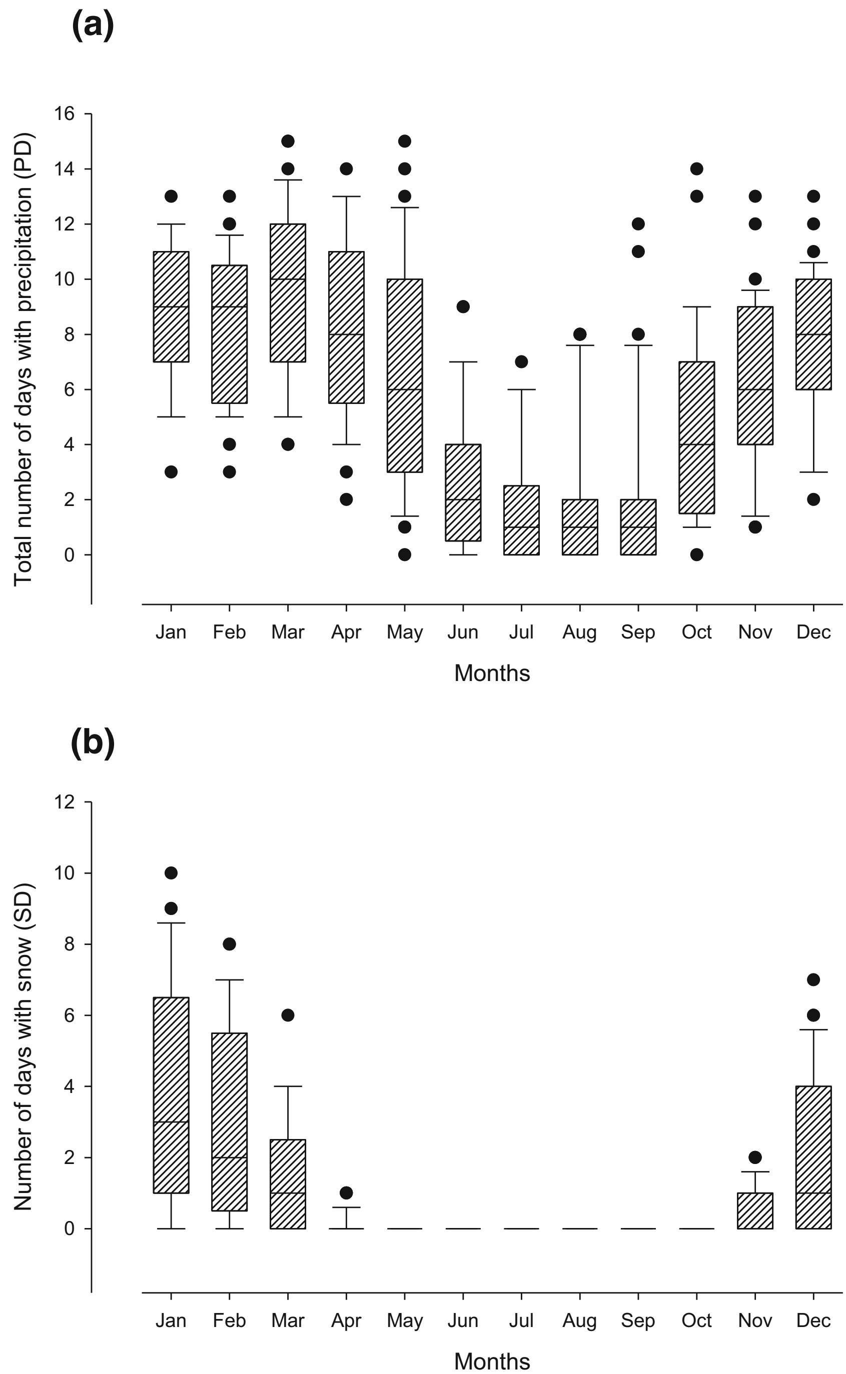
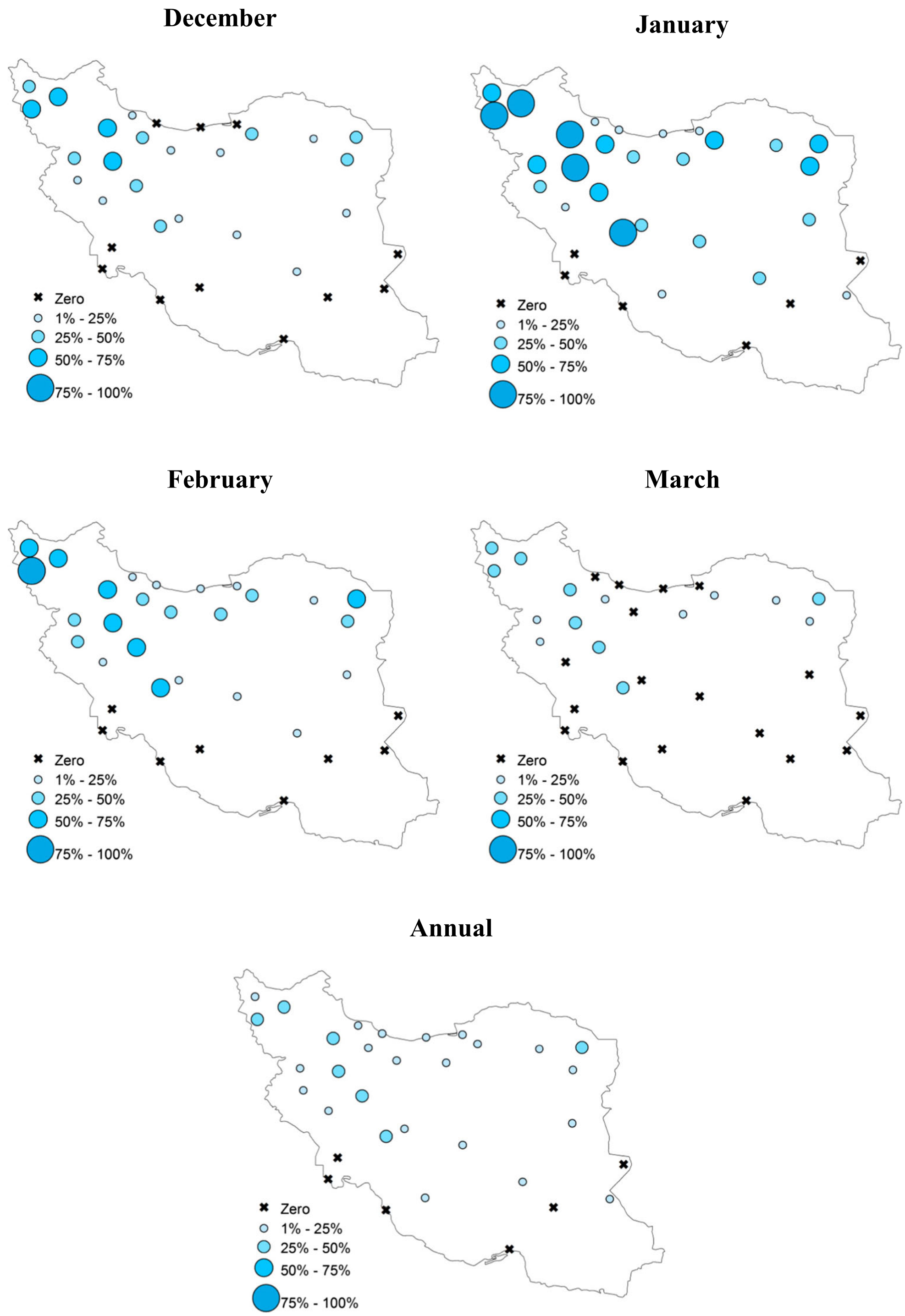


Fig. 3 Boxplots for the spatiotemporal long-term average of PD (a) and SD (b) through 1965–2014

area, respectively. The downward variations in January were mostly found over the northwest, north, and northeast regions, whereas in March, the declining of SD/PD was observed across the west and central zones (Fig. 6). Furthermore, the upward decadal alterations of the SD/PD ratio were not remarkable, by comparison with the declining variations. These findings support the previous studies (Feng and Hu 2007; Knowles et al. 2006; Özgür and Koçak 2019; Scherrer et al. 2004; Serquet et al. 2011; Twardosz et al. 2012; Wang et al. 2016) which reported decreasing changes in the snowfall/precipitation or SD/PD ratios, over the past decades in miscellaneous regions of the globe.

Fig. 4 Long-term averages of the SD/PD ratio at the studied stations during 1965–2014



4 Conclusion

In this research, variability in the SD/PD ratio was surveyed using records obtained from 33 synoptic stations in Iran over the last five decades, from 1965 to 2014. Applying the MK test, descending tendencies in the SD/PD ratio were found over the vast area of the country; however, in most of the cases, the observed inclinations were not significant. The findings of this research were concurred with those of the previous studies (Feng and Hu 2007; Knowles et al. 2006; Özgür and Koçak 2019; Scherrer et al. 2004; Serquet et al. 2011; Twardosz et al. 2012); although, further climatic research are

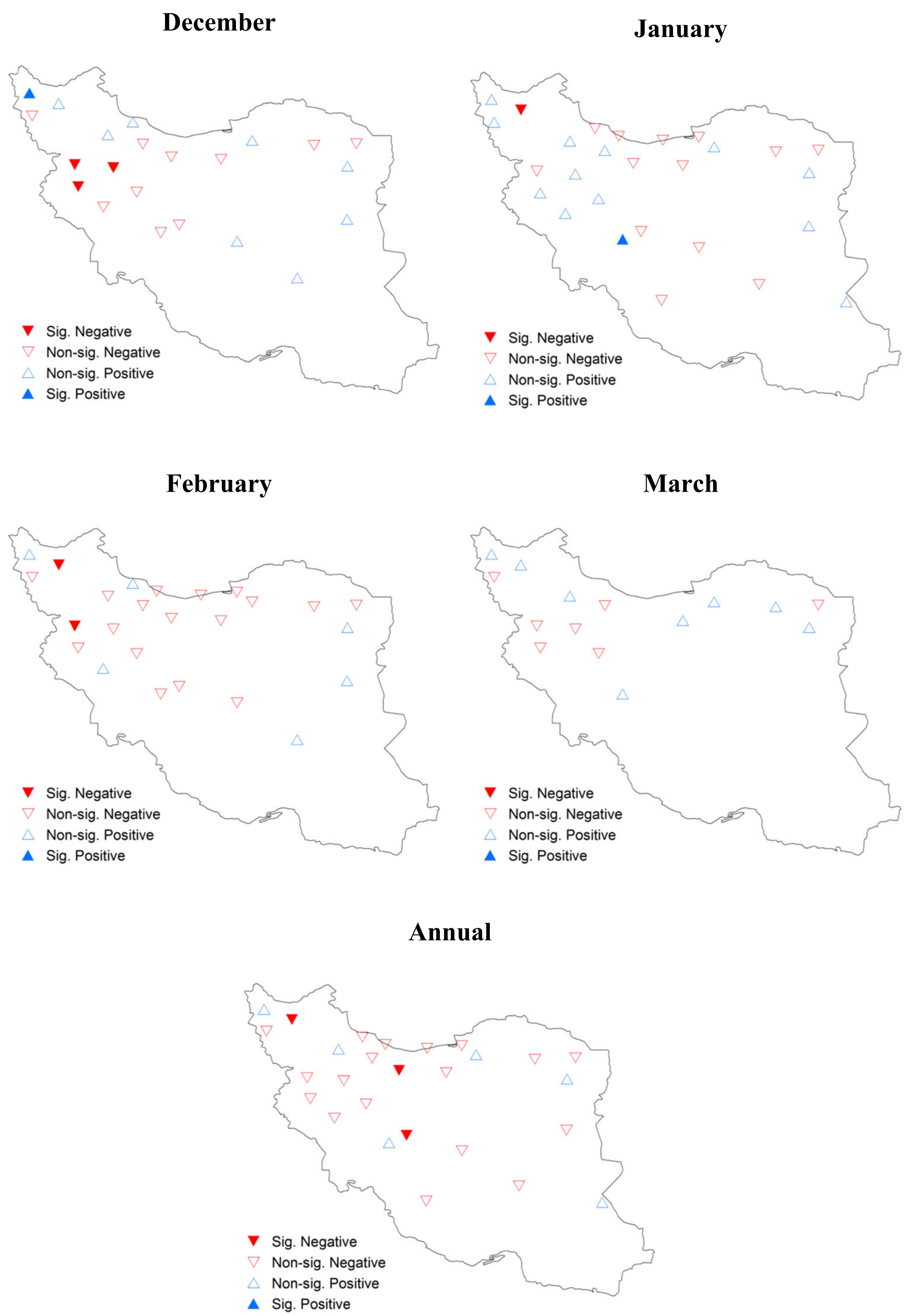
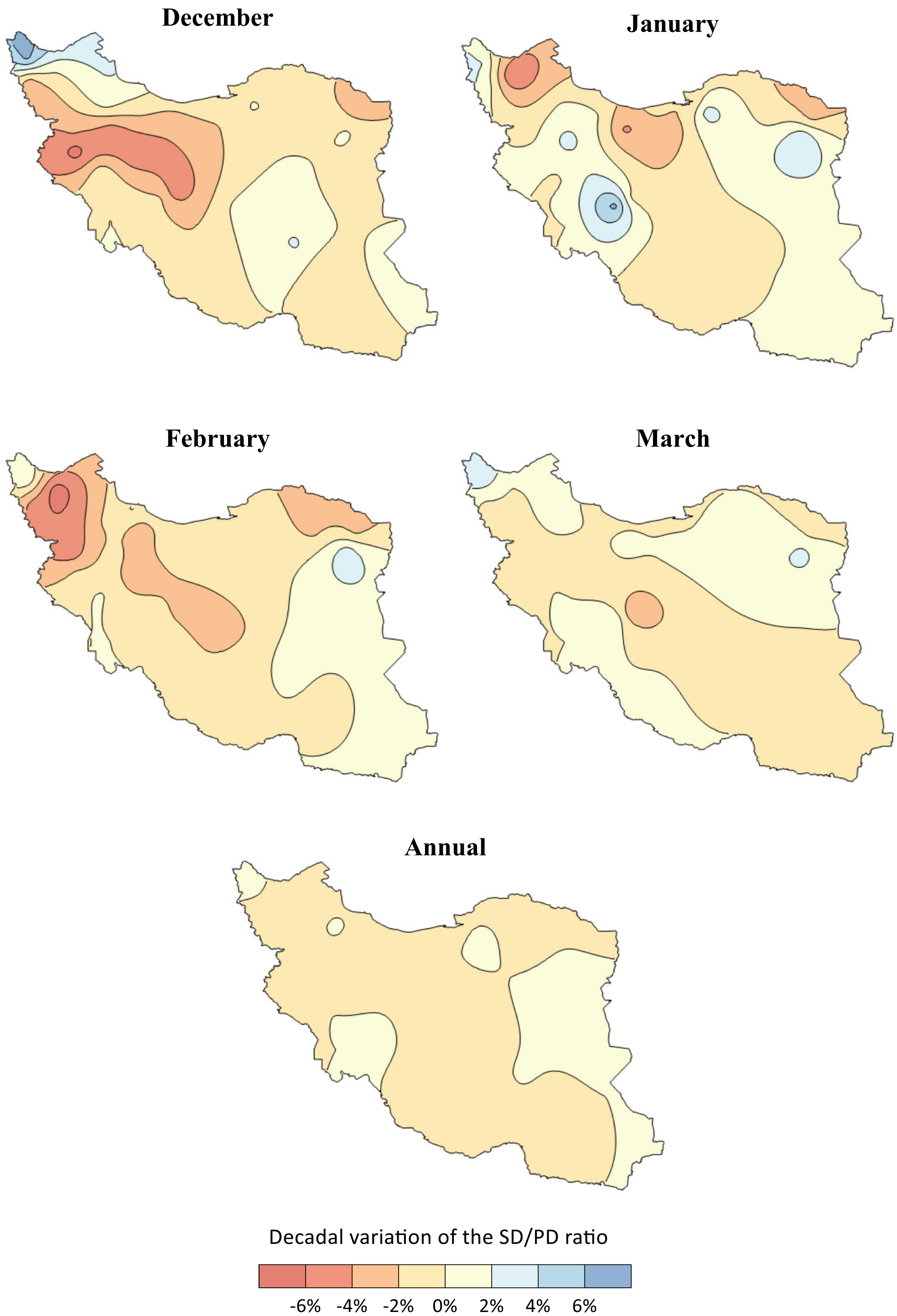


Fig. 5 Trends in the SD/PD ratio at the studied stations through1965–2014

required to scrutinize the variability in snow cover and depth over Iran.

Various research exhibited perceptible linkages between the large-scale climate oscillations (e.g., the North Atlantic oscillation—NAO) and snow-related parameters in disparate regions of the globe (Birsan and Dumitrescu 2014; Scherrer et al. 2004; Twardosz et al. 2012). Future snow-related studies in Iran could, therefore, concentrate on the investigation of associations between the major teleconnections and the form of precipitation, since the previous research revealed discernible impacts of the large-scale climate oscillations on precipitation amount and land surface phenology across the country, as well (Araghi et al. 2019b; Araghi et al. 2017b).

Fig. 6 Decadal variation (%) of the SD/PD ratio from 1965 to 2014



Spatiotemporal paucity of data records is one of the primary drawbacks of conducting such studies. In recent decades, the remotely sensed data (e.g., acquired data from the Moderate Resolution Imaging Spectroradiometer—MODIS) and also the gridded data sets (e.g., global and regional reanalysis data) have been widely used as dependable resources for assessing snow-related parameters in various regions (Alonso-González et al. 2018; Foppa and Seiz 2012; Jiang et al. 2019). The satellite-based data and remote sensing techniques as well as the gridded data sets could enhance the findings of in situ-based studies, and thus, they are suggested to be employed for further snow-related research in this region.

References

Ahrens CD (2016) Meteorology today, 11th edn. Cengage Learning, Boston, p 662

Alonso-González E et al (2018) Daily gridded datasets of snow depth and snow water equivalent for the Iberian Peninsula from 1980 to 2014. Earth Syst Sci Data 10:303–315

Araghi A, Mousavi-Baygi M, Adamowski J (2015a) Detection of trends in days with extreme temperatures in Iran from 1961 to 2010. Theor Appl Climatol 125:213–225

Araghi A et al (2015b) Using wavelet transforms to estimate surface temperature trends and dominant periodicities in Iran based on gridded reanalysis data. Atmos Res 155:52–72

Araghi A, Mousavi-Baygi M, Adamowski J (2017a) Detecting soil temperature trends in Northeast Iran from 1993 to 2016. Soil Till Res 174:177–192

Araghi A, Mousavi-Baygi M, Adamowski J, Martinez C (2017b) Association between three prominent climatic teleconnections and precipitation in Iran using wavelet coherence. Int J Climatol 37: 2809–2830

Araghi A, Martinez C, Adamowski J, Olesen JE (2018) Spatiotemporal variations of aridity in Iran using high-resolution gridded data. Int J Climatol 38:2701–2717

Araghi A, Adamowski J, Martinez CJ, Olesen JE (2019a) Projections of future soil temperature in Northeast Iran. Geoderma 349:11–24

Araghi A, Martinez CJ, Adamowski J, Olesen JE (2019b) Associations between large-scale climate oscillations and land surface phenology in Iran. Agric For Meteorol 278:107682

Birsan M-V, Dumitrescu A (2014) Snow variability in Romania in connection to large-scale atmospheric circulation. Int J Climatol 34: 134–144

Buisan ST, Saz MA, López-Moreno JI (2015) Spatial and temporal variability of winter snow and precipitation days in the western and central Spanish Pyrenees. Int J Climatol 35:259–274

Chen X, Liang S, Cao Y, He T, Wang D (2015) Observed contrast changes in snow cover phenology in northern middle and high latitudes from 2001–2014. Sci Rep 5:16820

Feng S, Hu Q (2007) Changes in winter snowfall/precipitation ratio in the contiguous United States, J Geophys Res Atmos 112

Foppa N, Seiz G (2012) Inter-annual variations of snow days over Switzerland from 2000-2010 derived from MODIS satellite data. Cryosphere 6:331–342

Hamed KH, Ramachandra Rao A (1998) A modified Mann-Kendall trend test for autocorrelated data. J Hydrol 204:182–196

Hirsch RM, Slack JR (1984) A nonparametric trend test for seasonal data with serial dependence. Water Resour Res 20:727–732

Hirsch RM, Slack JR, Smith RA (1982) Techniques of trend analysis for monthly water quality data. Water Resour Res 18:107–121

Jiang Y, Chen F, Gao Y, Barlage M, Li J (2019) Using multisource satellite data to assess recent snow-cover variability and uncertainty in the Qinghai–Tibet Plateau. J Hydrometeorol 20:1293–1306

Karamouz M, Nazif S, Falahi M (2013) Hydrology and hydroclimatology, principles and applications, 1st edn. CRC Press, Boca Raton, p 731

Kendall M (1975) Rank correlation methods, 4th Ed. ed. Charles Griffin, London

Knowles N, Dettinger MD, Cayan DR (2006) Trends in snowfall versus rainfall in the Western United States. J Clim 19:4545–4559

Lawrence DM, Slater AG (2010) The contribution of snow condition trends to future ground climate. Clim Dyn 34:969–981

Maidment DR (1993) Handbook of hydrology, 1st edn. McGraw Hill Inc., New York, p 1424

Mann H (1945) Nonparametric tests against trend. Econometrica 13:245–259

Martin JE (2006) Mid-latitude atmospheric dynamics: a first course. John Wiley & Sons Ltd, England

Noshadi M, Ahani H (2015) Focus on relative humidity trend in Iran and its relationship with temperature changes during 1960–2005. Environ Dev Sustain 17:1451–1469

Özgür E, Koçak K (2019) Climatology of snowfall/total precipitation days over Turkey. Theor Appl Climatol 137:2487–2495

Raziei T, Daryabari J, Bordi I, Pereira LS (2014) Spatial patterns and temporal trends of precipitation in Iran. Theor Appl Climatol 115: 531–540

Sabziparvar AA, Movahedi S, Asakereh H, Maryanaji Z, Masoodian SA (2015) Geographical factors affecting variability of precipitation regime in Iran. Theor Appl Climatol 120:367–376

Scherrer SC, Appenzeller C, Laternser M (2004) Trends in Swiss Alpine snow days: the role of local- and large-scale climate variability. Geophys Res Lett 31:1–4

Serquet G, Marty C, Dulex J-P, Rebetez M (2011) Seasonal trends and temperature dependence of the snowfall/precipitation-day ratio in Switzerland. Geophys Res Lett 38

Shelton M (2009) Hydroclimatology: perspectives and applications. Cambridge University Press, New York, p 438

Soltani S, Saboohi R, Yaghmaei L (2012) Rainfall and rainy days trend in Iran. Clim Chang 110:187–213

Trenberth KE, Dai A, Rasmussen RM, Parsons DB (2003) The changing character of precipitation. B Am Meteorol Soc 84:1205–1218

Twardosz R, Łupikasza E, Niedźwiedź T, Walanus A (2012) Long-term variability of occurrence of precipitation forms in winter in Kraków, Poland. Clim Change 113:623–638

Wang J et al (2016) Decrease in snowfall/rainfall ratio in the Tibetan Plateau from 1961 to 2013. J Geogr Sci 26:1277–1288

Wilks DS (2011) Statistical methods in the atmospheric science, 3rd edn. Academic Press, USA, 704 pp

Yue S, Pilon P, Phinney B, Cavadias G (2002) The influence of autocorrelation on the ability to detect trend in hydrological series. Hydrol Process 16:1807–1829

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