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Assessment of Continuity Changes in Spatial and Temporal Trend of Rainfall and Drought

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Abstract—Identifying the changes and effects of drought (as a natural creeping phenomenon) as accurately as possible is very effective and essential in managing how to deal with this phenomenon. To study drought in more detail, the main objective of this research is to consider the stability and changes of drought in different moving periods (MPs). These investigations were performed for various seasonal and annual time scales using rainfall values and reconnaissance drought index (RDI). The results showed sinusoidal changes in trend correlation coefficients (TCCs) for the 10-year MP, in which the wave amplitude became shorter and wavelength became longer as the MP lengthened. In recent MPs, the coefficient values of the trend were increasing. The RDI analysis showed that, in addition to the mentioned changes, the trend of autumn time scale changes in the 15- and 20-year MPs, especially after MP_7, was the opposite of the change trend in other time scales, especially the winter time scale. According to the results, the values of P(N/N) were greater than the values of P(N/P), which showed the stability of the decreasing trend of rainfall and RDI changes in different MPs, especially at 10 years.

Keywords: Drought stability, Moving period, Rainfall, RDI, Trend analysis.

1. Introduction

Meteorological drought is the beginning of droughts that will eventually lead to socioeconomic drought in the absence of proper management of the available water resources (Alizadeh, 2022). According to the water deficiencies in different regions and at different times, water planning and management are often challenging tasks and have the potential to lead to conflicts between various stakeholders (Sivakumar, 2011). This problem becomes far more complicated during periods of drought (Asadi Zarch et al., 2015). Therefore, more accurate monitoring and diagnosis of drought periods and their reliability can be a great help in better and more accurate management of water resources for different uses.

Numerous studies have examined how drought changes (Tsakiris et al., 2008; Azimi et al., 2020; Oikonomou et al., 2020; Tatli et al. 2020; Topcu & Seckin, 2021; Motavali Bashi Naeini et al. 2021; Kamali & Asghari, 2022; Chisadza et al., 2023; Achite et al., 2023). This studies considered different drought indices and discussed the ability of each. The researchers concluded that indices such as RDI (reconnaissance drought index), SPEI (standardized precipitation-evapotranspiration index), and PDSI (Palmer drought severity index), which use more meteorological parameters in their calculations, can better quantify drought.

Tsakiris et al. (2007) proposed the RDI index together with the well-known Standardized Precipitation Index (SPI) and the method of deciles. They concluded that although the RDI generally responds similarly to the SPI (and to a lesser extent to the deciles), it is more sensitive and suitable in cases of a changing environment. Kousari et al. (2014) investigated drought severities and different time series trends using RDI. This study indicated the frequent decreasing trends in RDI time series, particularly for long-term time series (12, 18, and 24 monthly time series) compared with short-term ones. Asadi Zarch et al. (2015) investigated the changes in drought characteristics across different aridity zones in Iran, with and without consideration of potential evapotranspiration (PET), using RDI (reconnaissance drought index) and SPI (standardized precipitation index) drought indices. The results indicated that although all the aridity zones

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experience both downward and upward drought trends, no significant trend was found over large parts of the zones. However, the agreement between SPI and RDI reduces from the hyper-arid zone on one extreme to the humid zone on the other. Shokoohi and Morovati (2015) evaluated the performance of RDI and SPI in Lake Urmia Basin, Iran. Results indicated the acceptable and suitable performance of SPI and RDI in drought recognition, with RDI being more sensitive to severe drought. While SPI had no long-term trend, RDI showed a negative trend and an abrupt change around 1996, which could be seen as a consequence of global warming. Zarei et al. (2016) evaluated the changing trend in drought severity based on the RDI index using linear regression, Mann-Kendall, and Spearman's rho tests. Results indicated the frequent decreasing trends in RDI time series for short-term time series more (one monthly time series) than long-term ones. Mohammed and Scholz (2017) proposed the alpha and normalized forms of RDI as a single climatic index to recognize geographical areas with differing drought characteristics and potential weather variability. Results indicated the more consistent trend of climate variability by applying time series of different durations of RDI compared to using time series of P and potential evapotranspiration separately. Khan et al. (2017) utilized the RDI, SPI, and SPEI indices to assess future drought events in the study area of Heilongjiang Province in China from 2016 to 2099. According to this research, the 1st and 2nd months of the years studied predicted a warming trend, while the 7th, 8th, and 9th months predicted a wetter trend. Also, RDI was more sensitive to drought and indicated a high percentage of years under severe and extreme drought conditions during the drought frequency analysis. Merabti et al. (2018) studied the spatial and temporal variability of droughts in northeast Algeria using SPI and RDI. In this study, the modified Mann-Kendall test was used to assess trends of the RPC scores and showed non-significant trends for decreasing drought occurrence and severity in both identified drought sub-regions and on all time scales. According to the results, both indices showed coherent and similar behavior; however, RDI was likely to identify more severe and moderate droughts in the southern and more arid sub-region, which may be due to its ability to consider the influences of global warming. Zarei and Mahmoudi (2021) evaluated the trend of drought severity changes from 1967 to 2017 and the pattern of the changing trend in drought using the RDI index in constant and progressively increasing periods for 24 stations in Iran. The results of this study indicated that at 79.17% of the stations on the annual time scale and 87.50%, 66.66%, and 29.16% of the stations on the winter, autumn, and summer time scales (respectively), the intensity of the decreasing trend in RDI in newer time periods was more than the decreasing trend in RDI in older time periods; however, on the spring time scale at 41.66% of the station, the intensity of decreasing trend in RDI in newer time periods was more than the decreasing trend in RDI in older time periods. Asadi Zarch (2022) applied the RDI to global land precipitation and PET data during 1959–2018 for seasonal and annual drought trend analysis. Drought trend analysis on the annual time scale indicated that the drying zone area is larger than the wetting zone. Seasonal drought trend analysis presents contradictory tendencies. Spring and summer indicate a drying trend. Conversely, fall and winter present a wetting tendency.

In all of the mentioned studies, the investigations were done using the entire time period of the available time series of the data. During the entire time period of the study, the changes and effects of drought may be different in different time periods, and stability of drought should be considered.

The goal of this research is analyzing the trend of rainfall and drought (the RDI index) once for all available data (1988–2020) and once in different moving periods (MPs) (10, 15, and 20 years) at different time scales (seasonal and annual). A trend analysis of trend correlation coefficients (TCCs) was also performed to consider the drought survival from one time period to another.

2. *Materials and Methods*

2.1. *Study Area and Data Collection*

This study was performed using the data from nine synoptic stations through Fars Province with area of 125,000 km^2, located in the southwest of Iran (27° 05′ to 31° 55′ N and 50° 07′ to 55° 54′ E) (Fig. 1). The average elevation of this province is

2015 m above sea level. Based on the climatic data series of nine selected stations in Fars Province (Table 1), the mean annual rainfall of the study area varies from 136 mm per year in Abadeh to 474 in Doroodzan. The average temperature of the study area varies from 14.4 °C in Abadeh to 27.50 in Lamerd. The climate conditions of this area based on the modified De Martonne index (De Martonne 1926; Aguirre et al., 2018; Zarei et al., 2019) are mainly arid and semi-arid. The study area includes more than 120 hydrological units with a harmful groundwater bill in most of these plains (discharge from groundwater is more than recharge). Fars Province is one of the main agricultural regions in Iran, which ranks first in the production of wheat and some other products in the country. In this study, 33 years (1988–2020) of meteorological data were used. Some meteorological and geographical properties of synoptic stations are presented in Table 1.

2.2. RDI Calculation

The RDI index was calculated using the procedure presented by Tsakiris et al. (2007), utilizing the ratios of precipitation over Reference Crop Evapotranspiration (ET0) for different time scales to be representative of the desired region. Many scientists have mentioned the advantages of RDI, such as sensitivity to a variety of climate conditions, capability to identify different types of drought by using different time scales and suitability for agricultural drought assessment (Khalili et al., 2011; Moghimi et al., 2021; Nikbakht & Hadeli, 2021; Rahmat et al., 2015; Tsakiris et al., 2007; Zarei et al., 2019).

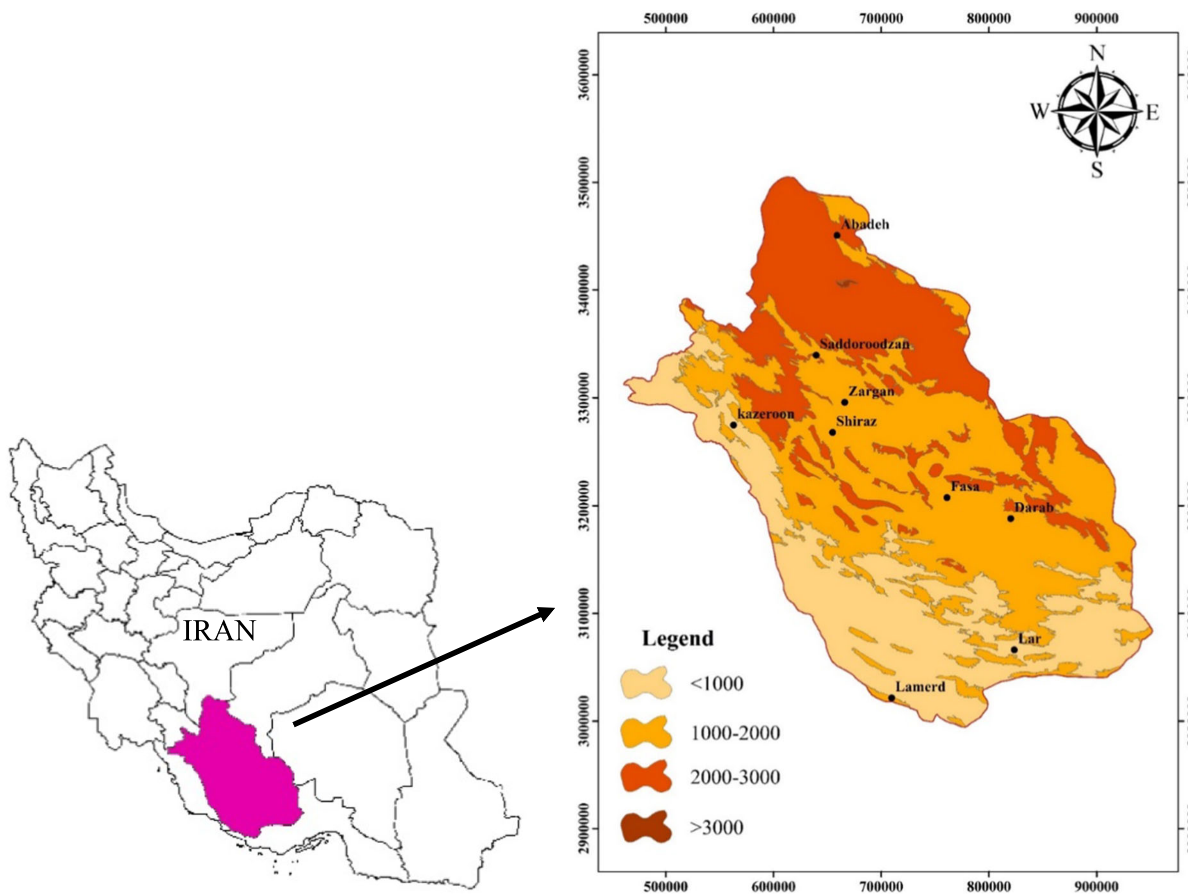

Figure 1
Location of the study area (Fars Province in southwest of Iran) and geographic distribution of the station

Table 1

Characteristics of selected synoptic stations

Station	Latitude (N)	Longitude (E)	Elevation (m)	Mean rainfall (mm/year)	Mean annual temperature (°C)
Abadeh	31.1	52.6	2030	136	14.4
Doroodzan	30.1	52.4	1652	474	18.3
Zarghan	29.7	52.7	1596	318	18.8
Shiraz	29.5	52.6	1484	330	18.8
Fasa	28.9	53.6	1288	283	19.4
Kazeroon	29.6	51.6	840	359	15.8
Darab	28.7	52.4	1098	273	23.7
Lar	27.6	52.4	792	197	25.2
Lamerd	27.3	53.1	411	225	27.5

Calculating RDI was carried out using equations as follows:

First, αk is calculated as the coefficient of the ith year in aggregated form as follows, using a monthly time step:

$$\alpha_k^i = \frac{\sum_{j=1}^{k} P_{ij}}{\sum_{j=1}^{k} \mathrm{PET}_{ij}} i = 1 \; to \; N \quad (1)$$

where Pij and PETij are precipitation and potential evapotranspiration of the jth month of the ith year that usually starts from October (K = 1) in the study region. N is the total number of years of the available data. Equation (1) can be calculated for any period of the year. It can also be recorded starting from any month of the year except October. As previously mentioned, ET0 was used to represent PETij, which was estimated using the Penman-Monteith equation (Allen et al. 1998). Computation of normalized RDI (RDIn) was the next step, using $\overline{\alpha}_k$ as the arithmetic mean of αk values:

$$\mathrm{RDI}_n^{(i)} = \frac{\alpha_k^{(i)}}{\overline{\alpha}_k} - 1 \quad (2)$$

Finally, the standardized RDI (RDIst) is computed as follows:

$$\mathrm{RDI}_{st(k)}^{(i)} = \frac{y_k^{(i)} - \overline{y}_k}{\widehat{\sigma}_{yk}} \quad (3)$$

where y_k is the $\ln(\alpha_0^{(i)})$, $\overline{y}_k$ is the arithmetic mean of y_k and $\widehat{\sigma}_{yk}$ is the standard deviation. In this research, different distributions were fitted to the α_k data series, and according to the goodness of fit tests, the gamma distribution was found to be the best in both seasonal and annual time scales.

The gamma distribution is defined by its frequency or probability density function:

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{\frac{-x}{\beta}} dx \; for \; x \geq 0 \quad (4)$$

where α and β are shape and scale parameters, x is the precipitation amount, and $\Gamma(\alpha)$ is the gamma function. Maximum likelihood solutions were used to estimate α and β.

$$\widehat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \quad (5)$$

$$\widehat{\beta} = \frac{\widehat{\alpha}}{\overline{x}} \quad (6)$$

$$A = ln(\overline{x}) - \frac{\sum ln(x)}{n} \quad (7)$$

Since the precipitation distribution may contain zeros and the gamma function is undefined for x = 0, the cumulative probability becomes:

$$H(x) = q + (1 - q)G(x) \quad (8)$$

where q is the probability of zero precipitation and $G(x)$ is the cumulative probability of the incomplete gamma function. If m is the number of zeros in an α_k time scale/s, then q could be estimated by *m/n*. The cumulative probability $H(x)$ is then transformed to the standard normal random variable z with mean zero and the variance of one, which is the value of RDI_{st} (Tsakiris et al., 2008). In the present study, seasonal [Autumn (September to November), Winter (December to February), and Spring (March to May)] and annual RDI_{st}s were used to represent the seasonal and annual RDI. Due to the lack of rainfall in summer in the study area, the calculations of this season were omitted. The annual time scale was considered from the beginning of the hydrological year (October) (October to September). Drought category classification suggested for the RDI is illustrated in Table 2 (Tsakiris 2004, 2007; Banimahd & Khalili, 2013; Zarei et al., 2016; Moghimi et al., 2019, 2021).

2.3. *Temporal Trend Analysis*

This analysis was performed for rainfall and RDI data series at seasonal (autumn, winter, and spring) and annual time scales of rainfall and RDI. These analyses were performed first for all 33 years' available data (1988–2020) and then for different MPs during the available historical period (10-, 15-, and 20-year MPs) for precise consideration of continuity in trend.

To detect the change trend for the mentioned time series, initially, the normality test was performed for the data, using the Shapiro-Wilk test. Then, for the normal data series, the Pearson method, and, for the abnormal data series, the non-parametric methods of Spearman's rho and Kendall's tau_b were used to estimate the trend analysis correlation coefficients (Chen & Popovich, 2002; Conover, 1998). These estimations were performed using R software.

Table 2

Drought classification of RDI (Moghimi et al., 2019; Zarei et al., 2016)

Drought class	RDI value
Extremely wet	RDI ≥ 2
Very wet	1.5 < RDI < 1.99
Moderately wet	1 < RDI < 1.49
Normal	0 < RDI < 0.99
Near normal	− 0.99 < RDI < 0
Moderately dry	− 1.49 < RDI < − 1
Severely dry	− 1.99 < SPI < − 1.5
Extremely dry	RDI ≤ − 2

2.3.1 *Analysis of Different MPs During Available Data*

Unlike previous studies, these analyses were not only performed for the one-time period (total available time series data) (Sect. 2.4.1) but were performed on a moving basis for different time periods (10, 15, and 20 years) with the goal of considering the continuity of drought in different MPs. For this analysis, the total time period of the available rainfall data and calculated RDI (1988–2020) was divided into different MPs (10, 15, and 20 years). Considering the 10-year MP, the whole period becomes 24 MPs, which include: 1988–1997 (MP_1), 1989–1998 (MP_2), …, 2011–2020 (MP_{24}). Considering the 15-year MP, the whole period becomes 19 MPs, which include: 1988–2002 (MP_1), 1989–2003 (MP_2), …, 2006–2020 (MP_{19}), and considering the 20-year MP, the whole period becomes 14 MPs, which include: 1988–2007 (MP_1), 1989–2008 (MP_2), …, 2001–2020 (MP_{14}). In the next step, the TCCs of these MPs were estimated using parametric and non-parametric methods.

2.3.2 *Trend Analysis of Time Series of TCCs*

To consider how to change TCCs, trend analysis of time series of TCCs related to different MPs (10, 15, and 20 years) was performed. How to obtain the temporal changes of TCCs was explained in the previous sections.

2.3.3 *Detecting Status Changes Using Markov Chain*

To consider status changes in trend correlation, the Markov chain stochastic model was used. A time series of discrete random variables, X_1, X_2, …, X_t, can be represented by the stochastic process of the Markov chain (Khalili et al., 2011; Wilks, 2006, 2011). The transition probabilities of m-order Markov chain depend on the states in the previous m time periods. The commonly used first-order Markov chain assumes that the transition probabilities of the next state depend only on the present state, a characteristic known as the Markovian property (Khalili et al., 2011):

$$P\{X_{t+1}|X_t, X_{t-1}, X_{t-2}, \ldots, X_1\} = p\{X_{t+1}X_t|\} \quad (9)$$

Transition probabilities indicate the probability of going to state j for the next time period, given that the current state is i for the mathematical explanation of these probabilities, and the transition probability matrix was used:

$$\mathrm{P_{ij}} = \mathrm{P}(\mathrm{X_{t+1}} = \mathrm{j}|\mathrm{X_t} = \mathrm{i}) \quad (10)$$

where $\mathrm{P_{ij}}$ represents the transition probability that $\mathrm{X_{t+1}}$ is equal to category j given $\mathrm{X_t}$ is equal to category i. For a given sample, the transition probability is estimated as follows:

$$\widehat{\mathrm{P}}_{ij} = \frac{\mathrm{n_{ij}}}{\mathrm{n_{i*}}} \quad (11)$$

where $\mathrm{n_{ij}}$ is number of j's following i's and $\mathrm{n_{i*}}$ is total number of i's. In the present study, the first-order (two-state) Markov chain was applied to the TCCs of rainfall and RDI time series data in different MPs and different time scales. The states of transition probability matrix are positive and negative trend correlation coefficients.

3. Results and Discussion

RDI values calculated for different time scales are presented in Fig. 2 for some of the studied stations. Results for other stations were not presented to save space. According to these figures, in recent years, the values of this index for the autumn and spring seasons have usually been higher than zero; for the winter season, they are usually lower than zero. Considering that the majority of rainfall in the study area is related to the winter season, these results indicate the occurrence of drought in recent years.

3.1. Temporal Trend Analysis

Results of the temporal change trend for the whole historical period (1988–2020) for all stations and time scales are shown in Table 3. These results for MPs of 10-, 15-, and 20-year are presented in Figs. 3, 4, and 5 only for three stations of Abadeh, Shiraz, and Lar to save space.

3.1.1 Rainfall Data

Results of considering the temporal trend of the whole available data series showed an increasing trend of precipitation changes on the autumn and spring time scales, which was significant for Lar station in the autumn and Abadeh station in the spring. In contrast, on the winter time scale, the change trend in rainfall was decreasing in all stations, which was significant in Doroodzan, Zarghan, Shiraz, and Kazeroon stations. For the annual time scale, the change trend in most stations was declining. Results of temporal trend of MPs for 10, 15, and 20 years indicated that changes in trend coefficients for winter and annual time scales were similar at all of the studied stations. Meanwhile, the changes in trend coefficients of the autumn time scale were often similar to those of winter and annual in all stations except the stations in the south of the study area (Darab, Lar, and Lamerd). The changes in trend coefficients of the spring time scale, in all stations, were often the opposite of winter and annual time scale changes, i.e., when the values of the winter time scale trend coefficients were increasing, these values were decreasing for the spring. These variations are presented in Figs. 3, 4, and 5 for stations Abadeh, Shiraz, and Lar; results for other stations are not shown to save space. In the study area, almost more than 90% of the annual rainfall is related to the winter and spring seasons; usually in each year, when winter rainfall decreases, spring rainfall increases significantly and vice versa, which can be the reason for the mentioned oppositeness. This phenomenon in the southern half of study area is more significant. In all of the studied stations, this oppositeness for 15-year MP was less than for the 10-year MP, with the exception of Fasa, Darab, Lar, and Lamerd, which are located in the southern half of the study area, because of the more significant difference between winter and spring rainfall in these stations than in the stations in the northern half of the study area. This oppositeness for 20-year MP was less than for 15 years for all of the studied stations.

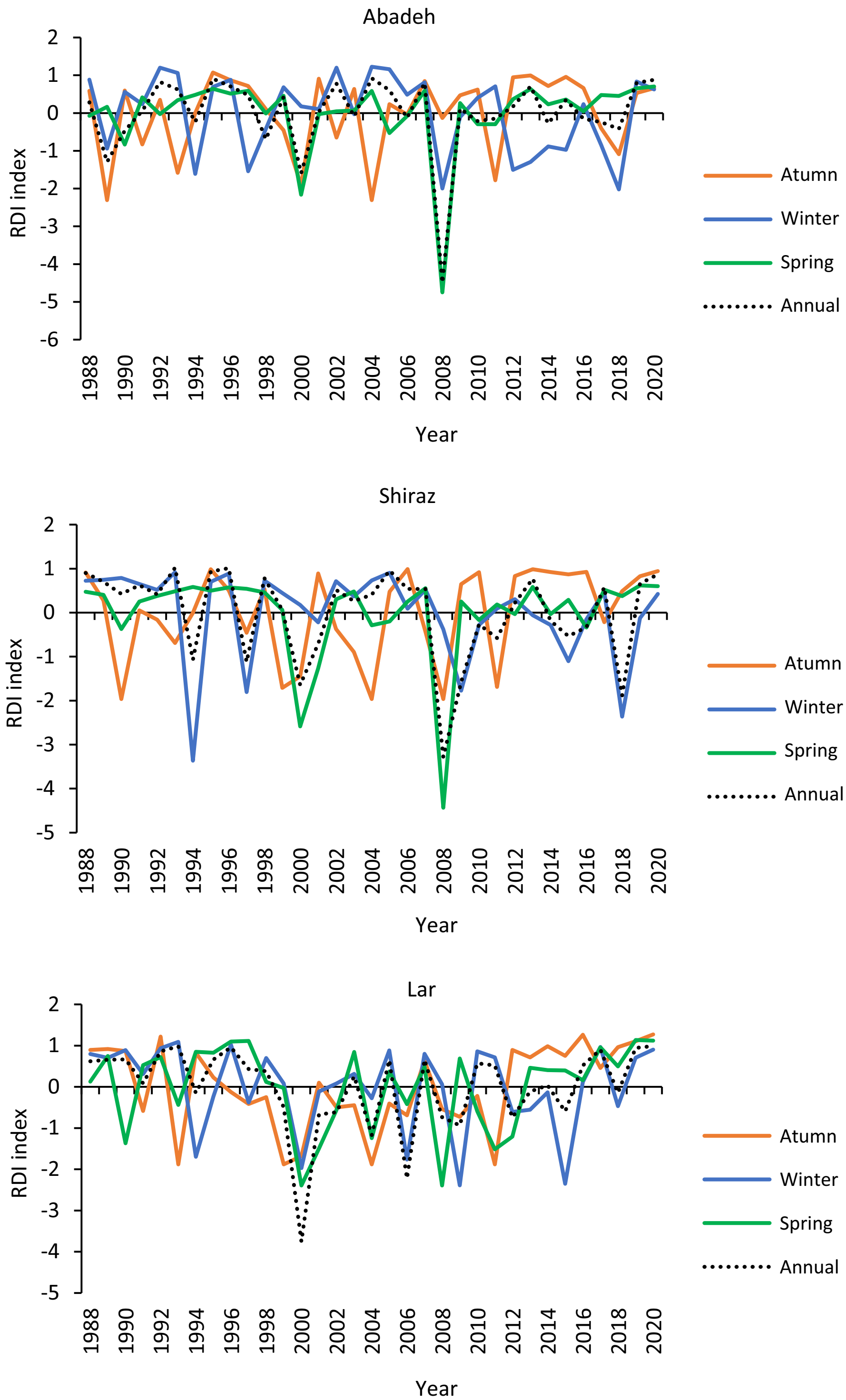

Figure 2
RDI values calculated for different time scales at different stations

3.1.2 RDI Data

In drought (the RDI index) trend analysis of all available data (1988 to 2020) (Table 3), the results indicated an increasing changing trend in the autumn, an unchanged or decreasing trend in the spring, and a decreasing trend on the winter and annual time scales. The results of Zarei and Mahmoudi (2021), Abedi and Kazemi Rad (2020), and Beygi Heidarlou et al. (2020) confirm these types of change. Meanwhile, the change trend on the autumn time scale, in Doroodzan, Fasa, Darab, and Lamerd stations, and the trend on the winter time scale in Doroodzan, Zarghan, Shiraz, and Fasa stations and in Doroodzan and Kazeroon stations on the annual time scale was significant. When analyzing trend changes in different MPs, the changes in the trend coefficients related to the annual and winter time scales and autumn and spring were similar (Figs. 3, 4, 5). As shown in the figures, changes in trend coefficients for annual and winter time scales for spring and autumn were often the opposite. This inconsistency was less in the 20-year MP and was more evident between winter and spring time scales. In the southern stations of the study area (Fasa, Darab, Lar, and Lamerd), the changes on the spring time scale were often similar to those for winter and annual (especially in recent MPs) and opposite to autumn; this discrepancy was evident in all MPs. According to the recorded historical data, the reason is that, in the years when there was a lot of rain in the winter season, the rain decreased in the spring and the evapotranspiration increased. Masoudian and Ataei (2005) confirm this results.

3.2. Trend of Temporal TCCs

3.2.1 Rainfall

In the 10-year MP, the change trend of temporal TCCs on the autumn time scale was negative for the stations located in the northern half of the studied area, and the southern half of the studied area, it was positive (Table 4). This trend of positive changes in Lar station was significant at the 5% significance level. These changes for the winter time scale were positive in all of the stations except Doroodzan and Zarghan located in the northern half of the study area. In this time scale, the trend change was not significant in any of the stations. On the spring time scale, the change trend was positive in all stations, but not significant in any of them. On an annual basis, only in Abadeh, Doroodzan, and Zarghan stations, located in the northern half of the study area, was a negative change trend, and in the rest of the stations, there was a positive change trend, which was significant at 5% in Lar station.

In the 15-year MP, compared to the 10-year MP, the values of the negative coefficients decreased and the values of positive coefficients increased, so that on the autumn time scale, the negative coefficients

Table 3

Correlation coefficients of trend analysis of whole rainfall and RDI available data (1988–2020)

Station	Rainfall				RDI			
	Autumn	Winter	Spring	Annual	Autumn	Winter	Spring	Annual
Abadeh	0.01	− 0.30	**0.48****	0.10	0.21	− 0.26	0.22	0.01
Doroodzan	0.00	**− 0.43***	0.13	− 0.25	**0.41***	**− 0.52****	− 0.17	**− 0.39***
Zarghan	0.08	**− 0.54****	0.22	− 0.31	0.34	**− 0.54****	0.02	− 0.25
Shiraz	0.05	**− 0.46****	0.28	− 0.24	0.32	**− 0.52****	0.01	− 0.27
Fasa	0.11	− 0.31	0.21	− 0.07	**0.37***	**− 0.44***	0.00	− 0.27
Kazeroon	0.04	**− 0.49****	0.31	− 0.26	0.07	− 0.30	− 0.15	**− 0.47****
Darab	0.14	− 0.26	0.11	− 0.09	**0.49****	− 0.16	0.02	− 0.04
Lar	**0.35***	− 0.19	0.09	0.00	0.25	− 0.19	0.07	− 0.11
Lamerd	0.27	− 0.23	− 0.02	− 0.04	**0.41***	− 0.32	− 0.14	− 0.27

Correlation coefficients are significant at the *0.05 and **0.01 significance levels (bold characters)

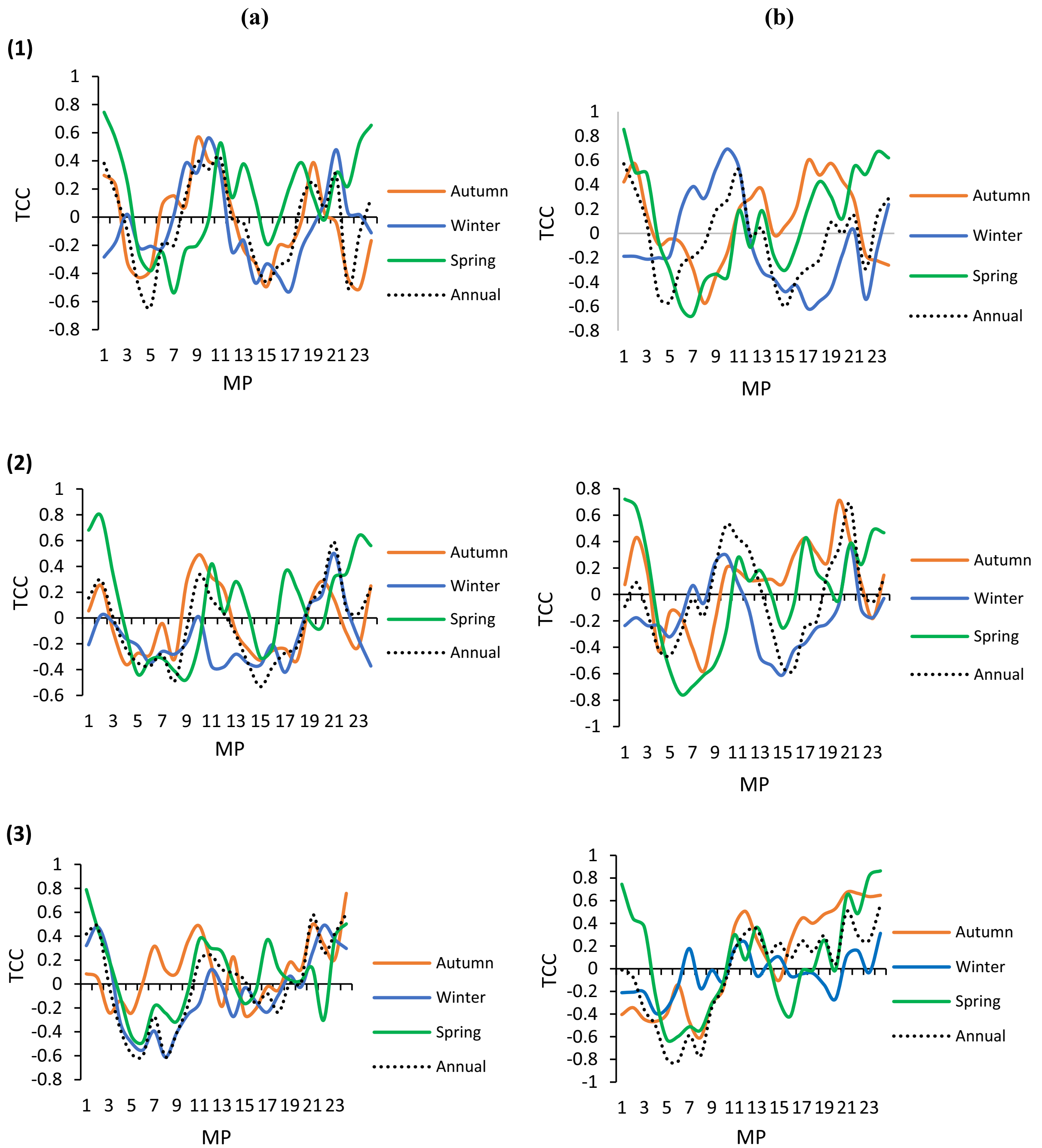

Figure 3
Temporal variations of TCCs of rainfall (**a**) and RDI (**b**) values in different time scales for 10-year moving period: (1): Abadeh; (2): Shiraz; (3): Lar

obtained in the northern half of the study area (Abadeh, Doroodzan, Zarghan, Shiraz, and Fasa) were significant. On the winter time scale, the coefficient of trend changes in Abadeh, Doroodzan, and Zarghan stations were negative (significant in Abadeh and Zarghan stations) and in Darab, Lar, and

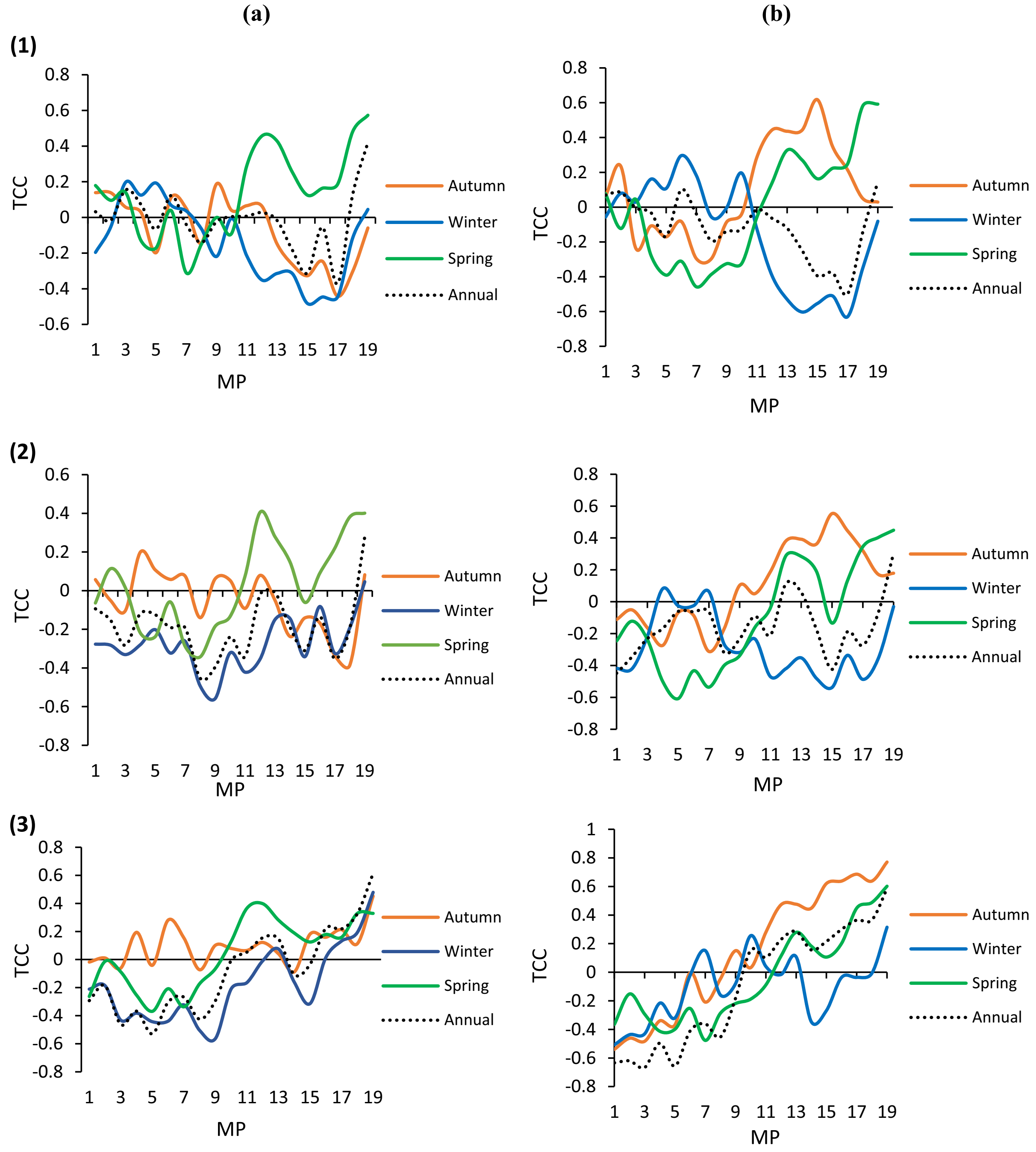

Figure 4
Temporal variations of TCCs of rainfall (**a**) and RDI (**b**) values in different time scales for 15-year moving period: (1): Abadeh; (2): Shiraz; (3): Lar

Lamerd stations were positive and significant. On the spring time scale, the change trend was positive and significant in all stations, except Droodzan and Fasa stations, and in these two stations, the coefficients were not significant. On the annual time scale, in Abadeh, Doroodzan, Zarghan, Fasa, and Kazeroon

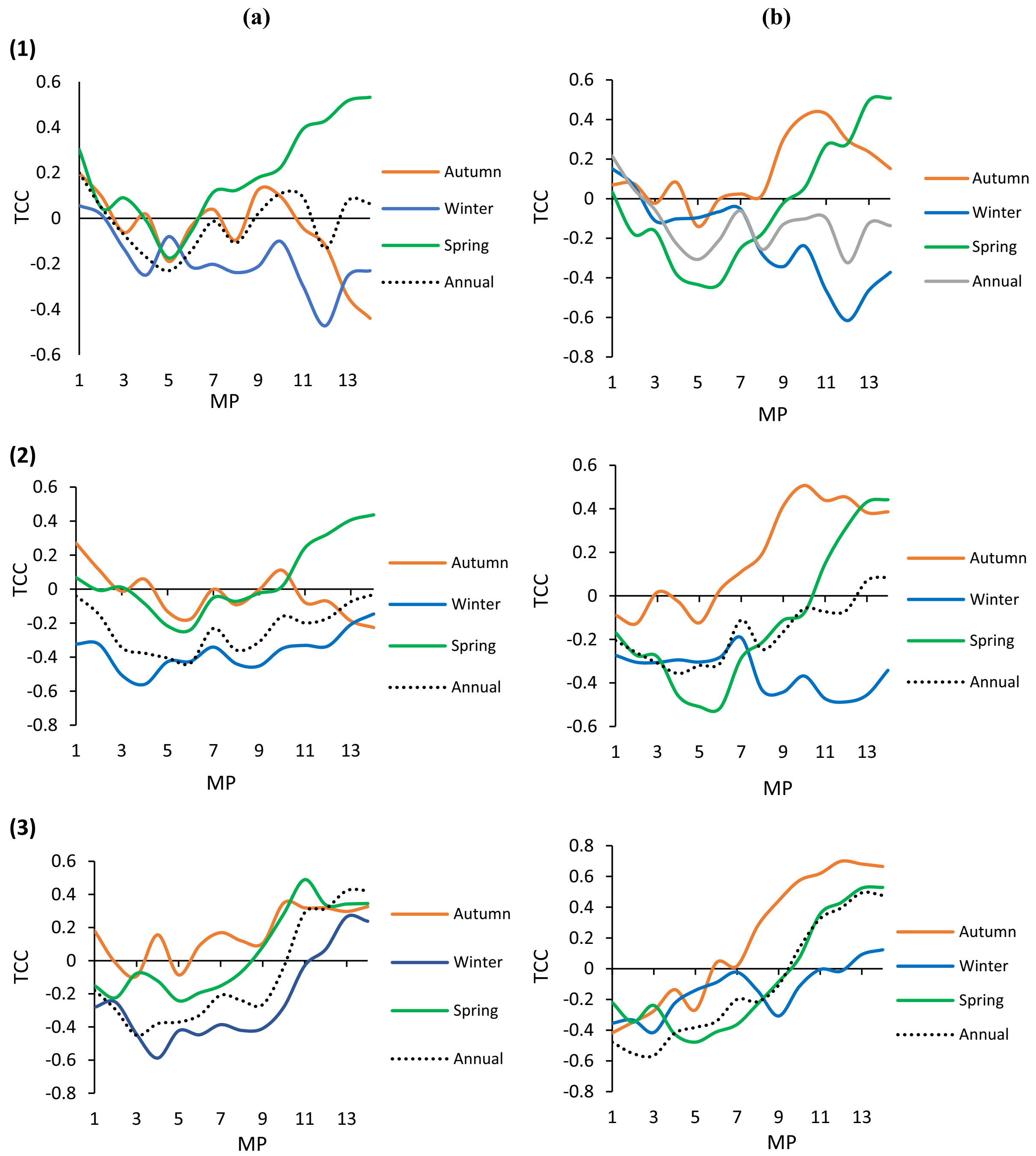

Figure 5
Temporal variations of TCCs of rainfall (**a**) and RDI (**b**) values in different time scales for 20-year moving period ((1): Abadeh; (2): Shiraz; (3): Lar)

stations, there was a negative change trend, and in the rest of the stations, there was a positive change trend. These coefficients were significant at 5% significance level in Doroodzan, Darab, Lar, and Lamerd stations.

Table 4

Trend analysis for different moving periods and time scales of rainfall

	10 years				15 years				20 years			
	Autumn	Winter	Spring	Annual	Autumn	Winter	Spring	Annual	Autumn	Winter	Spring	Annual
Abadeh	− 0.28	0.04	0.28	− 0.01	**− 0.68****	**− 0.58****	**0.60****	− 0.10	**− 0.64***	**− 0.71****	**0.71****	0.15
Doroodzan	− 0.13	− 0.10	0.06	− 0.06	**− 0.67****	− 0.38	0.14	**− 0.47***$^{}$	**− 0.68****	− 0.26	0.22	− 0.40
Zarghan	− 0.17	− 0.13	0.14	− 0.05	**− 0.51***	**− 0.57***	**0.58****	− 0.37	− 0.43	**-0.69****	**0.64***	− 0.36
Shiraz	0.05	0.22	0.19	0.22	**− 0.55***	0.40	**0.62****	0.18	**− 0.65***	**0.58***	**0.70****	0.35
Fasa	− 0.09	0.04	0.18	0.08	**− 0.49***	0.20	0.22	− 0.18	**− 0.68****	0.27	**0.63***	0.05
Kazeroon	0.04	0.14	0.14	0.11	− 0.44	0.19	**0.52***	− 0.15	**− 0.63***	0.403	0.46	− 0.10
Darab	0.11	0.34	0.30	0.22	0.28	**0.63****	**0.56***	**0.54***	0.16	**0.67****	**0.73****	**0.55***
Lar	**0.43***	0.34	0.09	**0.41***	**0.47***	**0.72****	**0.78****	**0.86****	**0.75****	**0.74****	**0.86****	**0.85****
Lamerd	0.12	0.32	0.08	0.40	0.16	**0.63****	**0.57***	**0.62****	0.31	**0.70****	**0.74****	**0.59***

Correlation coefficients are significant at the *0.05 and **0.01 significance levels (bold characters)

The results for the 20-year MP were the same as for the 15-year MP for all stations and time scales, except for Zarghan and Kazeroon stations on the autumn time scale, Shiraz station on the winter time scale, Fasa and Kazeroon stations on the spring time scale, and Doroodzan station on the annual time scale.

3.2.2 RDI index

On the autumn and spring time scales, the coefficients related to the temporal trend were positive for all cases (all of the studied stations and MPs) (Table 5). On the autumn time scale and 10-year MP, the changes in trend in Fasa, Kazeroon, Darab, Lar, and Lamerd stations were significant at the 5% level of significance. In this time scale and 15- and 20-year MP, the changes in trend were positive and significant at all of the studied stations. The value of these coefficients was higher in the southern half of the study area and increased in the 20-year MP compared to the 15-year MP because of the higher autumn rainfall in the southern stations of the study area and the prolongation of the MP under consideration.

On the winter and annual time scales, negative trend coefficients were obtained in the northern stations of the study area, but positive trend coefficients were obtained in the stations located in the south of the study area (except Darab station in 10-year and 20-year MPs and winter time scale,

Table 5

Trend analysis for different moving periods and different time scales of RDI

	10 years				15 years				20 years			
	Autumn	Winter	Spring	Annual	Autumn	Winter	Spring	Annual	Autumn	Winter	Spring	Annual
Abadeh	0.06	− 0.28	0.32	− 0.07	**0.51***	**− 0.71****	**0.70****	**− 0.51***	**0.63***	**− 0.90****	**0.75****	− 0.45
Doroodzan	0.15	− 0.20	0.16	0.00	**0.50***	**− 0.70****	**0.48***	− 0.39	**0.77****	**− 0.90****	0.46	− 0.44
Zarghan	0.29	− 0.22	0.14	0.06	–	–	**0.56***	− 0.07	**0.90****	**− 0.91****	**0.63***	− 0.10
Shiraz	0.40	0.04	0.29	0.24	**0.77****	− 0.39	**0.79****	0.40	**0.90****	**− 0.66***	**0.81****	**0.84****
Fasa	**0.45***	0.01	0.22	0.19	**0.55***	− 0.21	**0.47***	− 0.13	**0.70****	**− 0.61***	0.50	0.04
Kazeroon	**0.67****	0.05	0.28	0.27	**0.69****	**− 0.57***	**0.54***	0.25	**0.92****	− 0.17	**0.56***	0.45
Darab	**0.72****	− 0.18	0.39	0.00	**0.79****	0.00	**0.75****	**0.61****	**0.95****	− 0.08	**0.71****	**0.54***
Lar	**0.89****	**0.52****	0.38	**0.76****	**0.98****	**0.58****	**0.90****	**0.96****	**0.97****	**0.84****	**0.77****	**0.96****
Lamerd	**0.71****	0.31	0.21	**0.54****	**0.87****	0.02	0.40	**0.69****	**0.91****	0.23	**0.60***	**0.57***

Correlation coefficients are significant at the *0.05 and **0.01 significance levels (bold characters) which resulted in negative coefficients). The trend coefficients related to the 10-year MP and winter time scales were significant only in Lar station and on the annual time scale in the Lar and Lamerd stations. In 15-year MP and winter time scales, the negative trend coefficients were significant in Abadeh, Doroodzan, Zarghan, and Kazeroon stations, and the positive coefficients were significant only in Lar station. In this MP and annual time scale, negative coefficients were significant only in Abadeh station and positive coefficients in Darab, Lar, and Lamerd stations. In 20-year MP and winter time scale, the negative trend coefficients were significant in Abadeh, Doroodzan, Zarghan, Shiraz, and Fasa stations, and the positive coefficients were significant only in Lar station. In this MP and annual time scale, negative coefficients were not significant in any of the stations, and positive coefficients were significant in Shiraz, Darab, Lar, and Lamerd stations.

3.3. *Transition Probabilities*

According to the objectives and nature of this research, the first-order Markov chain with two states (positive and negative trend coefficients of temporal trend) was used in this research. Transition probabilities were calculated using Eq. 11 for data series of trend coefficients of rainfall values and RDI value temporal trend in different time scales.

3.3.1 Rainfall data

For the 10-year MP, the values of P(N/P) changed from 0.2 (Lar) to 0.64 (Lamerd) for autumn time scale, from 0.11 (Darab) to 0.67 (Kazeroon) for winter time scale, from 0.23 (Abadeh and Lar) to 0.33 (Lamerd) for spring time scale, and from 0.1 (Shiraz) to 0.5 (Doroodzan) for annual time scale (Table 6). In this MP and the northern stations of the study area, the minimum P(N/P) was obtained on the spring time scale. In the southern stations of the study area, this minimum was obtained on the winter time scale and sometimes on the annual time scale. The maximum P(N/P) in the northern stations of the study area was obtained on the winter and annual time scales, and in the southern stations of the study area, this maximum value was obtained on the autumn time scale and sometimes on the winter time scale. The occurrence of the minimum values was because the number of MPs in which the positive state of trend became negative was less on the spring and autumn time scales (for the northern stations) and the winter and annual time scales (for the southern stations). The occurrence of the maximum values was because the number of MPs in which the positive state of trend became negative was more on the winter and annual time scales (for the northern stations) and on the autumn and winter time scales (for the southern stations). The values of P(N/N) for the 10-year MP changed from 0.42 (Lamerd) to 0.83 (Abadeh) for autumn time scale, from 0.75 (Zarghan) to 0.93 (Darab and Lamerd) for winter time scale, from 0.60 (Fasa and Darab) to 0.79 (Lamerd) for spring time scale, and from 0.73 (Doroodzan) to 0.85 (Lamerd) for annual time scale (Table 7). Minimum values of P(N/N) occurred on the autumn and spring time scales, and maximum values of this transition probability occurred on the winter and annual time scales, except Abadeh station that in this station occurred on the autumn time scale. The values of P(N/N) were greater than the values of P(N/P) indicatiing a greater number of negative-to-negative transitions than positive to negative. This shows the stability of the trend of decreasing rainfall changes in the 10-year MP.

For the 15-year MP, the values of P(N/P) changed from 0.30 (Abadeh) to 0.67 (Fasa) for autumn time scale, from 0.00 (Darab and Lamerd) to 0.25 (Lar) for winter time scale, from 0.00 (Lar) to 0.38 (Doroodzan) for spring time scale, and from 0.00 (Darab) to 0.67 (Zarghan) for annual time scale. The minimum P(N/P) was obtained on the spring time scale in all stations except Darab and Lamerd stations (located in the southern part of the study area); in these stations it occurred on the winter and annual time scales. The maximum value of this transition probability in the northern stations of the study area occurred on the annual time scale, and in the southern stations of the study area, it was obtained on the autumn time scale. The values of P(N/N) for 15-year MP changed from 0.00 (Lar) to 0.75 (Abadeh) for autumn time scale, from 0.85 (Abadeh) to 1.00 (Doroodzan, Zarghan and Kazeroon) for winter time scale, from 0.40 (Abadeh) to 0.89 (Lar) for spring time scale, and from 0.60 (Abadeh) to 0.94

Table 6

Transition probability of positive-to-negative TCC for rainfall (P(N/P))

	10 years				15 years				20 years			
	Autumn	Winter	Spring	Annual	Autumn	Winter	Spring	Annual	Autumn	Winter	Spring	Annual
Abadeh	0.27	0.30	0.23	0.30	0.30	0.20	0.17	0.50	0.67	0.50	0.10	0.33
Doroodzan	0.40	0.38	0.27	0.50	0.44	–	0.38	0.50	0.67	–	0.17	1.00
Zarghan	0.36	0.57	0.25	0.38	0.45	–	0.22	0.67	0.71	–	0.25	1.00
Shiraz	0.33	0.50	0.25	0.10	0.50	–	0.22	–	0.75	–	0.33	–
Fasa	0.38	0.33	0.31	0.18	0.67	–	0.27	–	0.57	–	0.10	1.00
Kazeroon	0.33	0.67	0.27	0.38	0.50	–	0.27	–	0.75	–	0.14	–
Darab	0.50	0.11	0.31	0.40	0.50	0.00	0.22	0.00	0.38	0.00	0.20	0.00
Lar	0.20	0.38	0.23	0.17	0.31	0.25	0.00	0.17	0.20	0.00	0.00	0.00
Lamerd	0.64	0.13	0.33	0.20	0.45	0.00	0.25	0.25	0.18	0.00	0.00	0.00

Table 7

Transition probability of negative-to-negative TCC for rainfall (P(N/N))

	10 years				15 years				20 years			
	Autumn	Winter	Spring	Annual	Autumn	Winter	Spring	Annual	Autumn	Winter	Spring	Annual
Abadeh	0.83	0.77	0.70	0.77	0.75	0.85	0.40	0.60	0.57	1.00	0.67	0.71
Doroodzan	0.69	0.80	0.75	0.73	0.56	1.00	0.70	0.94	0.57	1.00	0.86	1.00
Zarghan	0.67	0.75	0.73	0.80	0.29	1.00	0.67	0.87	0.33	1.00	0.89	1.00
Shiraz	0.79	0.82	0.73	0.83	0.60	0.94	0.67	0.94	0.78	1.00	0.71	1.00
Fasa	0.80	0.86	0.60	0.82	0.67	0.94	0.43	0.94	0.50	1.00	0.67	1.00
Kazeroon	0.79	0.90	0.75	0.80	0.60	1.00	0.57	0.94	0.78	1.00	0.83	1.00
Darab	0.62	0.93	0.60	0.69	0.44	0.93	0.67	0.94	0.40	0.92	0.75	0.92
Lar	0.63	0.80	0.70	0.82	0.00	0.86	0.89	0.83	0.33	0.91	0.88	0.90
Lamerd	0.42	0.93	0.79	0.85	0.29	0.93	0.86	0.86	0.00	0.91	0.89	0.91

(Doroodzan, Shiraz, Fasa, Kazeroon, and Darab) for annual time scale. Minimum values of P(N/N) occurred on the autumn time scale in all of the stations except Abade, Fasa, and Kazeroon stations; in these they occurred on the spring time scale. The maximum values of this transition probability occurred on the winter and annual time scales except Lar station; in this station they occurred on the spring time scale.

For the 20-year MP, the values of P(N/P) changed from 0.18 (Lamerd) to 0.75 (Shiraz and Kazeroon) for autumn time scale, from 0.00 (Darab, Lar and Lamerd) to 0.50 (Abadeh) for winter time scale, from 0.00 (Lar and Lamerd) to 0.33 (Shiraz) for spring time scale, and from 0.00 (Darab, Lar and Lamerd) to 1.00 (Doroodzan, Zarghan and Fasa) for annual time scale. The minimum P(N/P) was obtained on the spring time scale in all stations except Darab, Lar, and Lamerd stations (located in the southern of the study area); in these stations it occurred on the winter time scale. The maximum value of this transition probability in the northern stations of the study area occurred on the annual time scale; in the southern stations, it was obtained on the autumn time scale. The values of P(N/N) for 20-year MP changed from 0.00 (Lar) to 0.78 (Shiraz and Kazeroon) for autumn time scale, from 0.00 (Lar and Lamerd) to 1.00 (Abadeh, Doroodzan, Zarghan, Shiraz, Fasa, and Kazeroon) for winter time scale, from 0.67 (Abadeh and Fasa) to 0.89 (Zarghan and Lamerd) for spring time scale, and from 0.71 (Abadeh) to 1.00 (Doroodzan, Zarghan, Shiraz, Fasa and Kazeroon) for annual time scale. Minimum values of P(N/N) occurred on the autumn time scale in all of the stations except Shiraz; in this station they occurred on the spring time scale. The maximum values of this transition probability occurred on the winter and annual time scales.

As the MP increases from 10 to 20 years, the number of the stations where the minimum value of P(N/P) occurred on the spring time scale and the number of the stations in which the maximum value of P(N/P) occurred on the autumn time scale were increased. For P(N/N), by increasing MP from 10 to 20 years, the number of the stations where the minimum value of P(N/N) occurred on the autumn time scale and the number of stations in which the maximum value of P(N/P) occurred on the winter time scale were increased. In fact, the reason for this was that with the lengthening of the MP, these minimum and maximum values became more visible in the mentioned time scales.

3.3.2 RDI data

For the 10-year MP, the values of P(N/P) changed from 0.07 (Kazeroon) to 0.33 (Doroodzan) for autumn time scale, from 0.2 (Kazeroon) to 0.75 (Fasa) for winter time scale, from 0.15 (Fasa) to 0.3 (Lamerd) for spring time scale, and from 0.00 (Lar) to 0.60 (Zarghan) for annual time scale (Table 8). In this MP, the minimum P(N/P) occurred on the autumn time scale, except in Doroodzan and Fasa; in these stations it occurred on the spring time scale. The maximum P(N/P) in the northern stations of the study area was obtained on the annual time scale; in the southern stations of the study area, it was obtained on the winter time scale. The occurrence of the minimum values was due to the fact that the number of MPs in which the positive change trend became negative was less on the autumn and spring time scales. The occurrence of the maximum values was due to the fact that the number of MPs in which the positive change trend became negative was more on the annual time scale (for the northern stations) and on the winter time scale (for the southern stations). The values of P(N/N) for 10-year MP changed from 0.20 (Fasa) to 0.82 (Lar) for autumn time scale, from 0.69 (Lar) to 0.85 (Kazeroon) for winter time scale, from 0.70 (Shiraz) to 0.87 (Kazeroon) for spring time scale, and from 0.64 (Doroodzan) to 0.90 (Lar) for annual time scale (Table 9). Minimum values of P(N/N) occurred on the autumn and annual time scales, except in Lar, where it occurred in winter in this station, and maximum values of this transition probability occurred on the winter and annual time scales, except in Kazeroon station, where it occurred on the spring time scale. The values of P(N/N) were greater than those of P(N/P), which indicated a greater number of negative-to-negative transitions than positive to negative. This shows the stability of the trend of decreasing rainfall changes in the 10-year MP.

Table 8

Transition probability of positive-to-negative TCC for the RDI (P(N/P))

	10 years				15 years				20 years			
	Autumn	Winter	Spring	Annual	Autumn	Winter	Spring	Annual	Autumn	Winter	Spring	Annual
Abadeh	0.23	0.29	0.25	0.40	0.10	0.29	0.22	0.67	0.20	0.50	0.20	0.50
Doroodzan	0.33	0.43	0.27	0.44	0.14	0.20	0.00	–	0.18	–	0.00	–
Zarghan	0.25	0.50	0.25	0.60	0.11	0.50	0.25	–	0.00	–	0.00	1.00
Shiraz	0.13	0.60	0.17	0.30	0.00	1.00	0.17	0.50	0.11	–	0.00	0.00
Fasa	0.17	0.75	0.15	0.22	0.00	0.67	0.33	1.00	0.00	–	0.25	–
Kazeroon	0.07	0.20	0.25	0.57	0.08	1.00	0.33	1.00	0.00	1.00	0.00	–
Darab	0.13	0.60	0.18	0.44	0.15	1.00	0.00	0.20	0.00	–	0.00	0.25
Lar	0.08	0.57	0.27	0.00	0.00	0.75	0.00	0.00	0.00	0.00	0.00	0.00
Lamerd	0.21	0.43	0.30	0.33	0.25	1.00	0.60	0.33	0.20	–	0.00	0.00

Table 9

Transition probability of negative-to-negative TCC for the RDI (P(N/N))

	10 years				15 years				20 years			
	Autumn	Winter	Spring	Annual	Autumn	Winter	Spring	Annual	Autumn	Winter	Spring	Annual
Abadeh	0.80	0.81	0.73	0.67	0.88	0.82	0.78	0.87	0.33	1.00	0.88	1.00
Doroodzan	0.50	0.81	0.75	0.64	0.50	0.92	0.88	0.94	0.00	1.00	0.92	1.00
Zarghan	0.43	0.73	0.73	0.78	0.89	0.93	0.80	0.94	0.83	1.00	0.90	1.00
Shiraz	0.71	0.83	0.70	0.69	0.88	0.88	0.83	0.88	0.50	1.00	0.90	0.92
Fasa	0.20	0.84	0.80	0.79	0.00	0.80	0.83	0.88	–	1.00	0.89	1.00
Kazeroon	0.75	0.85	0.87	0.75	0.60	0.94	0.93	0.88	0.67	1.00	0.92	1.00
Darab	0.57	0.83	0.83	0.71	0.40	0.81	0.92	0.85	–	1.00	0.90	0.89
Lar	0.82	0.69	0.75	0.90	0.88	0.71	0.91	0.89	0.80	0.92	0.89	0.89
Lamerd	0.56	0.75	0.77	0.82	0.50	0.81	0.69	0.87	0.00	1.00	0.91	0.92

For the 15-year MP, the values of P(N/P) changed from 0.00 (Shiraz, Fasa, and Lar) to 0.25 (Lamerd) for autumn time scale, from 0.20 (Doroodzan) to 1.00 (Shiraz, Kazeroon, Darab and Lamerd) for winter time scale, from 0.00 (Doroodzan, Darab and Lar) to 0.60 (Lamerd) for spring time scale, and from 0.00 (Lar) to 1.00 (Fasa and Kazeroon) for annual time scale. The minimum P(N/P) occurred on the autumn time scale in all stations except Doroodzan and Darab stations (located in the southern of the study area), where it occurred on the spring time scales. The maximum value of P(N/P) occurred on the winter time scale, except in Abadeh and Fasa stations, where it occurred on the annual time scales. The values of P(N/N) for 15-year MP changed from 0.00 (Fasa) to 0.89 (Zarghan) for autumn time scale, from 0.71 (Lar) to 0.94 (Kazeroon) for winter time scale, from 0.69 (Lamerd) to 0.93 (Kazeroon) for spring time scale, and from 0.85 (Darab) to 0.94 (Doroodzan and Zarghan) for annual time scale. Minimum values of P(N/N) occurred on the autumn time scale in all of the stations except Abade, Zarghan, and Shiraz stations, where they occurred on the spring time scale, and Lar station, where they occurred on the winter time scale. The maximum values of this transition probability occurred on the annual and annual time scales except in Abadeh, Kazeroon, Darab and Lar stations, where they occurred on the autumn, winter, spring, and spring time scales, respectively.

For the 20-year MP, on the autumn time scale, P(N/P) values were equivalent to zero in all of the stations except Abadeh, Doroodzan, Shiraz, and Lamerd stations; in these, it was 0.20, 0.18, 0.11, and 0.20, respectively. On the winter time scale, this value was undefined in all of the stations because of zero number of positive TCC state, except in Abadeh, Kazeroon and Lar stations. In these, it was equivalent to 0.50, 1.00, and 0.00, respectively. On the spring time scale, P(N/P) values were equivalent to zero in all of the stations except Abadeh and Fasa stations; in these, it was equivalent to 0.20 and 0.25, respectively. On the annual time scale, it was equivalent to zero in Shiraz, Lar, and Lamerd stations, was undefined in Doroodzan, Fasa, and Kazeroon stations, and was equivalent to 0.50, 1.00, and 0.25 in Abadeh, Zarghan, and Darab stations, respectively. The values of P(N/N) for 20-year MP, on the autumn time scale, were undefined in Fasa and Darab stations and changed from 0.00 (Doroodzan and Lamerd) to 0.83 (Zarghan) for other stations. This value was equivalent to 1.00 for all of the stations, except Lar station, where it was equivalent to 0.92. On the spring time scale, this value changed from 0.88 (Abadeh) to 0.92 (Doroodzan and Kazeroon), and on the annual time scale, it was 1.00 in all of the stations except Shiraz, Darab, Lar, and Lamerd stations, where this value was 0.92, 0.89, 0.89, and 0.92, respectively. Minimum values of P(N/N) occurred on the autumn time scale in all of the stations except Fasa and Darab stations, where they occurred on the spring and annual time scale, respectively. The maximum values of this transition probability occurred on the winter and time scales.

In general, for both rainfall and RDI data analysis, the values of P(N/N) were greater than P(N/P) because the number of negative-to-negative state transitions was higher than positive-to-negative state transitions.

3.4. *Spatial variation of TCCs*

To study the spatial variations of the TCCs, these changes were plotted for moving periods of 10 (MP1 to MP24), 15 (MP1 to MP19), and 20 years (MP1 to MP14). To save space, only the results for the 10- (MP1, MP12 and MP24) and 20-year (MP1, MP7, and MP14) moving periods are shown in Figs. 6, 7, and 8.

3.4.1 *Rainfall*

According to the 10-year moving period analysis in the northern half of the study area and for the winter time scale from MP1 to MP15, the number of trend coefficients decreased, and from MP15 to MP21, these values increased and did so again from MP21 to MP24; these coefficients reduced so that the values for recent MPs were negative (Fig. 6). In the southern half of the study area, where the altitude was lower than for the northern stations, on the winter time scale from MP1 to MP9, the values of trend coefficients decreased and increased from MP9 to 21 and decreased again from period MP21 to 24. Although the values of trend coefficients in recent periods were positive, they were decreasing.

On the autumn time scale, the changes in the northern stations were similar to winter, but in the southern stations, they were sometimes inverse to winter. On the spring time scale and in the stations of the northern half, the changes up to MP7 were similar to winter, but after that the changes were almost the opposite of winter, and in the southern stations up to MP14 the changes were similar to winter but from then on were almost the opposite of winter. The changes in trend coefficients related to the annual time scale in all stations were similar to the winter time scale.

With the lengthening of the moving period and for winter time scale in the 15- and 20-year mobile time period, in the northern half of the study area stations up to the MP15 and MP12, respectively, and in the southern half of the study area stations, up to the MP9 and MP4, respectively, the coefficients were decreasing and then increasing (Figs. 7 and 8). Changes in trend coefficients on the autumn and annual time scales were almost similar to the winter time scale, but the changes on the spring time scale, especially in recent periods, were the opposite of the winter time scale.

3.4.2 *RDI index*

In the 10-year moving period and on the winter time scale, the TCCs of the RDI index in the northern half of the study area were increased up to MP9 and MP10, then decreased to MP15 to MP17, and then increased (Fig. 6). In the southern half of the study area, the values of these coefficients were decreasing to MP5, from MP5 to MP9 were increasing, from MP9 to MP15 were decreasing, and after that were increasing. The changes in the coefficients related to annual time scale were similar to the winter time scale. Autumn and spring time scale changes in the northern half of the study area were contrary to the winter and annual time scale and in the southern half stations the spring time scale changes were almost the same as for the winter time scale, but the autumn time scale changes were contrary to the winter time scale.

With the extension of the moving period to 15 years, the values of trend coefficients for the winter time scale in all stations except Lar and Lamerd stations, which are the southernmost stations of the study area, up to the MP15 to MP17 were decreasing and then increasing (Fig. 7). At Lar and Lamerd stations the variations of these coefficients were generally increasing. As the moving period extended to 20 years, the values of trend coefficients for the winter time scale in the northern stations of the study area decreased (Fig. 8). In Fasa and Darab stations,

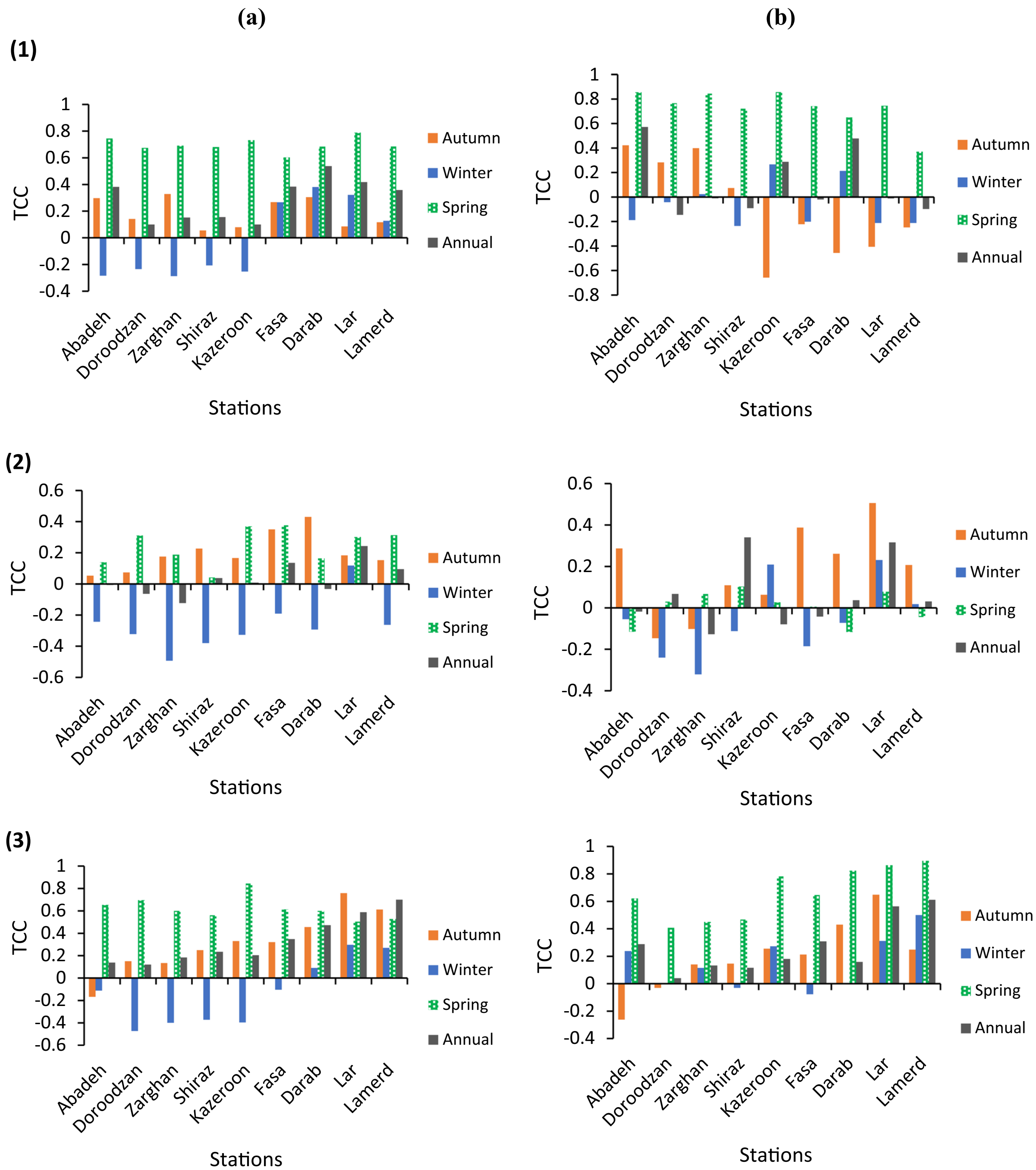

Figure 6
Spatial variations of TCCs of rainfall (**a**) and RDI (**b**) values in different time scales for 10-year moving period: (1): MP1; (2): MP12; (3): MP24

which are located in the southern half of the study area (upper part of the southern half), these changes did not have a specific trend, but in Lar and Lamerd stations, which are the southernmost stations of the study area, the change trend in these coefficients was increasing.

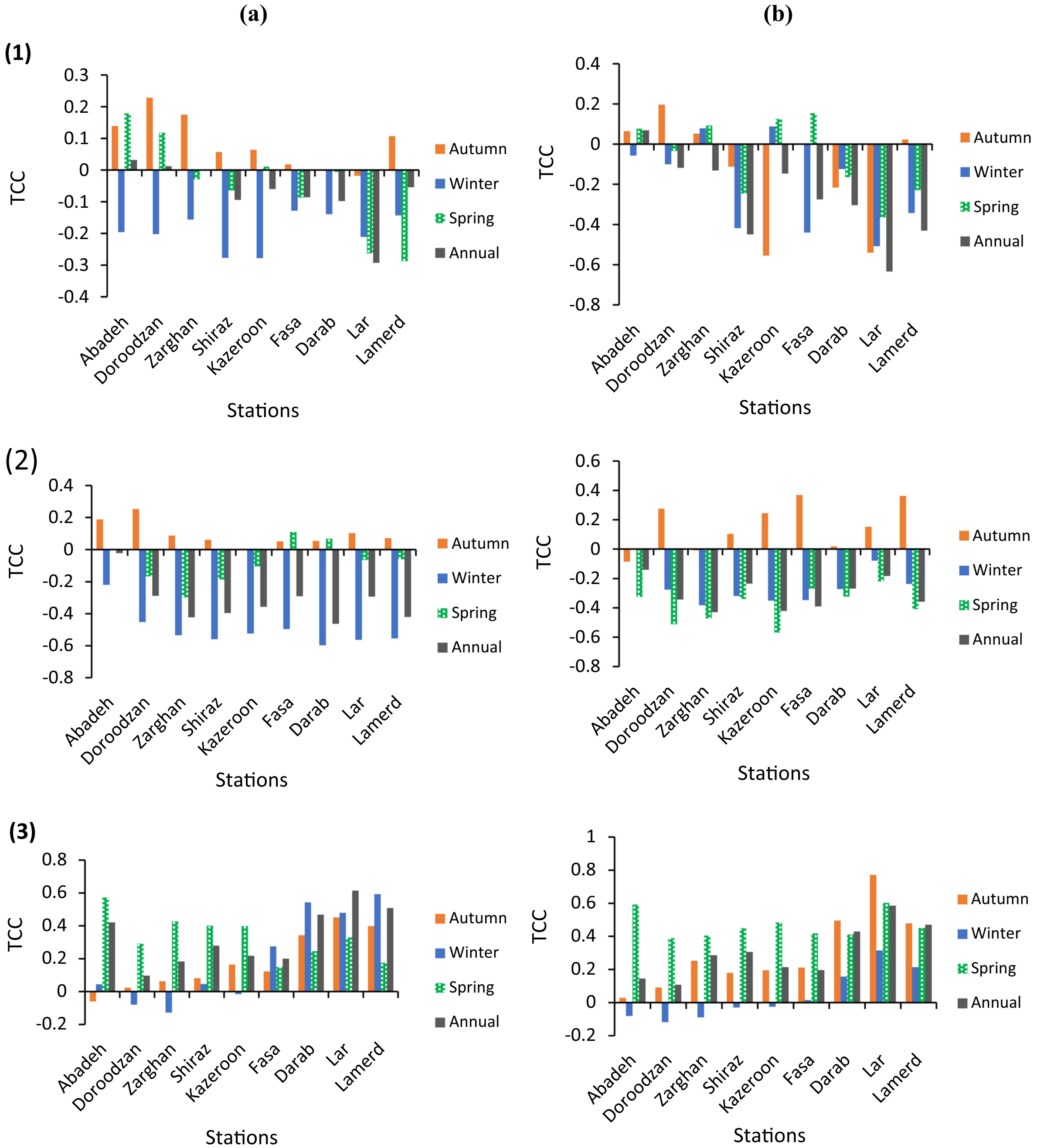

Figure 7
Spatial variations of TCCs of rainfall (**a**) and RDI (**b**) values in different time scales for 15-year moving period: (1): MP1; (2): MP9; (3): MP19

The change trend on the autumn time scale was somewhat similar to winter (MP7 to MP10), and since then it has been contrary to the winter time scale, which was more evident in the northern stations. The trend of annual time scale changes was similar to winter, and the trend of spring time scale changes was almost similar to winter except for recent periods, which were sometimes contrary to winter time scale.

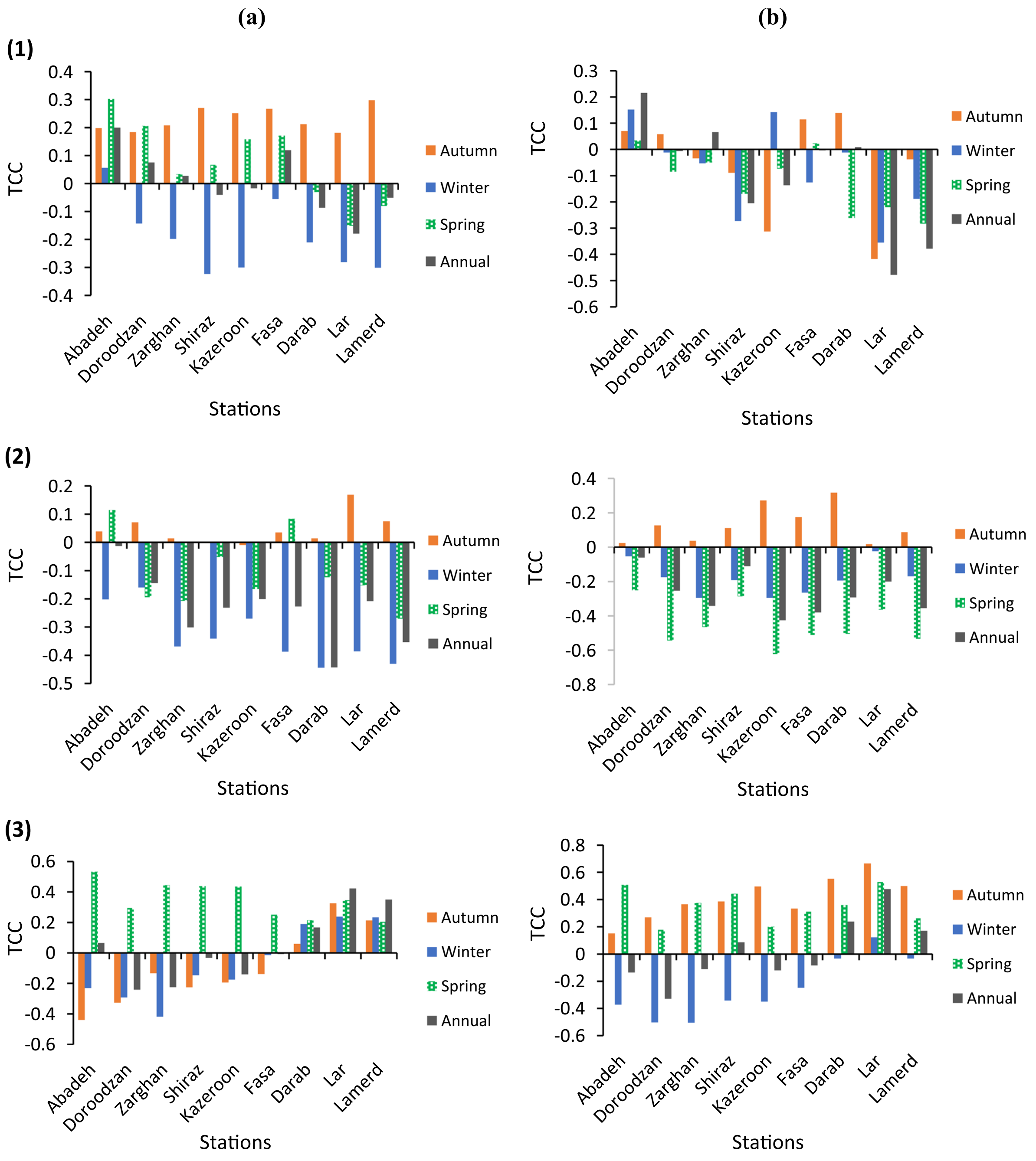

Figure 8
Spatial variations of TCCs of rainfall (**a**) and RDI (**b**) values in different time scales for 20-year moving period: (1): MP1; (2): MP7; (3): MP14

4. Conclusion

In this research trend analysis of rainfall and drought, the RDI index was considered for all available data (1988–2020) and in different MPs (10, 15, and 20 years). These considerations were applied at different time scales (seasonal and annual). Trend analysis of TCCs was also performed to consider the trend changes from one moving interval to another.

- Temporal trend analysis of all available data series of rainfall and RDI showed an increasing trend of precipitation changes on the autumn and spring time scales. In contrast, on the winter and annual time scales, the change trend in rainfall was decreasing in all stations.
- To evaluate the sustainability of drought, the same studies were performed for 10, 15, and 20 year MPs, which was one of the main objectives of this study. When analyzing trend changes of rainfall and RDI in different MPs (10, 15, and 20 years), the changes in trend coefficients for winter and annual time scales were similar at all of the studied stations. For RDI, the changes in the trend coefficients related to the autumn and spring were also similar, but for rainfall, the changes in trend coefficients of the autumn time scale were often similar to winter and annual in all stations except the stations in the south of the study area (Fars Province). Also, the changes in trend coefficients of spring time scale were often the opposite of winter and annual time scale changes in all stations. The mentioned inconsistency decreases with an increasing length of the MP from 10 to 20 years.
- Considering the temporal trend of TCCs of rainfall, on the autumn, winter and annual time scales, the change trend in temporal trend was decreasing for the stations located in the northern half of the study area and increasing in the southern half at all of the MPs. On the spring time scale, the change trend was positive in all stations. In 15- and 20-year MPs, the value of correlation coefficients and number of the station with significant coefficients increased significantly compared to the 10-year MP.
- Considering RDI trend of temporal TCCs on the autumn and spring time scales, these coefficients were positive for all of the studied stations and MPs. These coefficients were significant in the two mentioned time scales in 15- and 20-year MPs. In 10-year MPs, on the autumn time scale and only in the southern stations of the study area, these coefficients were significant. In general, with an increasing length of MP, the values of decreasing and increasing coefficients became higher.
- To check the stability of the trend change process, transition probabilities of the first-order Markov chain with two states (positive and negative trend coefficients of temporal trend) were calculated. For rainfall data, for all the MPs in the northern stations of the study area, generally, the minimum and maximum P(N/P) were obtained on the spring and annual time scales, respectively, and in the southern stations of the study area, these values were obtained on the winter and autumn time scales, respectively. For RDI data, the minimum and maximum P(N/P) occurred on the autumn and winter time scales. Minimum values of P(N/N) occurred on the autumn and spring time scales and the maximum values of P(N/N) occurred on the winter and annual time scales for rainfall and RDI data. The values of P(N/N) were greater than the values of P(N/P) that indicated a greater number of negative-to-negative transitions than positive to negative, which indicated the stability of the trend of decreasing rainfall changes in different MPs especially at 10 years. With the lengthening of the MP, these minimum and maximum values became more visible in the mentioned time scales.
- The limitation of this research was the limited statistical period available, which suggests that this research could be conducted with longer statistical periods and in different climates.

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Data availability

The data used in this research was available on the Fars province meteorological organization site (www.farsmet.ir).

Declarations

Conflict of interest The authors declare no conflict of interest.

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