

# Investigation of spatial and temporal variability of precipitation in Iran over the last half century

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**Abstract** Investigation of the precipitation phenomenon as one of the most important meteorological factors directly affecting access to water resources is of paramount importance. In this study, the precipitation concentration index (PCI) was calculated using annual precipitation data from 34 synoptic stations of Iran over a 50-year period (1961–2010). The trend of precipitation and the PCI index were analyzed using the Mann–Kendall test after removing the effect of autocorrelation coefficients in annual and seasonal time scales. The results of zoning the studied index at annual time scale revealed that precipitation concentration follows a similar trend within two 25-year subscales. Furthermore, the PCI index in central and southern regions of the country, including the stations of Kerman, Bandarabbas, Yazd,

Zahedan, Shahrekord, Birjand, Bushehr, Ahwaz, and Esfahan indicates a strong irregularity and high concentration in atmospheric precipitations. In annual time scale, none of the studied stations, had shown regular concentration ( $PCI < 10$ ). Analyzing the trend of PCI index during the period of 1961–2010 witnessed an insignificant increasing (decreasing) trend in 16 (15) stations for winter season, respectively, while it faced a significant negative trend in Dezful, Saghez, and Hamedan stations. Similarly, in spring, Kerman and Ramsar stations exhibited a significant increasing trend in the PCI index, implying significant development of precipitation concentration irregularities in these two stations. In summer, Gorgan station showed a strong and significant irregularity for the PCI index and in autumn, Tabriz and Zahedan (Babolsar) stations experienced a significant increasing (decreasing) trend in the PCI index. At the annual time scale, 50 % of stations experienced an increasing trend in the PCI index. Investigating the changes in the precipitation trend also revealed that in annual time scale, about 58 % of the stations had a decreasing trend. In winter, which is the rainiest season in Iran, about 64 % of stations experienced a decreasing trend in precipitation that caused an increasing trend in PCI index. Comparing the spatial distribution of PCI index within two 25 years sub-periods indicated that the PCI index of the second sub-period increased in the spring time scale that means irregularity of precipitation distribution has been increased. But in the other seasons any significant variations were not observed. Also in the annual time scale the PCI index increased in the second sub-period because of the increasing trend of precipitation.

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## 1 Introduction

Climate change in the current era is a very important environmental challenge. Our understanding of the impacts of human activities on the environment, especially those related to global warming caused by increased greenhouse gases indicates that, most probably, a number of hydro-climatic parameters are changing (Jhajharia et al. 2013). Based on scientific reports, the average temperature of the earth has increased about 0.6 °C over the twentieth century and it is expected that the amount of evaporation continues to rise (Tabari et al. 2011b; Jhajharia et al. 2014a). In this case, the atmosphere would be able to transport larger amounts of water vapor, influencing the amount of atmospheric precipitations (Tabari et al. 2011a). Low precipitation and its severe fluctuations in the daily, seasonal and annual time scales are the intrinsic characteristics of Iran's climates. Regarding the effects of precipitation on water resources such as groundwater level, surface water supplies and snow, utilization of indices for describing its changes seems to be essential. Two important indices are standardized precipitation index (SPI) and precipitation concentration index (PCI). The SPI is a useful index used in many studies, while the PCI index has recently been introduced and noticed. The PCI is a powerful index describing the precipitation time distribution mostly used in the annual time scale. An increase in this index means that the precipitation concentration has had irregular distribution in the region. In addition, PCI is a part of the known index of Fournier. Fournier has a solid background in the analysis of natural systems like soil erosion (Luis et al. 2011). The results of PCI calculation can be used as an alarming instrument in water resources management and environmental planning for coping with floods or erosions (Adegun et al. 2012). This concept can also be used in irrigation planning and design of novel systems. Unbalanced distribution of precipitation can lead to decreased performance of crops in response to decreased humidity storage in the land and increased number of required irrigation periods. In addition, unbalanced distribution of precipitation implies emerging of drought and a precipitation lower than the long-term average can result in dry condition. Since low soil humidity resulting in devastation of vegetation cover (Seyyedi et al. 2014). Consequently, this necessitates protective practices over the watershed to preserve hydraulic structures. Alijani et al. (2008) investigated Iran's precipitation intensities in 90 synoptic stations. They suggested that the precipitation concentration is irregular throughout the country and the stations at Caspian Sea border, Zagors and northeastern mountains have the highest contribution of precipitation and are subject to heavy rainfall. Luis et al. (2011) studied

the average values of annual, seasonal, humid and dry periods of the PCI around Spain for two time periods of 1976–2005 and 1964–1975. The analyses of the two sub-periods indicated significant variations in precipitation in Spain from 1964 to 2005. Adegun et al. (2012) evaluated the PCI index at two seasonal and annual time scales from 1974 to 2011 for two regions in Nigeria. The results showed that 87 and 71 % of the studied years in the first and second regions, respectively, fall into the mean concentration domain. Vali et al. (2013) used the PCI index for considering the precipitation trend in the Pradesh Andhra state from 1981 to 2010 at two annual and seasonal time scales. The results revealed an irregular precipitation trend (with a range from 16 to 35) in this region. Scientists believe that the changes in the concentration of greenhouse gases in response to consumption of fossil fuels have resulted in severe changes in some elements of hydrological cycles such as precipitation in different parts of the world. This has prompted many researchers to study the changes in the trend of different meteorological and hydrological variables (Kumar et al. 2009; Jhajharia et al. 2014a). Nonparametric methods are often used to investigate the trends in hydrological time series. Nonparametric tests are more suitable for data that are not statistically normal or have cut off data. Hirsch et al. (1982) have described the reasons for the application of nonparametric tests in the studies related to trends in detail. These tests can be used if the data time series is serially independent. The effect of the existence of autocorrelation and analysis of trends by using nonparametric tests was evaluated by Hamed and Rao (1998). They presented the theoretical relations for removing the impact of significant autocorrelation and used it for investigating the trend of precipitation and flow time series.

Some researchers reported that the use of the Mann–Kendall test by removing the effect of autocorrelation is more accurate than classic Mann–Kendall test and does not compromise the test power (Kumar et al. 2009; Dinpashoh et al. 2014). Jiang et al. (2007) examined temporal and spatial trend of daily precipitation and monthly streamflow data from 147 stations between 1961 and 2000 in the Yangtze River basin, China. They used The MK and simple regression methods. Their results indicated that there is a significant positive trend in summer precipitation in many stations, particularly in June and July at the center and lower part of the Yangtze river basin in 1990s. The positive trend in the frequency of heavy showers, that has the highest contribution in increasing the summer precipitation in this basin, and the significant positive trend in the flow rate at the center and lower part of the basin have been associated with spatial and temporal precipitation trends and concentrated showers over the past 40 years. They realized that the showers have caused

the most extreme floods at the center and down the basin. Pal Al-Tabbaa (2009) investigated the trend of seasonal partial precipitations in winter, spring, and fall in the Kerala region in India using the MK test. The results showed that the trend of partial precipitations is increasing in winter and fall, resulting in higher incidence of floods in these seasons. However, the precipitation trend was decreasing in spring. Zhang et al. (2010) used the Mann–Kendall test to examine the variations of the parameters of temperature, precipitation, and the flow discharge of the Tarim river basin located in China. They stated that the increasing trend in temperature caused an increasing trend in the flow discharge of the Tarim River by increasing the precipitation and snowmelt in this basin. Yang et al. (2012) studied the trend of temperature and the average monthly precipitation over 53 years in the Zhangweinan river basin and five meteorological stations around it using the Mann–Kendall test. They reported a significant decreasing trend in the annual precipitation and an increasing trend in temperature in summer and spring. (Jain et al. 2013) investigated long-term variations in the precipitation and temperature in Northwestern India using the Mann–Kendall method. They reported that there is no significant trend in the monthly, seasonal, and annual precipitation from 1871 to 2008. However, the temperature experienced an increasing trend at all of the three time scales. Duhan and Pandey (2013) investigated the temporal and spatial variations of precipitation in the Madhya Pradesh region in India for a 102-year period. They used the Mann–Kendall test and Sen’s slope estimator to determine the uniform trend of precipitation and used the Pettitt test to detect probable change points. The results demonstrated that all of the studied stations have experienced a decreasing trend at the annual time scale, when 1978 had the highest probability for the trend changing date. Hosseinzadeh Talaee et al. (2014) investigated homogeneity of annual and monthly precipitation in the 41 synoptic stations of Iran during 1966–2005. Their results showed that the annual series of precipitation were homogeneous based on the Bayesian and Cumulative Deviations tests, while seven stations detected inhomogeneities by the von Neumann test. They also reported that almost all the monthly precipitation series were homogeneous. Chen et al. (2014) used the Mann–Kendall test to investigate the trend in precipitation, temperature, and flow of the Yangtze River basin in China from 1955 to 2011. They observed that the average temperature had an increasing trend, while precipitation did not experience any significant changes and the runoff had an increasing trend. Moradi Dashtpajardi et al. (2015) used the Mann–Kendall test to examine the trend of the standardized precipitation index (SPI) time series in dry and semi-dry regions of Iran from 1975 to 2005. Their results revealed that the trend of SPI index is negative in dry and semi-dry regions of

Iran. Caloiero (2014) used the Mann–Kendall test to examine the precipitation trend of 294 rain gauge stations for a 50-year period in New Zealand. Although no significant trend was observed at these stations, the precipitation trend was decreasing in spring and fall and increasing in winter and spring. Based on the research background, it seems that no comprehensive study has been conducted on concentration of precipitation in Iran. The aim of this study is to calculate the PCI at two seasonal and annual time scales and to investigate its trend over the last half-century.

## 2 Materials and methods

### 2.1 Study area

Iran with an area of over 16,480,000 km<sup>2</sup> is situated in the northern hemisphere and southwest of Asia. Almost all parts of Iran have four seasons. In general, a year can be divided into two warm and cold seasons. Iran with an average annual precipitation of 62.1–344.8 mm is located between two meridians of eastern 44° and 64° and two orbits of northern 40° and 25°. Approximately 94.8 % of the country is arid or semi-arid with low atmospheric precipitation and high evaporation–transpiration. Iran’s climate is influenced by:

1. A Siberian high-pressure system that causes rainfall, snow, and decreased temperature through precipitating in southern widths within the northern band. It brings about only reduced temperature in other areas.
2. Mediterranean rain-bearing system entering from the west causing rainfall or snow in many western, central, and eastern parts of Iran.
3. A low-pressure southern system, causing showers in the southern and southwestern strips.

In this study, 34 stations were selected among more than 200 synoptic stations existing in the country, for investigating the precipitation concentration. The selected stations have at least 50-year (1961–2010) precipitation data and distributed uniformly over the country. Table 1 provides a summary of geographic information and statistical characteristics of precipitation of the selected stations. Figure 1 demonstrates the location of these stations over the country.

### 2.2 PCI index

The PCI index has been proposed as an index of precipitation concentration. The annual and seasonal scales of this index are calculated as Eqs. (1) and (2), respectively (Oliver 1980):

**Table 1** Basic characteristics of the stations used in this study

Station	Latitude	Longitude	Average precipitation (mm)	Elevation (m)	Autumn precipitation (%)	Summer precipitation (%)	Spring precipitation (%)	Winter precipitation (%)
Abadan	30.36	48.25	12.77	6.6	16	0	24	60
Ahwaz	31.33	48.66	18.88	22.5	18	0	22	60
Arak	34.1	49.76	27.53	1708	15	2	41	42
Babolsar	36.71	42.65	47.08	−21	43	11	13	33
Bam	29.1	58.35	4.9	1066.9	5	3	47	45
Bandarabbas	27.21	56.36	14.26	9.8	5	2	27	66
Birjand	32.86	59.2	13.72	1491	7	0	43	50
Bushehr	28.98	50.83	20.49	19.6	16	0	13	71
Dezful	32.4	48.38	32.88	143	15	0	25	60
Esfahan	32.61	66.51	10.11	1550.4	13	2	40	45
Ghazvin	36.25	50.05	26.37	1279.2	16	3	42	39
Gorgan	36.85	54.26	48.13	13.3	30	12	29	29
Hamedan	35.2	48.71	26.83	1679.7	16	3	42	39
Kerman	30.25	56.96	11.34	1753.8	5	1	41	53
Kermanshah	34.35	47.15	37.61	1318.6	19	0	39	42
Khorramabad	33.43	48.28	41.64	1147.8	16	0	37	47
Khoy	38.55	44.96	24.1	1103	20	14	46	20
Mashhad	36.26	59.63	20.97	999.2	10	3	50	37
Ramsar	36.9	50.66	100.51	−20	49	13	16	22
Rasht	37.25	49.6	111.15	36.7	41	11	17	31
Sabzevar	36.2	57.71	15.55	977.6	10	2	41	47
Saghez	36.25	46.26	40.6	1522.8	17	2	43	38
Sanandaj	35.33	47	37.64	1373.4	19	1	41	39
Shahrekord	28.32	50.85	27.67	2048.9	13	1	34	52
Shahrud	36.41	54.95	77.12	1345.3	12	5	47	36
Shiraz	29.53	59.6	26.41	1484	8	1	26	65
Tabass	33.6	56.91	6.85	711	7	0	41	52
Tabriz	38.08	46.28	23.73	1361	21	8	47	24
Tehran	35.68	51.31	19.55	1190.8	15	3	37	45
Torbat Heydarieh	35.26	59.21	22.3	1450.8	7	2	42	49
Urmia	37.53	45.08	27.46	1315.9	22	6	45	27
Yazd	31.9	54.28	4.76	1237.2	7	1	40	52
Zahedan	29.46	60.88	6.59	1370	9	3	32	56
Zanjan	36.68	48.48	25.35	1663	19	6	46	29

$$PCI_{\text{annual}} = \frac{\sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^{12} P_i\right)^2} \times 100 \quad (1)$$

$$PCI_{\text{Seasonal}} = \frac{\sum_{i=1}^3 P_i^2}{\left(\sum_{i=1}^3 P_i\right)^2} \times 25 \quad (2)$$

where  $P_i$  is the amount of monthly precipitation in the  $i$ th month. Based on the proposed formula, the minimum value of theoretical PCI is 8.3, indicating absolute uniformity in the precipitation concentration (i.e. the same amount of precipitation occurs every month). A PCI of 16.7 shows

that the whole precipitation has been concentrated within half of the time period and a value of 25 for this index indicates that the total precipitation occurs within half of the time period (i.e. the total precipitation has occurred within 4 months). According to this classification, Oliver (1980) suggested that PCI values <10 reveal a uniform precipitation distribution (low precipitation concentration). PCI values between 11 and 15 imply a moderate precipitation concentration and the range of 16–20 exhibit irregular precipitation distribution. PCI values >20 represent a strong irregularity in precipitation distribution (high precipitation concentration) (Luis et al. 2011). The PCI



**Fig. 1** Location map of the selected stations in Iran

classification by Oliver (1980) is summarized in Table 2. The results of applying this index in the various climates of the world such as Spain, Nigeria and India showed that the PCI index can be useful in order to investigate the precipitation concentration distribution (Luis et al. 2011; Adegun et al. 2012; Vali et al. 2013).

**2.3 Trend analysis**

The aim of process test is to specify whether an ascending or a descending trend exists in data series. Since parametric tests have some assumptions including normality, stability, and independence of variables, where most of these assumptions do not apply to hydrologic variables, the non-parametric methods are more preferred in meteorological

and hydrological studies. The nonparametric methods are less sensitive to extreme values compared to parametric tests in the examination of trends. Nonparametric tests can also be utilized for data time series regardless of linearity or non-linearity of the trend (Khalili et al. 2014). One of the most well-known nonparametric tests is Mann–Kendall test (Mann 1945; Kendall 1975). Overall, this test has four revisions described by Dinpashoh et al. (2014). In the present study, the third revision that completely removes the auto-correlation effect of time series is used.

**2.3.1 Mann–Kendall test (MK)**

The classic form of Mann–Kendall test (Mann 1945; Kendall 1975) has been used in many studies. If the number of data time series is  $n$  within the studies period, the statistic  $S$  is calculated as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(x_j - x_k) \tag{3}$$

where  $x_j$  is the value of  $j$ th data,  $n$  is the number of observations, and  $\text{sgn}(\theta)$  is the sign function defined as follows:

**Table 2** Classification of PCI index (Oliver 1980)

Condition	Value
Uniform precipitation distribution	<10
Moderate precipitation concentration	11–15
Irregular distribution	16–20
Strong irregularity	>20

$$\text{sgn}(x) = \begin{cases} +1 & \text{if } (x_j - x_k) = 0 \\ 0 & \text{if } (x_j - x_k) > 0 \\ 1 & \text{if } (x_j - x_k) < 0 \end{cases} \quad (4)$$

When  $n \geq 8$ , the statistic  $S$  has a normal distribution, where its mean and variance is calculated as follows:

$$E(s) = 0 \quad (5)$$

$$\text{Var}(S) = \frac{n - (n - 1)(2n + 5) - C}{18} \quad (6)$$

where  $C$  is a factor related to variance correction. If successive repetitive data exist in data series,  $C$  is calculated by the following relation and applied to the variance:

$$C = \sum_{t=1}^m t_i(t_i - 1)(2t_i - 5) \quad (7)$$

where  $t_i$  is the number of tie data within the  $i$ th group. Finally, the MK test statistic ( $Z$ ) is calculated as follows:

$$Z = \begin{cases} \frac{S - 1}{\sqrt{\text{Var}(s)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S + 1}{\sqrt{\text{Var}(s)}} & \text{if } S < 0 \end{cases} \quad (8)$$

The null hypothesis (no trends) is accepted when  $-Z_{1-\alpha/2} \leq Z \leq Z_{1-\alpha/2}$ , otherwise  $H_0$  is rejected and its opposite hypothesis i.e. the existence of a trend is accepted (Dinpashoh et al. 2014).

### 2.3.2 The modified Mann–Kendall test (MMK)

The main assumption of Mann–Kendall test is that the sample data has no significant autocorrelation. However, some hydrological series might have a significant autocorrelation coefficient (Dinpashoh et al. 2014). When a series has a positive autocorrelation coefficient, there is an increased chance for Mann–Kendall test to reveal existence of a trend in this series. In this case, the null hypothesis i.e. lack of trend is rejected, yet this hypothesis should not actually be rejected (Dinpashoh et al. 2014). The modified Mann–Kendall test was presented by Hamed and Rao (1998) and has been used by Kumar et al. (2009) for the analysis of the trend of Indian rivers. In this method, the effect of all significant autocorrelation coefficients is removed from the time series and is applied to series whose autocorrelation coefficients are significant in one or more cases. Here, the modified variance  $V(S)^*$  is calculated as follows:

$$V(S)^* = V(S) \frac{n}{n^*} \quad (9)$$

$$\frac{n}{n^*} = 1 + \frac{2}{n(n-1)(n-2)} \cdot \sum_{i=1}^{n-1} (n-i)(n-i-1)(n-i-2)r_i \quad (10)$$

where  $r_i$  is the  $i$  delayed autocorrelation coefficient and  $V(S)$  is estimated by Eq. (6). To calculate the  $Z$  statistic in the modified Mann–Kendall test in Eq. (8),  $V(S)$  is substituted by  $V(S)^*$ . The value of  $Z$  statistic obtained from the above equation is compared with normal standard  $Z$  at  $\alpha$  significant level.

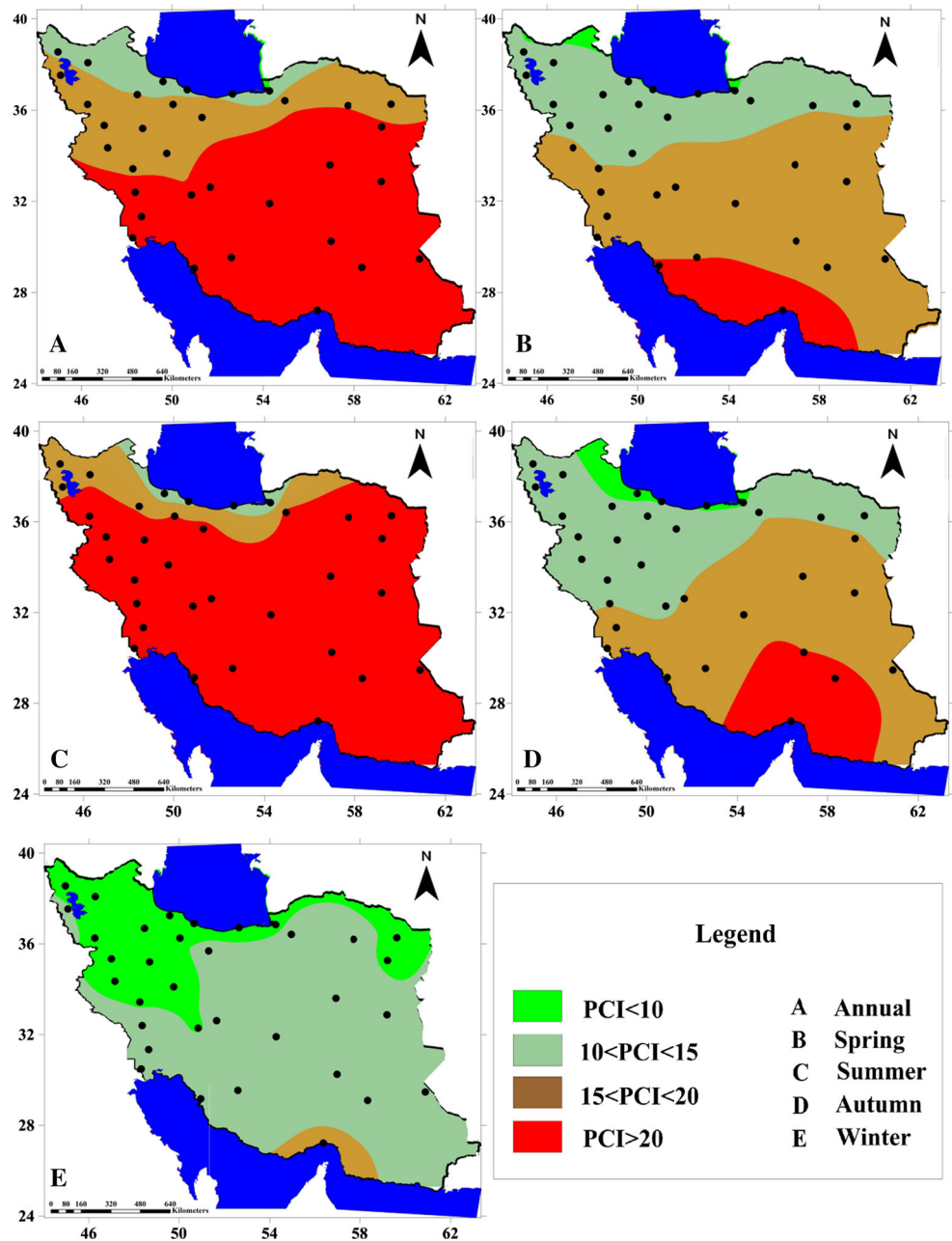
## 3 Results and discussion

The PCI index was calculated using the monthly precipitation of the selected stations at seasonal and annual time scales over a 50-year period. This period was then divided into two 25-year sub-periods for the investigation of changes in average values of PCI. The spatial distribution of PCI index within the two 25-year periods have been presented in Figs. 2 and 3, respectively, for seasonal and annual time scales.

In order to draw zoning maps of PCI values and statistics  $Z$  values of MMK test, the accuracy of Kriging and Inverse Distance Weighted (IDW) methods compared and the Kriging method with higher correlation coefficient between measured and modeled data had better results than Inverse Distance Weighted method that is in accordance with Asong et al. (2015) and Khalili (2014).

In the first 25-year span, the irregular precipitation distribution has been observed in the Bandarabbas station and its surroundings in winter season. In none of the studied stations, highly irregular precipitation occurred. The highest share of PCI relates to the precipitation average distribution class, and the northern, northwestern, and northeastern parts of the country have a uniform precipitation distribution. In winter, within the first 25-year period, the country has had ideal conditions in terms of precipitation and its concentration in the mentioned regions. Within the second 25-year period, the intensity of irregular precipitation concentration decreased, as the regions that had confronted strong precipitation irregularities are now added to regions with uniform concentration. At the seasonal scale and in winter, the country's share of uniform distribution diminished in the second 25 years, and overall most parts of Iran have been covered by average precipitation distribution. The uniform precipitation distribution in recent years (second 25 years) has decreased in winter such that no uniform distribution has been observed in the northeast of the country and uniform distribution belongs to the Caspian sea border strip, southern regions of west and east Azerbaijan stations (Urmia, Khoy and Tabriz stations) along with Kermanshah, Sanandaj, and Zanjan stations. The results of the PCI investigation in the spring revealed that this index indicated a strong irregularity in precipitation concentration around

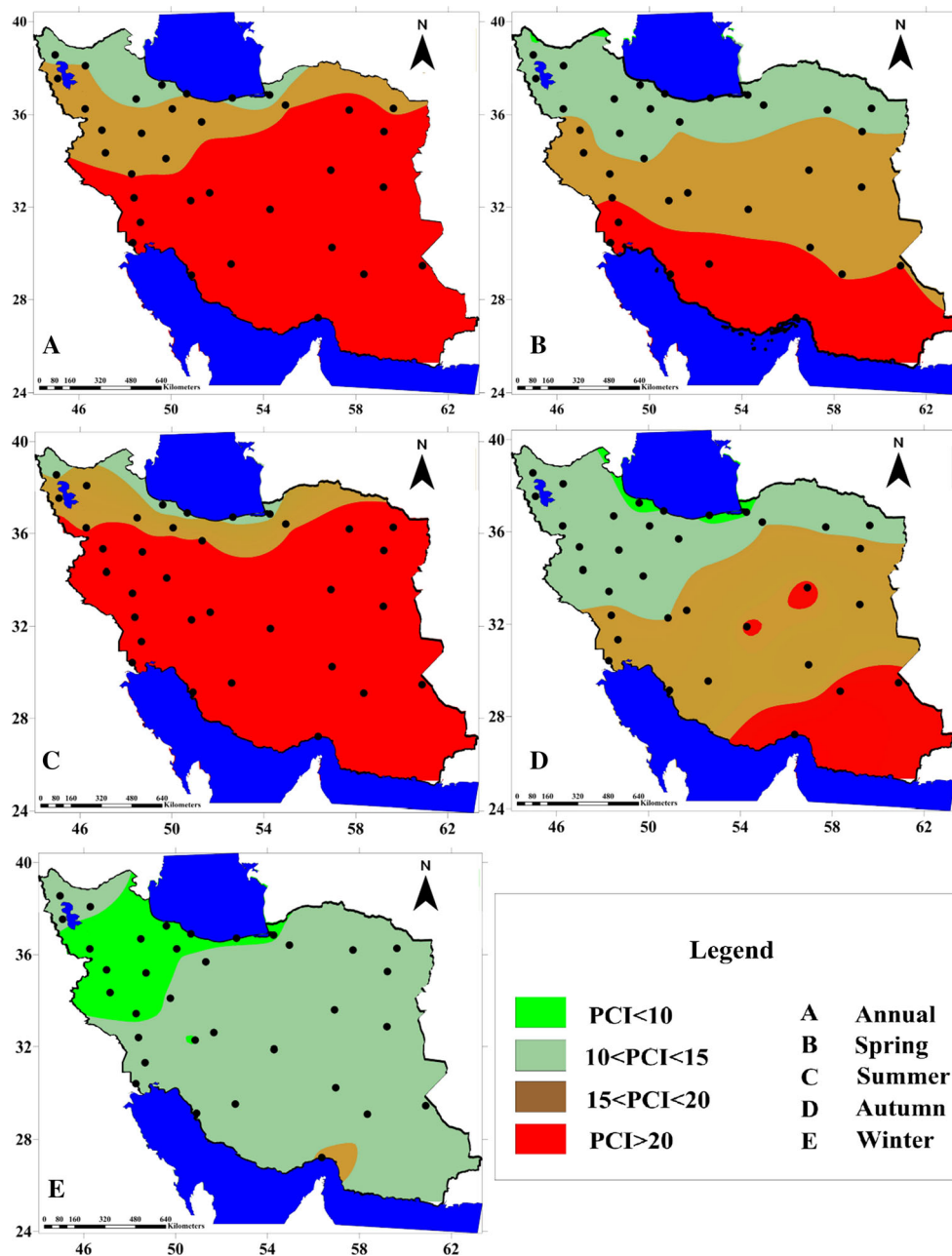
**Fig. 2** Spatial distribution of PCI index in annual and seasonal time scales in the first sub-period of 1961–1986



Persian Gulf borders within the first 25 years. Within the second 25- year period, the regions with non-uniform and irregular have been developed and have covered the entire southern parts of Iran. Central parts of Iran have also irregular precipitation concentration in the spring. Within the first 25 years, uniform precipitation distribution has been observed in Gorgan station in spring, where it changed into a region with moderate precipitation concentration within the second 25- year period. The PCI analysis at the annual time scale exhibited that the stations with highly irregular precipitation have the highest frequency. For further investigations, the 50-year period was divided into

two 25-year sub-periods. The changes in these two sub-periods have been represented as Figs. 2 and 3. Based on the annual results of PCI index, in northern and north-western parts of Iran, the PCI is between 11 and 15 suggesting moderate precipitation concentration in terms of time in these regions. It is also clear that the precipitation concentration in these regions has been maintained around average during the 50-year period in all months of the year. The average precipitation in these regions is more than other regions and almost belongs to stations with high precipitation amounts (Caspian Sea border, Ardabil and western and eastern Azerbaijan). Regions with uniform

**Fig. 3** Spatial distribution of PCI index in annual and seasonal time scales in the second sub-period of 1986–2010

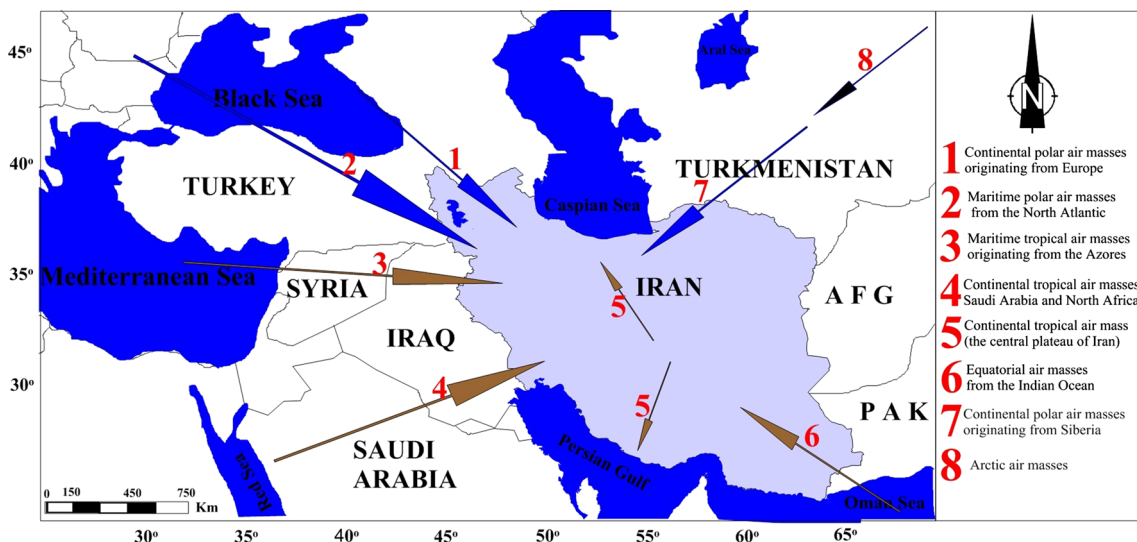


precipitation concentration were accounted for the least number of considered stations. The results of PCI analysis within the studied period revealed that within the last 50 years, precipitation distribution has not been uniform in any stations and only within the first 25 years, the Gorgan station had uniform distribution. In the second 25 years the Gorgan station also experienced moderate irregularities in precipitation.

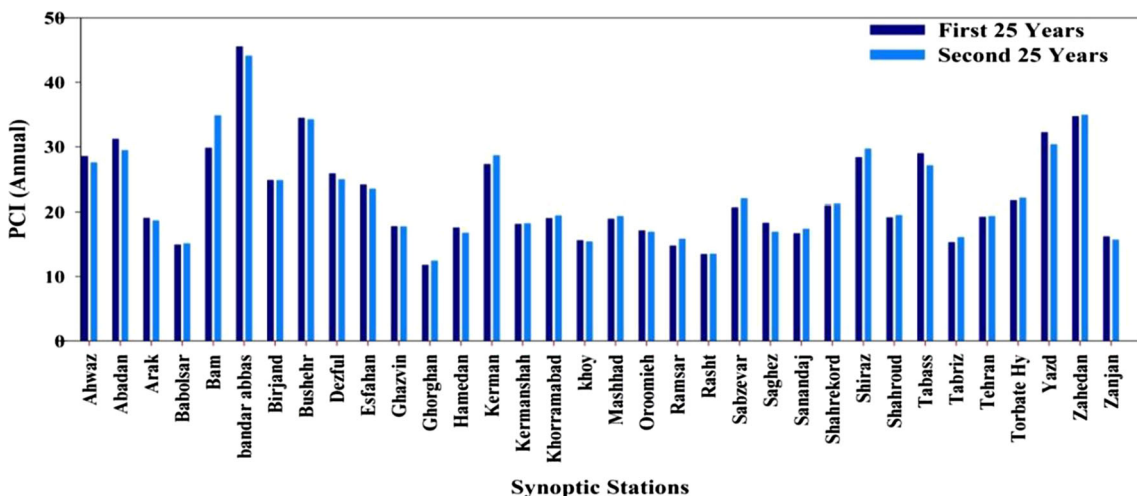
From the results of this study it can be concluded that regions with average precipitation distribution have been influenced by Arctic continental masses originating from Siberia entering from northeast of Iran and southeast of the

Caspian Sea and by continental-polar air masses originating from Europe, and by polar-marine masses coming from the North Atlantic ocean entering from northwest of Iran. But for proving this subject more research needed. Regarding the mentioned air masses and existence of the Zagros Mountains in these regions, the northern and northwestern stations have more regular precipitation than other regions. Within the second 25-years sub-period, the average precipitation concentration has increased in northeastern and northwestern parts of the country. Increased precipitation concentrations in northwestern regions imply improved precipitation in terms of temporal





**Fig. 4** Effective air masses upon Iran in the summer and winter seasons (Atlantic atmospheric and climatic disasters, I.R of Iran meteorological organization)



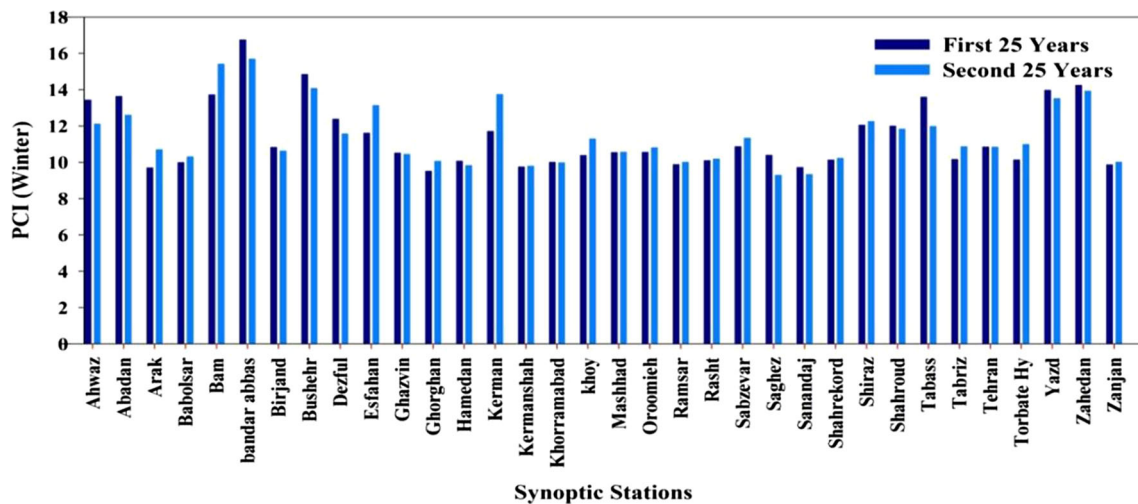
**Fig. 5** Values of annual PCI index for the studied stations of Iran during two 25-years sub-periods

concentration of precipitation in these regions. Irregular precipitation concentration is evident in Korderstan, Kermanshah, Hamedan, Lorestan, Arak, Ghazvin, Tehran, northern Semnan and Razavi Khorasan, southern part of West Azerbaijan, Zanjan, and Northern Khorasan provinces. These regions have been affected by marine tropical air mass. 42 % of the studied stations are faced with severe irregularity in precipitation concentration based on Oliver (1980) classification, including central and southern parts of the country, according to Figs. 2 and 3. Based on Fig. 4, these regions are affected by continental-tropical air masses originating from Saudi Arabia and Northern Africa together with equatorial masses from the Indian Ocean and tropical-continental. The results of this index provide

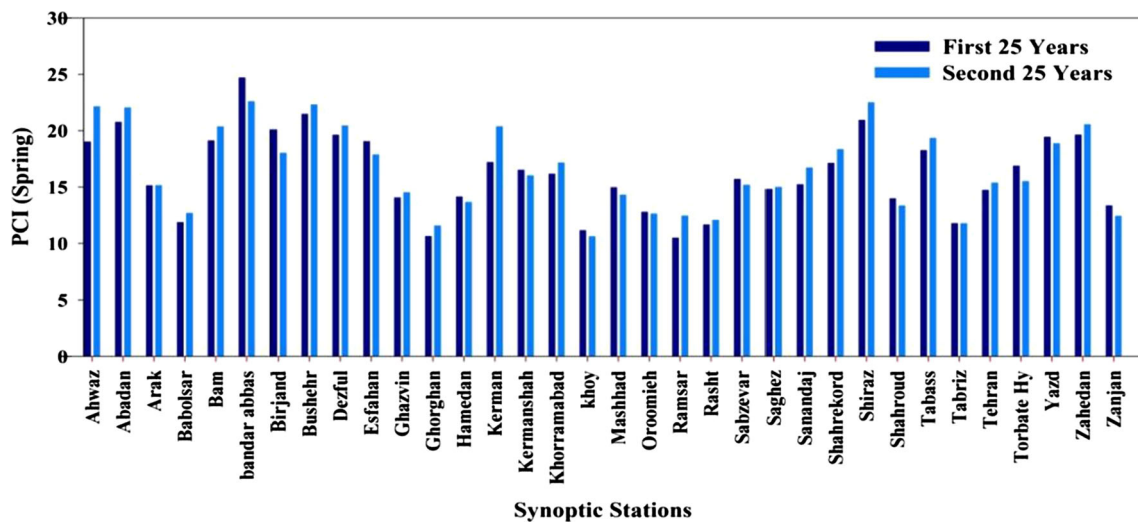
valuable information for water resources managers in regions with low-precipitation (Gozzini et al. 2012).

The PCI values in the annual and seasonal time scales within the two 25-year sub-periods are provided in Figs. 5, 6, 7, 8 and 9. According to Fig. 5, it can be seen that the regions surrounding Caspian Sea border and northwest of the country possess a better concentration compared to other regions in summer. Figure 6 reveals a lower precipitation concentration in central and southern parts of the country. Figures 7, 8 and 9 demonstrate the quantitative values of PCI for winter and spring seasons as well as the annual time scale.

Table 3 provides the results of PCI analysis and precipitation on seasonal and annual time scales (including



**Fig. 6** Values of seasonal (winter) PCI index for the studied stations of Iran during two 25-years sub-periods



**Fig. 7** Values of seasonal (spring) PCI index for the studied stations of Iran during two 25-years sub-periods

four seasonal series and one annual series) for 34 studied stations after removing the effect of all significant auto-correlation coefficients. In this table, bold numbers represent the significance of the trend, where significance levels of 10, 5, and 1 % have been marked by one, two, and three stars (\*), respectively. The results of process test and precipitation will be further presented.

### 3.1 Trend analysis of the PCI

According to Table 3, in winter the Abadan, Ahwaz, Bandarabbas, Birjand, Kermanshah, Sanandaj, Shahroud, Shiraz, Tabass, Urmia, and Zahedan stations experienced an insignificant decreasing trend in PCI, while Dezful, Saghez, and Hamedan stations had a significant decreasing trend. At other stations, an insignificant increasing trend was observed

in the PCI series. Overall, 16 out of 34 considered stations, witnessed increasing PCI trend implying increased irregularities in winter precipitation. In spring the PCI trend in Abadan, Ahwaz, Babolsar, Bam, Bushehr, Gorgan, Ghazvin, Rasht, Sanandaj, Shahrekord, Shiraz, Tabriz, Tehran, and Zahedan sites was also increasing, insignificantly. Kerman and Ramsar stations experienced a significant increasing trend in PCI suggesting heightened irregularities in spring precipitation. According to Table 3, the insignificant decreasing trend in PCI is also observed at other stations implying concentration of spring precipitation in 15 stations of the country. Since in summer and fall the precipitation levels decrease throughout the country, therefore it can be expected that the irregularities in the precipitation also fall down, as evident in Table 3. In summer, the Gorgan station shows a strong irregularity in response to a significant trend

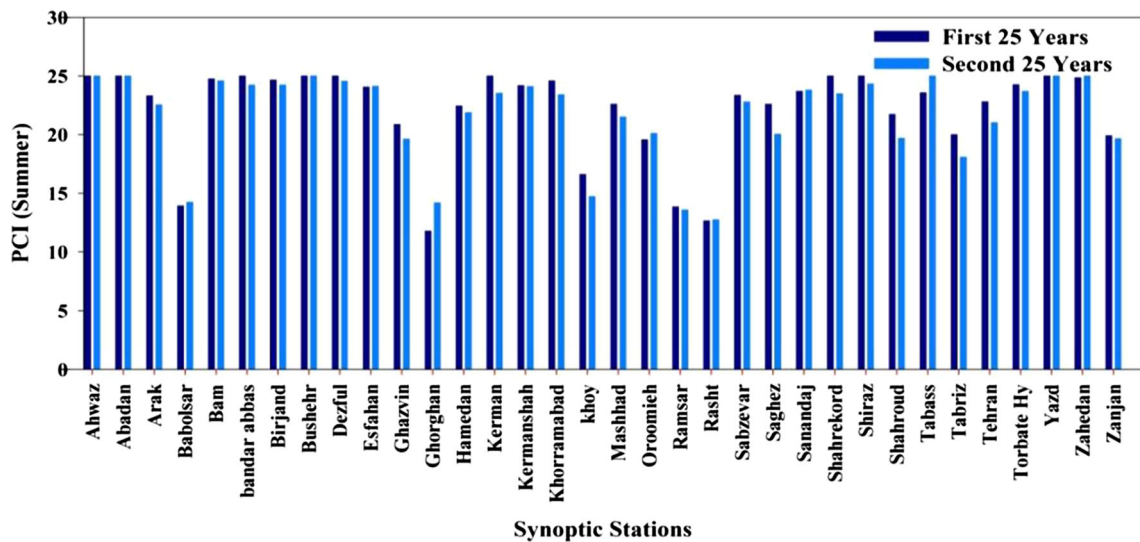


Fig. 8 Values of seasonal (summer) PCI index for the studied stations of Iran during two 25-years sub-periods

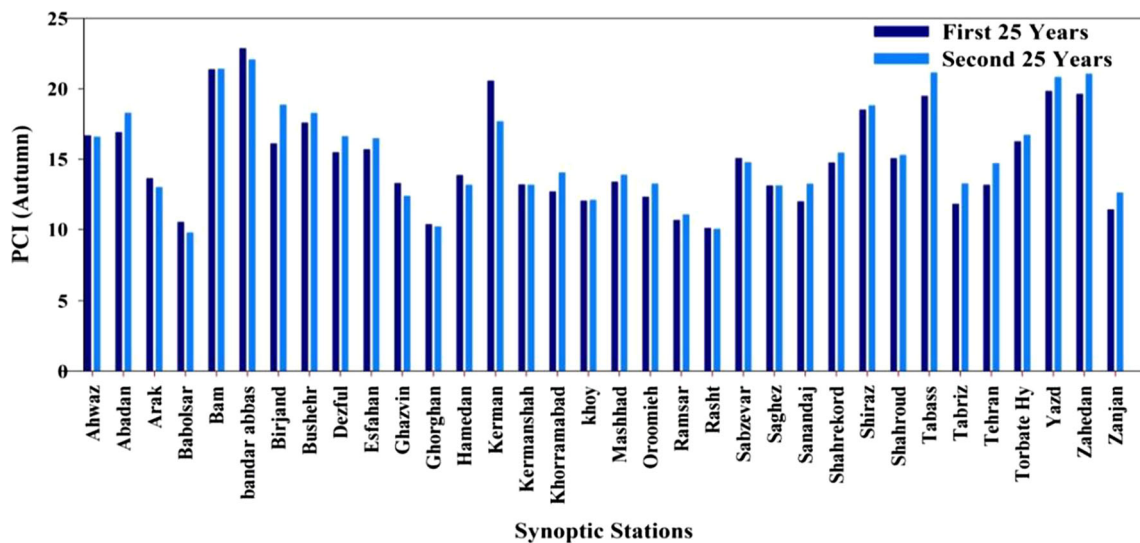


Fig. 9 Values of seasonal (autumn) PCI index for the studied stations of Iran during two 25-years sub-periods

in PCI. In the fall, Tabriz and Zahedan (Babolsar) stations also experienced a significant increasing (decreasing) trend in PCI. At the annual time scale, 50 % of the stations witnessed the increasing trend in PCI, where this developing trend was observed in Bam, Tabriz, and Gorgan stations. Hamedan station also (according to Table 3) reveals a significant decreasing trend in PCI. Figure 10 illustrates the spatial changes in the PCI trend at annual and seasonal scales. At the annual scale, an insignificant decreasing trend in PCI was observed in a vast region of the country, but these changes have an insignificant increasing trend in northeastern, Caspian Sea borders, some parts of northwest and south of the country, revealing increased irregularities in precipitation in these regions. In spring, the PCI trend exhibits an insignificant increase in PCI for southern and Caspian Sea

border regions. In summer and fall, this index is more regular showing an increase in precipitation. In winter, also apart from northeastern parts and regions around the Caspian Sea border, some parts of central and northwestern areas of the country, other regions experienced an improvement in winter precipitation concentration. Figure 10 manifests that the Bam and Gorgan stations show significant increase in precipitation irregularities. The eastern part of Urmia Lake also experienced such an increase, although these changes are not significant. A reduction in precipitation reported by Din-pashoh et al. (2014) substantially influenced the conditions of the region’s water resources. This can even be one the reasons behind Urmia Lake drying, as an increasing trend of PCI means reduced precipitation in a region. Hosseinzadeh Talae et al. (2014) indicated that precipitation series of Iran

**Table 3** Z-Statistic values of seasonal and annual precipitation and PCI using MMK method for Iran (1961–2010)

Stations	Precipitation trend					PCI trend				
	Annual	Autumn	Summer	Spring	Winter	Annual	Autumn	Summer	Spring	Winter
Abadan	0.93	0.2	1.60	-0.75	0.68	0.03	-0.11	0.00	0.76	-1.25
Ahwaz	-0.50	0.7	1.29	-0.68	-0.01	0.5	1.03	0.00	0.45	-0.33
Arak	0.28	<b>1.69*</b>	-1.13	<b>-2.49***</b>	-0.85	-1.12	-1.20	-0.81	-1.19	1.42
Babolsar	1.55	<b>2.29***</b>	-0.95	-0.90	0.41	0.38	-1.80	0.40	0.45	0.63
Bam	-1.33	-0.3	1.42	<b>-2.12**</b>	-0.12	<b>2.19**</b>	0.74	0.09	1.29	1.43
bandar abbas	0.06	0.45	1.34	-0.08	0.06	-0.36	-1.00	-1.73	-1.48	-0.85
Birjand	-0.62	-0.64	1.21	-1.09	0.28	-0.75	1.36	-0.26	-0.98	-1.24
Bushehr	0.83	-0.87	0.69	-0.67	1.33	0.73	0.43	0.00	0.48	0.46
Dezful	-0.4	0.05	1.07	0.07	-0.49	-0.78	0.34	-1.52	-0.24	-1.87
Esfahan	<b>1.78*</b>	0.35	1.83	1.10	<b>1.79*</b>	-0.90	-0.27	-0.14	-0.89	0.63
Gorghhan	<b>-2.36***</b>	-1.37	<b>-2.17**</b>	<b>-3.32***</b>	-1.38	1.90	0.33	<b>3.88***</b>	1.15	1.33
Hamedan	-0.64	0.46	-1.33	-0.97	-0.3	<b>-2.58***</b>	-1.27	-0.87	-1.39	<b>-2.85***</b>
Kerman	<b>-1.90*</b>	1.09	-0.08	-1.57	-0.49	0.71	-1.12	-1.80	<b>1.94**</b>	0.66
Kermanshah	<b>-2.47***</b>	0.02	1.46	<b>-2.07**</b>	-1.45	-0.1	-1.12	-0.32	-0.58	-0.05
Khorramabad	<b>-1.80*</b>	-0.11	1.14	-0.97	-0.92	0.38	0.92	-0.93	0.61	-0.92
khoy	<b>-2.11**</b>	-0.16	-0.11	-1.41	<b>-2.73***</b>	-1.02	0.08	-0.93	-1.02	1.63
Mashhad	-0.05	0.00	0.74	-0.18	0.66	0.03	0.66	-0.90	-1.15	0.55
Qazvin	0.74	1.07	-0.79	0.26	-0.51	-0.90	-1.52	-0.71	0.78	-0.9
Ramsar	-1.03	-0.49	-1.10	-0.04	-0.88	0.31	0.36	-0.59	<b>3.66***</b>	-0.66
Rasht	-0.43	-0.16	-1.12	-0.59	-0.20	0.10	-0.08	0.16	0.97	0.61
Sabzevar	0.75	0.37	0.80	0.08	0.80	0.45	-0.07	-1.08	-1.49	0.00
Saghez	<b>-1.75*</b>	0.4	0.89	<b>-2.44***</b>	-1.38	-1.17	-0.49	-1.59	-0.63	-2.34
Sanandaj	<b>-1.69*</b>	0.00	0.09	<b>-2.29**</b>	<b>-1.66*</b>	0.08	0.36	-0.19	0.33	-1.17
Shahrekord	-0.31	0.99	1.72	-0.13	-0.57	-0.81	-0.11	-1.12	0.60	0.33
Shahrroud	-0.08	-0.15	0.92	-0.76	0.89	-1.18	-0.17	-0.95	-1.32	-0.95
Shiraz	0.10	0.00	1.39	-0.51	0.28	0.76	0.80	<b>-2.33***</b>	0.66	-0.7
Tabass	0.18	-0.27	0.12	-0.13	1.64	-1.14	1.42	0.25	-0.13	-1.43
Tabriz	<b>-2.83***</b>	<b>-2.47***</b>	-0.58	<b>-2.15**</b>	<b>-3.32***</b>	1.72	<b>1.99**</b>	-0.95	0.35	1.03
Tehran	1.14	1.14	-0.05	1.10	0.03	-0.56	-0.15	-0.41	0.50	-0.08
Torbate Hy	-0.05	0.50	1.07	0.10	-0.44	0.25	-0.13	-0.82	-0.67	0.92
Urmia	-1.52	-0.75	-0.61	-0.82	<b>-2.94***</b>	-0.10	1.20	0.3	-0.16	-0.11
Yazd	1.33	1.52	1.52	1.12	1.62	-0.51	-0.42	0.00	-0.30	0.04
Zahedan	-1.60	-0.60	0.38	-1.33	<b>-1.76*</b>	0.40	1.62	0.13	0.10	-0.81
Zanjan	<b>-1.79*</b>	-0.41	1.30	-1.63	<b>-1.84*</b>	-1.08	0.65	0.42	-1.53	0.58

Bold numbers with one, two and three stars indicate significance values at the 10, 5 and 1 % levels, respectively

are homogenous except Sanandaj station, which detected as inhomogeneous for summer and the series are labeled doubtful.

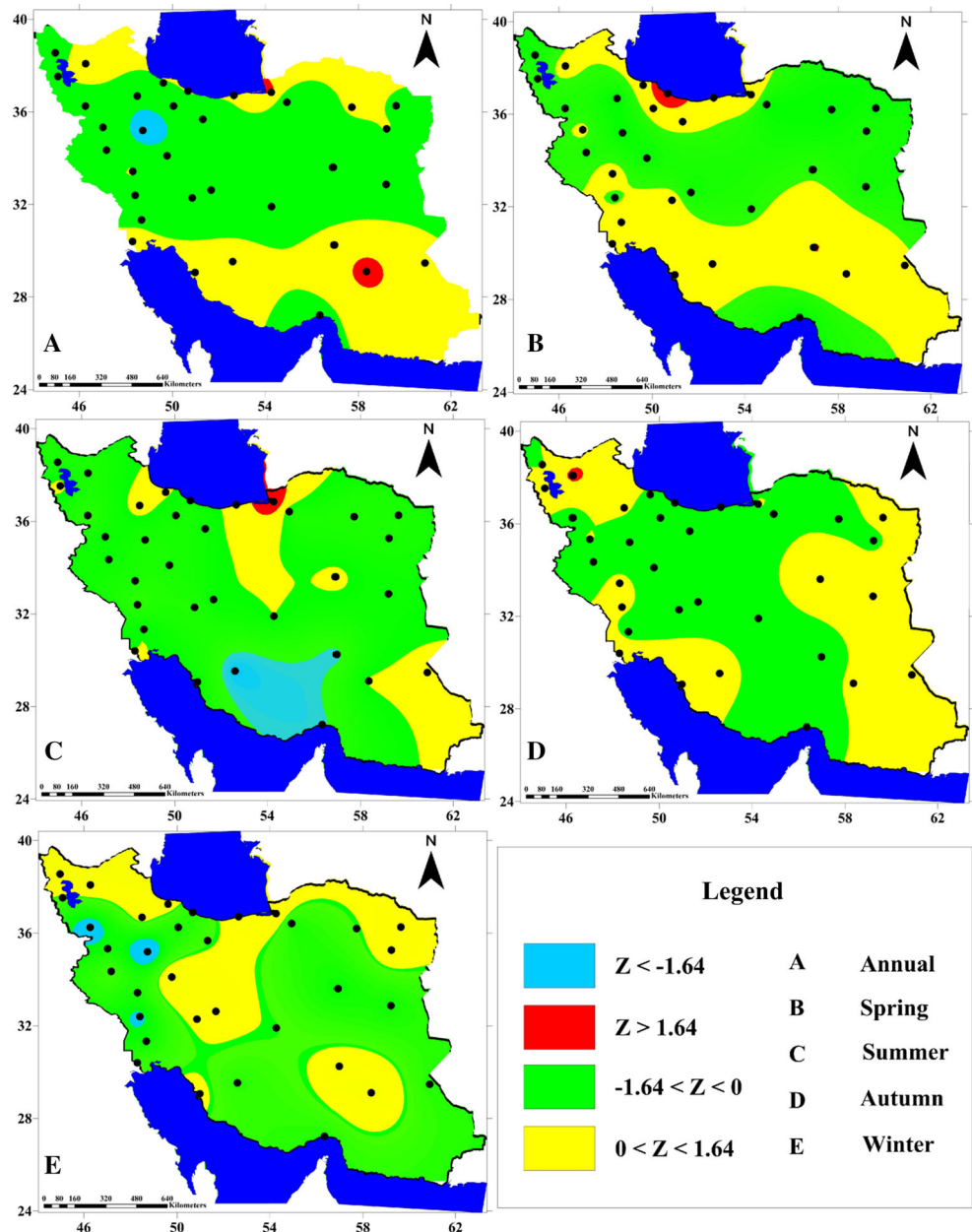
### 3.2 The results of Mann–Kendall trend test for precipitation

Based on the results provided in Table 3 and Fig. 11, it can be observed that in winter Ahwaz, Arak, Bam, Dezful, Gorgan, Hamedan, Kerman, Kermanshah, Khorramabad, Ghazvin, Ramsar, Rasht, Saghez, Sanandaj, Shahrekord, and Torbat Heydariyeh experienced an insignificant decreasing trend in

precipitation. In Khoy, Sanandaj, Tabriz, Urmia, Zahedan, and Zanjan stations, the decreasing precipitation trend in winter was significant. The winter precipitation of Esfahan stations experienced a significant increasing trend, while it was insignificant in other stations. Overall, 20 out of 34 studied stations have been afflicted with a decreasing precipitation trend in winter. In spring the condition is similar to winter, as the results of MMK test presented in Table 3 manifests that Arak, Babolsar, Gorgan, Kermanshah, Saghez, Sanandaj, and Tabriz experienced a significant decreasing trend in spring precipitations.

In spring, Dezful, Esfahan, Ghazvin, Sabzevar, Tehran, Torbat Heydariyeh, and Yazd stations had an insignificant

**Fig. 10** Values of statistics Z of the MMK method for seasonal and annual PCI over Iran during 1961–2010

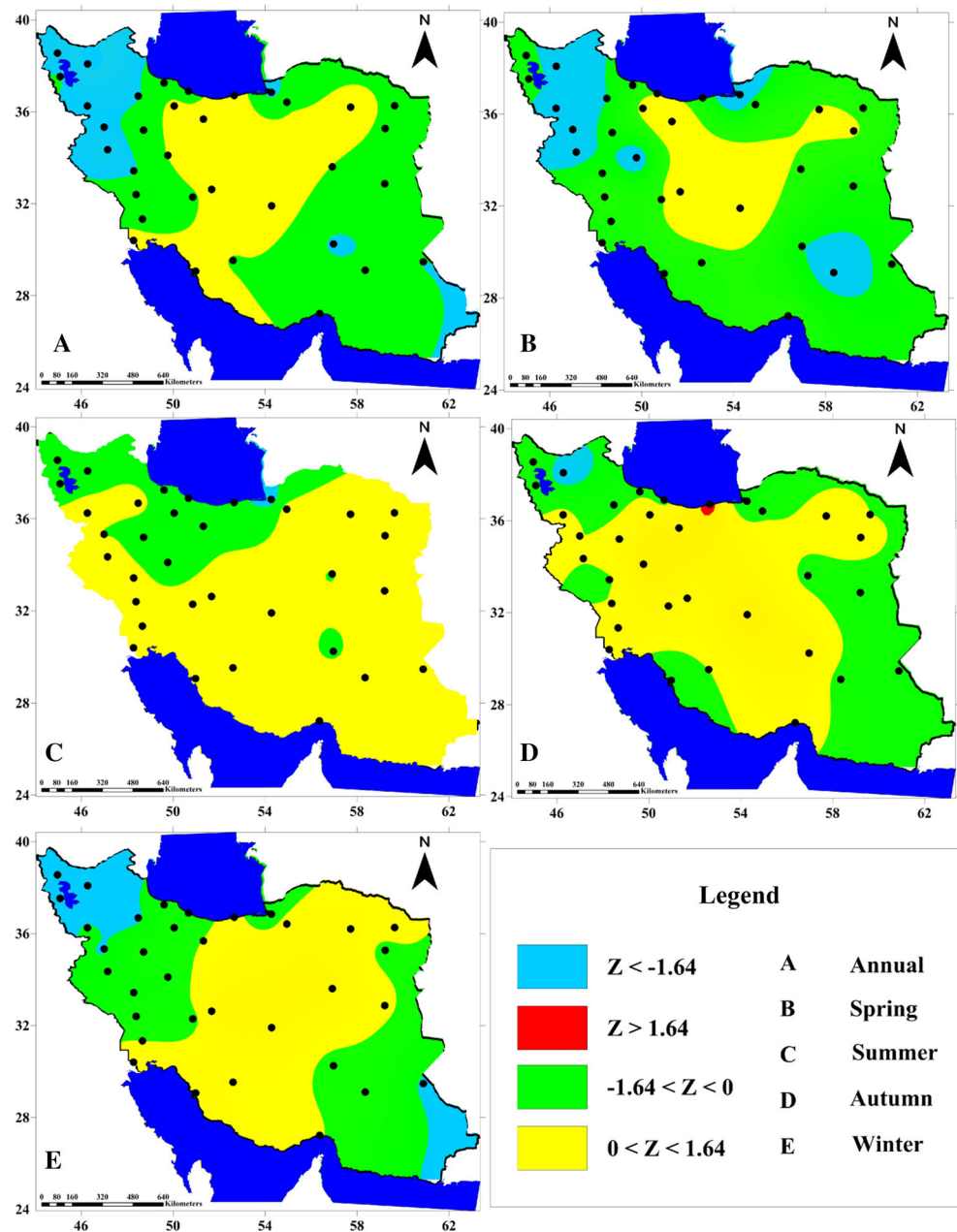


increasing trend, where no significant increasing trend happened in any stations. Other stations also experienced an insignificant decreasing trend in precipitation. Overall, in spring 27 out of 34 studies stations indicated a decreasing trend in spring precipitations. In summer, the precipitation in Gorgan station decreased significantly. Considering the PCI trend in this station, which is a significant increasing one (Table 3), confirms the relationship between precipitation trend and PCI for this station. In the figure of fall, Tabriz station experienced a significant decreasing trend in precipitation and thus the PCI for this station exhibit that irregularities in precipitation have also increased significantly. In contrast, Babolsar station had a

significant increasing trend in fall precipitations and correspondingly the PCI confirms improved precipitation concentration for this station. In annual time scale, 22 (12) out of 34 studied stations had a decreasing (increasing) trend. Among these, Gorgan, Kerman, Kermanshah, Khorramabad, Khoy, Saghez, Sanandaj, Tabriz, Zahedan, and Zanjan experienced a significant decreasing trend in annual precipitation and Esfahan was the only station experiencing a significant increasing trend in precipitation.

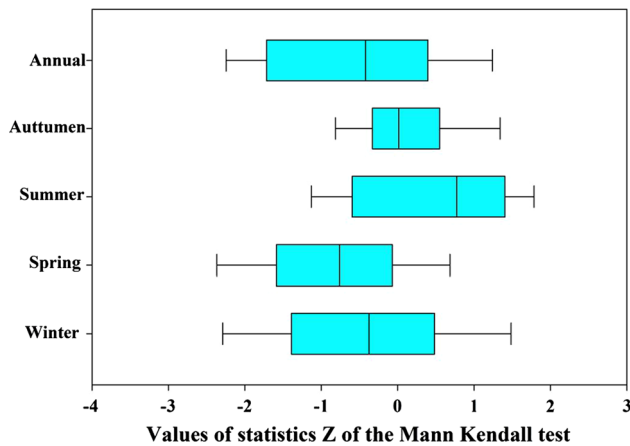
Figure 11 presents spatial changes in precipitation trend at seasonal and annual time scales. It is evident from results that, the northwest of the country experienced a significant decreasing trend in annual precipitation. This has had

**Fig. 11** Values of statistics  $Z$  of the MMK method for seasonal and annual precipitation over Iran during 1961–2010



serious socioeconomic and environmental implications for this region with a clear example of Urmia Lake drying. Annual precipitation in eastern, northeastern and some parts of the western regions of the country has also had an insignificant decreasing trend, while central areas experienced an insignificant increasing trend in precipitation. In spring, most regions of the country have experienced a decreasing precipitation trend and a small part of central areas had an insignificant increasing trend in spring precipitation. However, the northwest of the country had been facing a significant decreasing trend in precipitation. As this region receives about 50 % of its precipitation in

spring, significant decreasing variations in this region imply intensified droughts, confirmed by Mirabbasi et al. (2013). The incidence of irregularities in precipitation is another consequence of decreased spring precipitations. In the summer and fall, which occur 20 % of the total precipitation in the country, an insignificant increasing trend was observed in central areas, while in the northwest regions of the country the precipitation had a decreasing trend. Winter has a very important role in the provision of water demands in the country and occurs about 44 % of the total precipitation in this season. According to Fig. 11e, northwest of the country has been facing a significant



**Fig. 12** Box plots of statistics Z for seasonal and annual precipitation time series in Iran during 1961–2010

decreasing trend in winter precipitations. An insignificant decreasing trend is evident in central and eastern precipitations.

Figure 12 presents a box plot of the Z-statistic calculated using MMK test at two seasonal and annual time scales. In this figure, the line drawn within the rectangles is the median of Z. The width of rectangles in the upper and lower parts represent 75 and 25 percentile, respectively. The end parts of the orthogonal lines in the upper and lower sections represent the maximum and minimum values of the Z-statistic, respectively. According to the Fig. 12, in winter and spring the values of the Z-statistic are in the negative part, confirming a decreasing trend in precipitation of these seasons. This is of importance because according to Table 1, 44 and 36 % of Iran's precipitation (80 % in total) occur in winter and spring, respectively. The existence of a decreasing precipitation trend has also been confirmed in other studies (Kousari et al. 2011 and Some'e et al. 2012). Also results of this study is accordance with Tabari and Hosseinzadeh Talae (2011b), especially for the northwest of Iran that decreasing trend was reported in annual and seasonal (spring and winter) time scales.

This decreasing trend can be justified as follows:

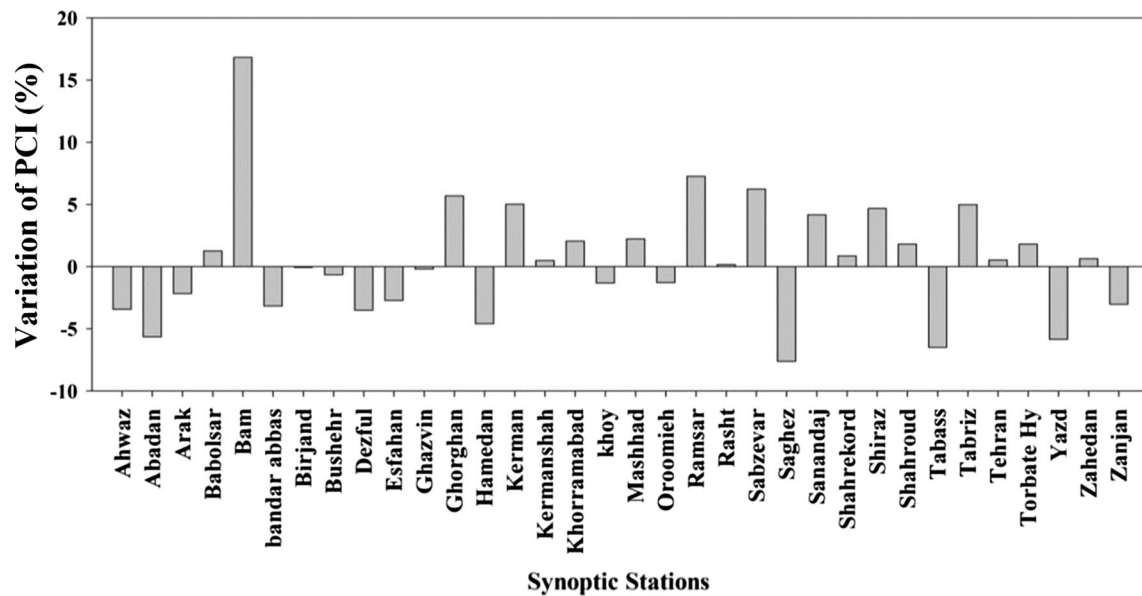
Humidity in the air is a necessity for precipitation and its changes are associated with other factors such as water on the ground, sufficient energy for the evaporation process, a proper mechanism for vapor transportation etc. These factors determine variations in the air vapor pressure in a complex process. For occurring the precipitation, not only water vapor and humidity are necessary, but also a mechanism is required for cooling down the air to reach saturated vapor pressure. On the other hand, Tabari and Hosseinzadeh Talae (2011a), Saboohi et al. (2012), Kousari et al. (2013), and Zarenistanak et al. (2014) indicated that there is an increasing trend in temperature throughout Iran, especially in the cold months and hence it

is possible to attribute changes in temperature as one of the reasons of reduced precipitation in Iran. Because increasing temperature in the studied regions led to increase the capacity of atmosphere to receive and keep humidity and cause the air not to become cold enough for the provision of precipitation conditions. In other words, an increasing temperature trend results in elevated storage of humidity in the atmosphere. This in turn inhibits the regrouping of conditions necessary for precipitation. Decreasing (increasing) trends in maximum and minimum relative humidity (maximum and minimum temperature) were also witnessed in all the time scales, which were significant during the annual time scale, and the pre-monsoon and post-monsoon seasons (during annual and post-monsoon) (Jhajharia et al. 2014b). Also (Lenderink and Meijgaard 2008) stated that the Clausius–Clapeyron relation is found to be a good predictor of changes in extreme daily precipitation in GCMs. The highest precipitation intensities are usually related to convective showers on a (sub-) daily timescale and climate models do not explicitly resolve these showers, but use implicit parameterizations instead. Furthermore, the dependency of precipitation intensity on temperature found in the climate is linked to the climate response in a long climate simulation with a regional climate model.

The differences between annual PCI calculated within the two 25-year periods are shown in Fig. 13. This figure represents a 8.25 % reduction in annual PCI in the Saghez synoptic station compared to the first 25 years and 16 % increase in the Bam synoptic station compared to the first 25 years. Figure 13 illustrates PCI changes at the annual time scale for the studied stations. In other stations, the PCI faced some fluctuations. In a study on the investigation of precipitation concentration in the Andhra Pradesh state in India, Valli et al. (2013) did not also observe a uniform concentration, which is consistent with the findings of the present research.

## 4 Conclusion

In this study, PCI was used to analyze the precipitation concentration at two annual and seasonal time scales throughout the Iran (from 1961 to 2010). The results indicated that within the first 25 years, 20, 35, and 40 % of the stations had moderate, irregular, and highly irregular precipitation distributions, respectively. Within the second 25 years, 18 % of the stations had annual precipitation moderate distribution, 35 % had irregular distribution, and 47 % showed high levels of irregularity in annual precipitations. The results of zoning of the PCI at the annual time scale indicated that the precipitation concentration follows the same pattern within the two sub-periods. These results



**Fig. 13** Variations of annual PCI values in the second sub-period (1986–2010) compared to the first sub-period (1961–1986)

also suggest a high PCI in the center of Iran and in provinces with low precipitation such as Kerman, Bandarabas, Yazd, Zahedan, Shahrekord, Birjand, Bushehr, Ahwaz, and Esfahan. These stations have a high irregularity in precipitation according to the classification by Oliver (1980). At the annual time scale and on average, the highest value of PCI belonged to the Bandarabas and the lowest to the Gorgan stations. Uniform concentration ( $PCI < 10$ ) was observed in none of the studied stations at the annual time scale. The PCI zoning results at the seasonal scale demonstrated that precipitation concentration had the same trend within the two 25-year sub-periods. These results also revealed a high PCI in the center of Iran and in provinces with low precipitation such as Kerman, Yazd, and Zahedan. These stations, according to Oliver (1980) classification, have irregular and sporadic precipitation in winter precipitations. Overall, the PCI analysis of the seasonal and annual scales indicated that the regions covered by polar-continental, Europe-originated polar-continental and North Atlantic ocean-originated polar-continental have the best precipitation concentration throughout the country. The results of this index provide valuable information for water resources managers in regions with low-precipitation.

The results of the PCI trend analysis in winter manifested increased irregularity in the country's precipitations, so that about 50 % of the studied stations faced an increasing trend in PCI. In spring this index exhibited an insignificant increasing trend in Abadan, Ahwaz, Babolsar, Bam, Bushehr, Gorgan, Ghazvin, Rasht, Sanandaj, Shahrekord, Shiraz, Tabriz, Tehran, and Zahedan stations, implying increased spring precipitations. In summer, Gorgan station faced a strong irregularity in response to a

significant trend in PCI. In the fall, Tabriz and Zahedan (Babolsar) also experienced an increasing (a decreasing) trend in PCI. At the annual time scale, about 50 % of the stations experienced an increasing trend in PCI, where a significant increasing trend was observed in Bam, Tabriz, and Gorgan stations.

The results of modified Mann–Kendall (MMK) test for PCI in Iran revealed a decreasing trend over the last 50 years. Based on the obtained results in winter, the Khoy, Sanandaj, Tabriz, Urmia, Zahedan, and Zanjan stations experienced a significant decreasing trend and 20 out of 34 studied stations experienced a decreasing trend in winter precipitation. The condition of the spring season was similar to winter, as the Arak, Babolsar, Gorgan, Kermanshah, Saghez, Sanandaj, and Tabriz encountered a significant decreasing trend in spring precipitations. As many as 79 % of the studied stations witnessed this decreasing trend in spring precipitations. In summer, Gorgan station had a significant decreasing trend resulting in enhanced PCI for this station. In the fall, Tabriz experienced this decrease for which the PCI trend indicates that irregularities in precipitation has increased significantly. In contrast, Babolsar station experienced a significant increasing trend in fall precipitations where the corresponding PCI index confirms improved precipitation distribution for this station. At the annual time scale, 22 out of 34 studied stations had a decreasing and remaining 12 stations had an increasing trend. The existence of an increasing trend in PCI albeit insignificant reveals changes in Iran's precipitations confirmed by Mann–Kendall test for precipitations in 34 studied stations. Overall, it can be concluded that the decreasing trend in Iran's precipitation



has resulted in increasing PCI and thereby increased irregularities in precipitations, especially in winter and spring seasons.

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