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Spatial distribution of the daily, monthly, and annual precipitation concentration indices in the Lake Urmia basin, Iran

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Abstract— Investigations of the long-term observations of climate variables, as a practical approach to monitor climate changes, have attracted the interest of many researchers around the world. One of the important variables in this context is precipitation. The investigation of precipitation, one of the most important meteorological factors directly affecting accessibility to water resources, is of special importance. In every region, studies of precipitation on daily, monthly, or annual scales provide important information on the distribution, concentration, and dispersion of precipitation, as well as some conclusions about the associated hydrological problems. In this study, the precipitation concentration was calculated and zoned by means of the precipitation concentration index (*PCI*) in the basin of Lake Urmia, using monthly and annual rainfall data of 42 selected rain gauge stations, from which 24 stations located in the West Azerbaijan province (in the west of Lake Urmia) and 18 stations located in the East Azerbaijan province (in the east of Lake Urmia) during 1984–2013. The results of the studies of the precipitation concentration index over the basin of Lake Urmia showed that the dominant concentrations of spring, autumn, and winter precipitation were moderate, indicating a moderate distribution for the precipitation of the months in these seasons. In addition, in the period under study, uniform and regular precipitation concentrations ($PCI<10$) were observed only in winter and in the borders of the basin. In summer, almost the entire surface of the basin (excluding its northeastern part) faced a strongly irregular distribution of precipitation, indicating irregular rainfall in July, August, and September. Most of the basin of Lake Urmia is covered by an irregular distribution of precipitation on an annual scale. By investigating the precipitation distribution in the first and the last 10 years of the statistical period considered and by comparing them, it was revealed that the greatest increase in the precipitation concentration index was in autumn, it rose by approximately 20.55 percent. According to the results, on the basin scale, the concentration index showed that the daily rainfall of the Lake Urmia basin was neither in regular nor in strongly irregular conditions at any of the stations studied. All the stations studied were in fairly regular, moderate concentration and fairly irregular conditions of daily precipitation distribution. The results also showed that the moderate concentration includes most of the daily precipitation distributions throughout the basin.

Key-words: precipitation pattern, precipitation concentration, Lake Urmia, meteorological drought, Lorenz curve.

1. Introduction

In the present era, climate change is one of the most important environmental challenges. Understanding the human impacts on the environment, particularly those related to the warming caused by the increase in greenhouse gases, reveals that a number of parameters are being changed. According to scientific reports, the average surface air temperature has increased by 0.6 oC during the 20th century, where an upward trend is also expected for the evaporation rate. Hence, the atmosphere will be able to transfer more water vapor, and so, the precipitation rate will consequently be affected (*Tabari et al.,* 2011). Under the influence of global warming, rainfall patterns have changed, and extreme weather events like floods, droughts, rains, storms, and so on have occurred as a result. For instance, a significant reduction in the number of rainy days was confirmed in many parts of the world, including China (*Gong and Ho,* 2002; *Ren et al.,* 2000; *Zhai et al.,* 2005; *Zhang et al.,* 2008). One of the most important aspects of climate change, which needs to be studied more accurately, is the investigation of temporal distribution of precipitation and its historical changes. Therefore, it seems necessary to employ indices to express the changes caused by the effects of precipitation on water resources like groundwater, surface water, and snow reserves. Some prominent indices are the standardized precipitation index (SPI), precipitation concentration index (PCI), and concentration index (CI). Low amounts of precipitation and severe fluctuations on daily, seasonal, and annual scales are the inherent characteristics of Iran's climate.

The precipitation concentration index (*PCI*) is a strong indicator of the temporal distribution of precipitation, which is commonly used on annual scales. The increase in the value of this index means that precipitation has a minor distribution in the region. The *PCI* is also an evaluator to determine the precipitation changes in a specific region, and its analytical results demonstrates the availability of water in an environment. Information about the outcome can be used in management programs. Changes in the intensity, duration, time, and amount of precipitation are major indicatives of climate change. These changes can be assessed by the concentration index. The concentration index (*CI*) and the corresponding concentration curve are actually used to measure the quantity inequality of a parameter of a particular variable. For example, in statistics, this index can be used to determine better health subsidies for the poor in different countries. It is also possible to use this index to study precipitation distribution in a basin or a country, or in any other field of science. The concentration index is defined by a concentration curve (Lorenz curve). In this curve, the *x* axis is the cumulative percentage of samples, which is ranked by specified values, and the *y* axis in the curve is the cumulative percentage of the multiplication of the midpoint of clusters by the number of observations in each cluster. In fact, the Lorenz curve is a concept utilized in economic theories to assess the spatiotemporal changes in time series of daily precipitation and precipitation concentration. The Lorenz curve provides a graphical representation of the cumulative percentage of the total annual precipitation. In addition, in this curve, data are extracted using the Gini coefficient and the Lorenz asymmetry coefficient so as to measure the precipitation concentration parameter.

To illustrate the performance of the two indices in examining the spatiotemporal changes, a practical example is given with real data in the following. In fact, the concentration index (CI) is an index used to evaluate the statistical properties of daily precipitation. PCI is a part of the well-known Fournier index, which has a strong background in the analysis of natural systems like soil erosion (*De Luis et al.,* 2011). The results obtained from calculating PCI could be employed in managerial programs of hydrologic, water, and environmental resources as a tool for early warning when faced with floods or erosion (*Adegun et al.,* 2012). This concept can also be used in planning irrigation and designing modern systems. Unbalanced distribution of precipitation could reduce crop yield by reducing the stored moisture in the ground and by increasing the number of irrigation periods. In addition to this, an unbalanced distribution of precipitation means more drought, and it is possible that even rainfalls with less than the average amount of precipitation in an area may cause severe floods. This is because the soil moisture is decreased, as a result of which vegetation is devastated. Finally, it increases the protective measures in the basin in order to maintain the water structures.

Martin-Vide (2004) calculated the concentration index for daily precipitation in Peninsular Spain and divided the region into two regions with the highest distribution and regular distribution. *Zhang et al.* (2009) calculated the concentration index for the precipitation series of the Pearl River basin (*Zhang et al.,* 2009). *Alijani et al.* (2008) examined the rainfall intensity of Iran at 90 synoptic stations, and showed that the precipitation distribution throughout Iran is irregular, and that the Caspian border stations, Zagros mountain chains, and the northwest part of the country have the most significant contributions of precipitation and are subject to severe rainfalls (*Alijani et al.,* 2008). *Li et al.* (2011) calculated CI values for the Kaidu River basin (*Li et al.,* 2011). *De Luis et al.* (2011) studied the amount of annual, seasonal, and humid and dry periods of PCI adjacent to Spain for two periods (1976–2005 and 1964–1975). The analyses of two sub-periods revealed that the significant changes in precipitation in Spain occurred between 1964 and 2005. *Adegun et al.* (2012) have evaluated PCI on seasonal and annual scales since 1974 through 2011 for two regions in Nigeria. The results of PCI for the region showed that 87 and 71 percent of the examined years fell within the first and second limits of the moderate concentration range, respectively. *Cortesi et al.* (2012) examined the daily precipitation concentration in different regions of Europe (*Cortesi et al.,* 2012). *Shi et al.* (2013) studied the daily precipitation concentration in the Lankang River basin using the concentration index, and concluded that the results of this indicator are able to improve the water resources management of the river (*Shi et al.,* 2013). *Valli et al.* (2013) used PCI, in a part of their study, to show the rainfall patterns in the state of Andhra Pradesh from 1981 to 2010 at two annual and seasonal scales. The results indicated that there was an irregular precipitation distribution (with values ranging from 16 to 35) in the region (*Valli et al.,* 2013). *Khalili et al.* (2016) investigated the distribution of monthly and annual precipitation at synoptic stations of Iran during the last half century in two 25-year periods. Scientists believe that changes in the concentration of greenhouse gases, resulting from the consumption of fossil fuels, have led to drastic changes in some certain components of the hydrological cycle, including precipitation in different parts of the world; wherein Lake Urmia is not excluded from these changes and has faced critical conditions in recent years. According to the statistics provided by the relevant organizations, it is seen that there is no significant changes in the amounts of precipitation over the basin; it seems that the temporal distribution of precipitation, as well as the rainfall pattern, have changed in recent years. Hence, the aim of the present study is to investigate the changes in the pattern and distribution of daily, monthly, and annual precipitation at rain gauge stations in the basin of Lake Urmia from 1984 to 2013.

2. Materials and methods

2.1. Study area

Lake Urmia is the accumulation center of surface runoff surplus to the demand of the rivers within the enclosed basin of Lake Urmia. With an area of approximately 5,750 square kilometers and an average altitude of 1,276 meters above mean sea level, this lake is located in the middle of the northern basin. The Lake Urmia basin is located in the northwest part of Iran. There are 16 wetlands with areas ranging from five to 120 hectares (some of which have dried up), mostly containing fresh or fresh and saline water, and possess high value as ecosystems. The Lake Urmia basin is situated within the eastern longitudes from 14–44 to 47–53 and northern latitudes of 35–40 and 30–38. In the basin of Lake Urmia, precipitation changes from 220 to 900 mm and the mean rainfall is 263 mm, whereas the precipitation increases from the central parts of the basin towards the surrounding highlands. In this study, daily, monthly, and annual rainfall data from the rain gauge stations located in the basin of the lake have been used from 2013 to 1984, a period of 30 years. The positions of Lake Urmia and the rain gauge stations studied in the basin are illustrated in *Fig. 1,* and the attributes of the rain gauge stations are presented in *Table 1*.

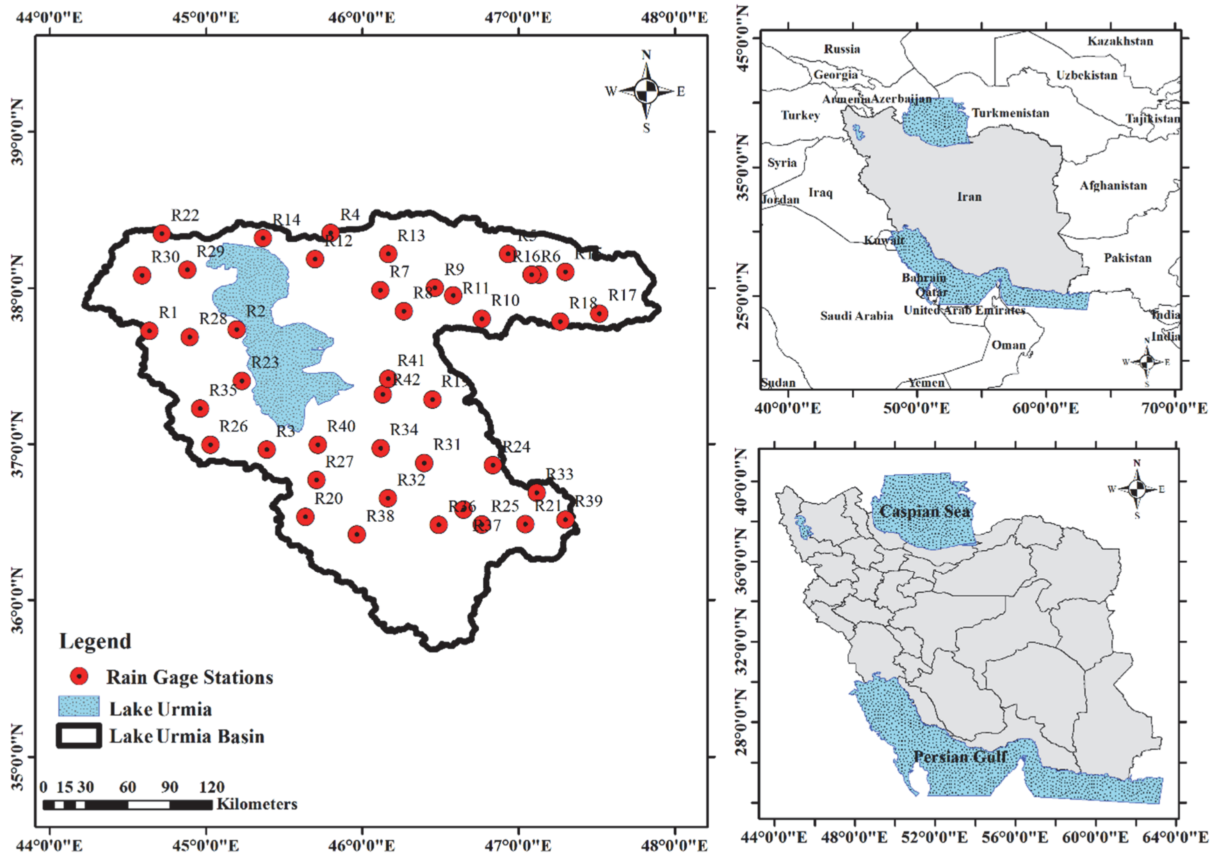

Fig. 1. Location map of the selected stations in the Lake Urmia basin.

Table. 1. Statistical properties of rain gauge stations located in the Lake Urmia basin in the period from 1984 to 2013

Station Number	Station	Elevation (m)	Longitude	Latitude	Annual Precipitation (mm/y)
1	Agchekol	1710	46.45	37.28	424.0
2	Bashsizojan	1850	46.77	37.80	352.6
3	Basmanj	1700	46.47	38.00	172.0
4	Ghezelche	1844	47.30	38.10	339.5
5	Ghoshchi	1980	47.27	37.78	768.3
6	Haris	1690	47.52	37.83	463.7
7	Khoshehmehr	1320	46.13	37.32	309.0
8	Khormazard	1556	46.17	37.42	398.3
9	Mehraban	1608	47.13	38.08	327.2
10	Pardel	1415	46.17	38.22	238.1
11	Payam	1790	45.80	38.35	457.7
12	Saeedabad	1950	46.58	37.95	381.3
13	Saray	1545	46.93	38.22	287.6
14	Isfahlan	1400	46.12	37.98	272.6
15	Shabestar	1400	45.70	38.18	297.4
16	Tasoj	1390	47.08	38.08	372.5
17	Zarnaq	1600	45.37	38.32	297.7
17	Zenjanab	2110	46.27	37.85	332.9
19	Afan	1620	45.64	36.53	578.8
20	Alasagel	1700	47.04	36.49	392.7
21	Babarood	1282	45.23	37.40	342.8
22	Badamloo	2119	46.84	36.86	638.4
23	Bagch	1898	46.77	36.48	348.3
24	Chehreq	1611	44.59	38.08	366.3
25	Chobchole	1361	46.40	36.88	306.3
26	Dashband	1318	46.17	36.65	397.3
27	Gerdeyaghob	1280	45.72	37.00	268.7
28	Ghezel Gonbad	1374	45.97	36.42	402.5
29	Ghezel-Ghaber	1657	46.65	36.58	322.6
30	Ghoshkhana	2260	47.30	36.51	379.8
31	Moshabad	1281	45.20	37.73	248.4
32	Naqade	1306	45.39	36.96	323.2
33	Pey Ghala	1306	45.03	36.99	486.1
34	Pole sorkhe	1350	45.71	36.77	35.0
35	Sari Ghamesh	1391	46.49	36.48	322.5
36	Sero	1628	44.64	37.72	360.8
37	Tamar	1387	44.88	38.11	212.6
38	Tapik	1398	44.90	37.68	368.6
39	Urban	1840	44.72	38.35	310.0
40	Zarineh	1390	46.12	36.97	422.5
41	Zereshoran	2100	47.12	36.69	427.6
42	Zharabad	1569	44.96	37.23	542.3

2.2. Concentration index (CI)

CI is a concentration index that is used to assess the daily concentration and the statistical structure of precipitation. The daily statistical structure of precipitation can be depicted by precipitation concentration curves, which are related to cumulative precipitation percentages to the cumulative percentage of days with rainfall. The concentration index (CI) is a curve that defines the contrast or concentration of different amounts of daily precipitation. The method of calculating the concentration index (CI) is based on the principle that the overall proportion of days with rainfall to the total precipitation is adjustable by a negative exponential distribution (*Brooks and Carruthers*, 1953; *Martin-Vide*, 2004). Considering the geographical characteristics and the temporal period, the possibility of a small amount of daily precipitation would be more than large quantities of precipitation. So, starting with the classification from the lowest class, the absolute eventuate frequency will be decreased (*Martin-Vide*, 2004). To investigate the effects of different amounts of daily rainfall and to determine the share of the high values of precipitation to the entire rainfall, the cumulative rainfall percentage (Y) and the cumulative percentage of days (X) were studied during Y events. Based on the studies of (*Martin-Vide,* 2004; *Olascoaga*, 1950; *Riehl*, 1949), in order to investigate the concentration index (CI), first of all, the daily precipitation data are classified in 1 mm/day clusters. The number of days with specified rainfall is determined in each cluster, and its cumulative value is calculated as well.

Finally, the cumulative percentage of rainy days and the amount of precipitation associated with the rainy days are obtained. According to the aforementioned stages, an exponential curve of the cumulative percentages of rainy days (X) versus the cumulative rainfall percentage (*Y*) is achieved. *Martin-Vide* (2004) recommended the $Y = (a \times X)\exp(\mathrm{b} \times X)$ model for this curve, where *a* and *b* are the regression coefficients.

The Gini concentration index (*Gini*=2*S* / 10000) is employed as a concentration measuring index, where *S* equals the area enclosed by the first quarter bisector and a polygon line or Lorenz curve. In fact, the precipitation concentration is based on the *Gini* coefficient. The Lorenz curve is depicted by $Y = (a \times X)\exp(\mathrm{b} \times X)$ model, where coefficients *a* and *b* are calculated by the least squares method (*Martin-Vide,* 2004). After determining coefficients *a* and *b*, the definite integral of the exponential curve between 0 and 100 illustrates the area under curve or *A'*:

$$A' = \left[\frac{a}{b} e^{bX} (X - \frac{1}{b}) \right]_0^{100} . \qquad ((1)$$

Based on this equation, the area enclosed by the curve and the distribution line of X = 100 between 5000 and the value calculated by Eq.(2) are different (*Martin-Vide,* 2004; *Zamani et al.,* 2018). From these precipitation concentrations, which are similar to the *Gini* coefficient, it can be found that:

$$CI = S'/5000\,. \tag{2}$$

Therefore, the value of *CI* is a fraction of the amount of *S′* and the triangle area formed at the bottom of the chart. Coefficients *a* and *b* can be obtained by the following equation:

$$\ln a = \frac{\sum X_i^2 \sum \ln Y_i + \sum X_i \sum X_i \ln X_i - \sum X_i \sum \ln X_i - \sum X_i \sum X_i \ln Y_i}{n\sum X_i^2 - (\sum X_i)^2}\,, \tag{3}$$

$$b = \frac{n\sum X_i \ln Y_i + \sum X_i \sum \ln X_i - n\sum X_i \ln X_i - \sum X_i \sum \ln Y_i}{n\sum X_i^2 - (\sum X_i)^2}\,. \tag{4}$$

In Eqs. (3) and (4), *X* and *Y* values are described in detail in *Table 3*. The flowchart of the proposed methodology is demonstrated in *Fig. 2*.

Preparing the daily rainfall data

↓

Classified the daily rainfall data in 1 mm/day clusters

↓

Determined the number of days with specified rainfall, and its cumulative value is calculated as well

↓

The cumulative percentage of rainy days and the amount of precipitation associated with the rainy days are obtained

↓

The Lorenz curve is depicted by $Y = (a \times X)\exp(\mathrm{b} \times X)$ model by Eqs. (3) and (4)

↓

Evaluated the area under curve by Eq. (1)

↓

Evaluated the concentration index by Eq. (2)

Fig. 2. Flowchart of the proposed *CI* methodology

2.3. Precipitation concentration index (PCI)

The *PCI* is an indicator used to determine the precipitation changes of a specific region, and its analytical results demonstrates the water availability in an environment. The *PCI* is recommended as a measure of the precipitation concentration and distribution. The seasonal and annual scales of this index are calculated by Eqs. (5) and (6) (*Oliver*, 1980), respectively:

$$PCI_{Seasonal} = \frac{\sum_{i=1}^{3} p_i^2}{(\sum_{i=1}^{3} p_i)^2} * 25, \tag{5}$$

$$PCI_{Annual} = \frac{\sum_{i=1}^{12} p_i^2}{(\sum_{i=1}^{12} p_i)^2} * 100, \tag{6}$$

where P_i is the amount of monthly precipitation for the *i*th month. The number 3 in Eq. (5) indicates the number of months in a season. On the basis of the suggested formula and the initial results of *Oliver* (1980), the minimum theoretical value of *PCI* is 8.3, indicating a complete uniformity in precipitation distribution (which means that the same amount of precipitation occurs in each month). A *PCI* equals to 16.7 shows that the total rainfall is concentrated in the half of the temporal interval, and a value of 25 for this index indicates that the total precipitation received has occurred in one-third of the temporal interval (this means that the total rainfall occurs in four months). *Oliver* (1980) – according to the preliminary results of his studies – suggested that a *PCI* less than 10 shows a uniform distribution of rainfall (low concentration of precipitation). *PCI* values from 11 to 15 represent average precipitation concentration, and values between 16 and 20 reflect the irregular distribution of precipitation. Based on the classification of *Oliver* (1980), a *PCI* greater than 20 is indicative of a great chaotic distribution of precipitation (strong precipitation concentration) (*De Luis et al.,* 2011).

Results of applying this index in the various climates of the world such as Spain, Nigeria, and India showed that *PCI* index can be useful in investigating precipitation concentration distribution (*Adegun et al.,* 2012; *De Luis et al.,* 2011; *Tahroudi et al.,* 2019; *Valli et al.,* 2013; *Zamani et al.,* 2018; *Khozeymehnezhad, and Tahroudi, 2019*).

3. Results and discussion

3.1. The results of the concentration index in Lake Urmia basin

The statistical analysis of daily, monthly, and annual precipitation data of enclosed basins such as Lake Urmia basin is climatically important from the distribution point of view. Hence, the investigation of an index, which is able to show distributions and concentrations, can be very valuable. The *PCI* is calculated at annual and seasonal scales by using the data of monthly and annual precipitation from the selected rain gauge stations over the basin of Lake Urmia in the period from 1984 to 2013 along with Eqs. (5) and (6). The mean results are presented in *Table 2.*

Table 2. Results of calculation of the *PCI* index in rain gauge stations located in the Lake Urmia basin

Station Number	Station	Latitude	Longitude	Spring	Summer	Autumn	Winter	Annual
1	Agchekol	37.28	46.45	11.86	20.02	12.13	9.88	15.29
2	Bashsizojan	37.80	46.77	11.67	17.06	12.71	9.79	14.98
3	Basmanj	38.00	46.47	11.05	16.84	12.43	10.17	14.95
4	Ghezelche	38.10	47.30	11.51	17.81	11.13	10.83	15.88
5	Ghoshchi	37.78	47.27	11.39	19.70	11.77	9.32	15.29
6	Haris	37.83	47.52	11.60	16.64	13.17	10.22	16.91
7	Khoshehmehr	37.32	46.13	12.79	23.21	12.96	10.57	17.41
8	Khormazard	37.42	46.17	12.72	21.53	13.18	10.31	17.11
9	Mehraban	38.08	47.13	11.87	16.75	11.9	10.70	16.90
10	Pardel	38.22	46.17	11.19	18.76	12.15	11.1	15.60
11	Payam	38.35	45.80	10.92	18.67	11.59	10.21	15.44
12	Saeedabad	37.95	46.58	11.96	17.29	13.95	10.29	16.97
13	Saray	38.22	46.93	11.41	17.49	12.46	10.06	14.87
14	Isfahlan	37.98	46.12	11.75	20.09	12.61	10.67	17.07
15	Shabestar	38.18	45.70	12.25	20.30	12.38	10.4	17.36
17	Tasoj	38.08	47.08	11.24	15.13	12.37	10.52	15.50
17	Zarnaq	38.32	45.37	12.08	17.72	13.3	11.08	17.60
18	Zenjanab	37.85	46.27	10.68	19.16	13.04	10.28	15.99
19	Afan	36.53	45.64	13.61	22.05	13.03	9.60	17.08
20	Alasagel	36.49	47.04	12.92	21.65	14.31	9.46	16.06
21	Babarood	37.40	45.23	13.36	21.49	13.82	10.84	17.38
22	Badamloo	36.86	46.84	12.30	21.99	11.49	9.3	15.57
23	Bagch	36.48	46.77	12.64	23.71	13.79	10.17	18.13
24	Chehreq	38.08	44.59	10.38	14.85	12.34	10.45	14.23
25	Chobchole	36.88	46.40	14.24	25.00	12.36	10.61	18.54
26	Dashband	36.65	46.17	13.51	23.25	13.52	10.2	18.12
27	Gerdeyaghob	37.00	45.72	13.3	22.06	13.61	10.76	19.69
28	Ghezel Gonbad	36.42	45.97	14.82	23.79	14.51	10.28	18.61

Table 2. Continued

Station Number	Station	Latitude	Longitude	Spring	Summer	Autumn	Winter	Annual
29	Ghezel-Ghaber	36.58	46.65	13.58	23.03	13.97	9.66	16.97
30	Ghoshkhana	36.51	47.30	13.26	22.95	12.85	9.48	16.86
31	Mosh Abad	37.73	45.20	12.53	21.18	13.79	11.58	18.54
32	Naqade	36.96	45.39	12.96	21.15	12.66	10.55	16.99
33	Pey Ghala	36.99	45.03	13.62	21.00	12.00	9.63	15.89
34	Pole sorkhe	36.77	45.71	12.82	21.53	13.01	10.47	17.81
35	Sari Ghamesh	36.48	46.49	12.96	21.15	12.66	10.55	16.99
36	Sero	37.72	44.64	11.46	17.30	11.95	10.74	15.95
37	Tamar	38.11	44.88	12.18	21.06	15.12	12.77	19.08
38	Tapik	37.68	44.90	12.97	20.21	14.81	11.40	18.33
39	Urban	38.35	44.72	11.40	18.05	12.33	13.27	17.52
40	Zarrine	36.97	46.12	13.12	20.95	13.1	10.15	17.44
41	Zereh Shoran	36.69	47.12	12.21	21.75	14.88	9.35	16.93
42	Zhar Abad	36.58	46.65	13.65	20.65	13.34	10.56	16.75

The results of studying the precipitation concentration of Lake Urmia showed that on an annual scale over the basin, there is no regular concentration at the rain gauge stations studied (*PCI* <10). On an annual scale, Stations 4, 3, 2, 18, 11, 22, and 24 are of moderate concentration and distribution of precipitation. Also, on this scale, rain gauge Stations 1, 10, 8, 19, 20, 21, 23, 25, 28, 29, 34, 36, 40, 41, and 42 have irregular distribution of monthly precipitation in more than 50 percent of the studied years, which means that the distribution of precipitation is irregular in 12 months in the studied years. Strongly irregular distribution was also observed on this scale at Tepik (38), Moshabad (31), Gerdeyaghob (27), and Dashband (26) stations.

In spring, there is at least one regular precipitation concentration (*PCI*<10) on the seasonal scale over the basin and through the years studied. In spring, at all the stations surveyed, 50 percent of the years that were investigated have moderate precipitation concentration and distribution. Meanwhile, Stations 22 and 41 experienced an almost uniform precipitation distribution in spring; also, on this scale, Stations 37 and 39 were of the highest number of years with irregular precipitation concentration. This means that in the years studied, the distribution of precipitation was irregular in three months of each year. A strongly irregular distribution of precipitation on this scale was evident in one to three years of the years studied at Stations 2, 12, and 7 in the east of Lake Urmia and at Stations 42, 41, 40, 39, 38, 35, 33, 32, 31, 30, 29, 28, 27, 26, 25, 23, 21, 20, and 19 in the western part of the basin. The results suggested an increase in the precipitation irregularity at the western stations compared to the eastern stations over the last 30 years. On the seasonal scale and in summer, throughout the basin during the years studied, no regular precipitation concentrations were observed. In summer, the prevailing concentration of the stations was classified as strongly irregular. Meanwhile, the number of stations to the west of Lake Urmia was higher in percentage terms, and their concentrations were more irregular than the stations to the east of the lake. Stations located in the eastern part of the lake in this season (summer) were of relatively less moderate and irregular precipitation concentrations. The results showed that in summer, the precipitation in the different months of this season is distributed in an extremely irregular manner. On a seasonal scale and in autumn, through the basin and over the years studied, a regular concentration of precipitation was seen in a few years at each station. In autumn, the prevailing concentration of precipitation was in two categories of moderate and irregular concentrations at the stations studied. In the meantime, as in summer, the stations in the western part of the lake were more in percentage terms and had more irregular concentrations than the stations in the eastern part of the basin.

The extremely irregular concentration of precipitation was observed in one to three years at most of the stations. No strongly irregular precipitation concentration was observed on a seasonal scale and in winter over the basin in the years studied. In winter, the prevailing precipitation concentration of the stations studied were within either moderate or regular concentration categories. In winter, the precipitation distribution was more regular in January, February, and March than in the other months of the year. To investigate the distribution of the precipitation concentration index in the basin of Lake Urmia, the results of the studies of the index were zoned in the region on two seasonal and annual scales, and are presented in *Fig. 3*.

As it is obvious from *Fig. 3*, in spring, small regions to the northwest and northeast of Lake Urmia have regular concentrations and distributions. There is also a small region that is irregularly concentrated in terms of precipitation distribution in the southwestern part of the Lake Urmia basin.

Finally, it is clear, that most parts of the lake basin have moderate concentration and distribution of precipitation in spring. Precipitation around the lake in this season and in April, May, and June is in the moderate distribution category in terms of the distributions of the months. In summer, the prevailing concentration of rain gauge stations is strongly irregular in the basin of Lake Urmia.

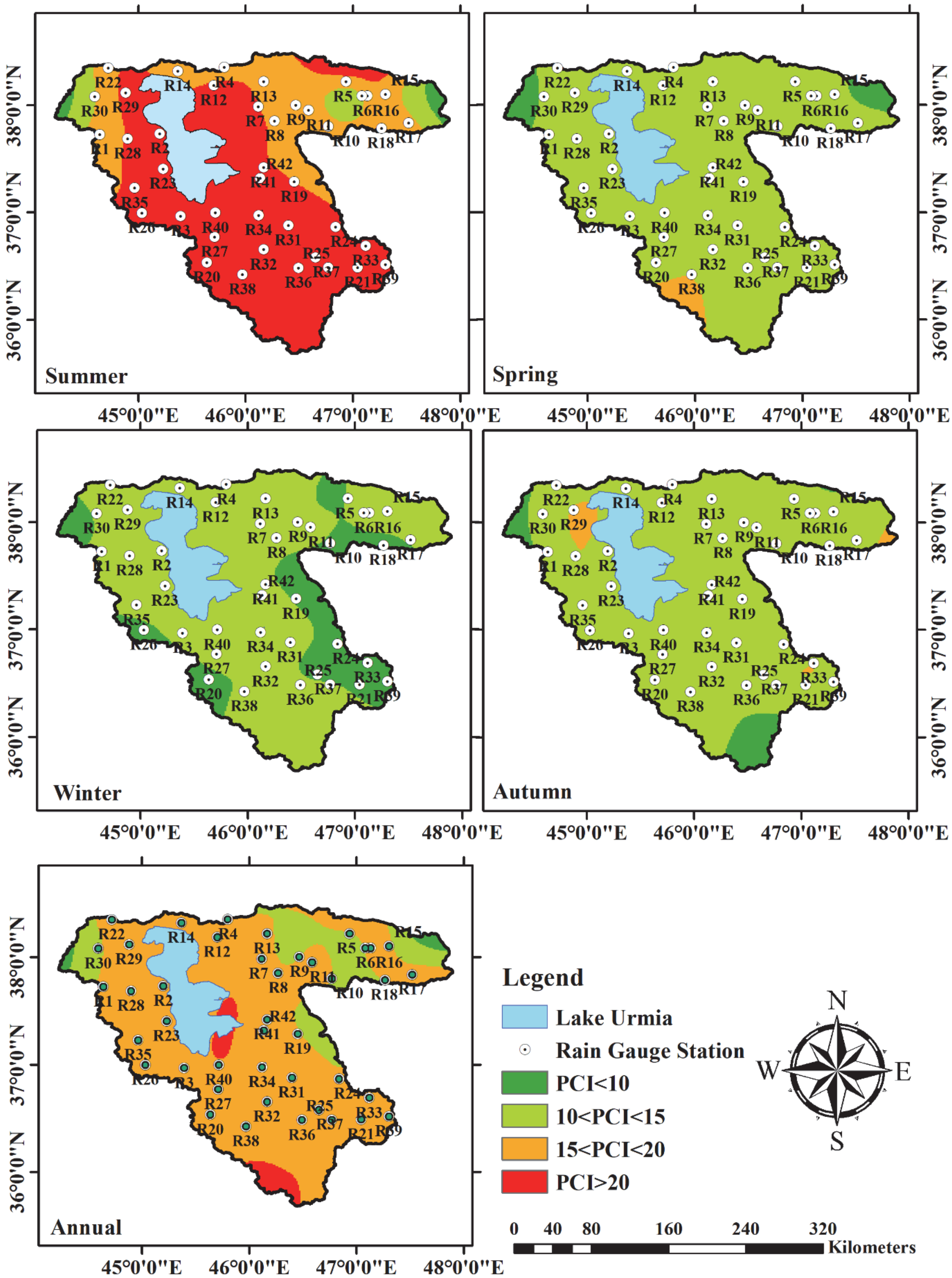

Fig. 3. Spatial distribution of *PCI* in annual and seasonal time scales in the period of 1984–2013.

As it can be seen in *Fig. 3*, the surroundings of the lake and the southern parts of the basin possess strongly irregular distribution of precipitation. The results indicated strongly irregular distribution of precipitation in the months of summer (July, August, and September) and a decrease in the summer rainfall. In this season (summer), the areas in the northwestern and northeastern parts of the basin and to the northwest of Lake Urmia have irregular concentrations of precipitation, while by getting away from the lake, the distribution of precipitation is more regular. The results of zoning the concentration index of rainfall in autumn showed that almost all the regions in the lake basin have moderate concentration and distribution of precipitation. In this season (autumn), a small area to the northwest of Lake Urmia has an irregular distribution of monthly precipitation.

Compared to the other seasons, the distribution of rainfall is more regular in winter. In winter, most of the rain gauge stations in the basin of the lake showed moderate distribution of precipitation. In the surroundings of the lake in this season, the concentration is moderate. Border areas in the basin of Lake Urmia in winter have regular distribution of precipitation. No irregular and strongly irregular concentrations were seen in this season (winter). On the annual scale, the distribution of most of the stations was irregular, which means that the precipitation distribution was irregular among the months of a year. The southeastern part of Lake Urmia on an annual scale has strongly irregular precipitation concentration. Areas in the northwestern and northeastern parts of the Lake Urmia basin are more regularly concentrated. The results of the present research are in accordance with the studies of (*Khalili et al.,* 2014; *Khalili et al.,* 2016) in investigating the concentration and trend of precipitation at synoptic stations of Iran.

3.2. Investigating the concentration index (CI) while studying the precipitation distribution in the basin of Lake Urmia

Basically, the concentration index shows whether or not the share of rainfall events against the total amount of precipitation events can be generally well described by a negative exponential distribution. This method consists of the collection and classification of daily rainfall values with a 1 mm increase, and then determining the relative effectiveness of different classes by analyzing the relative contribution (1 percent) of precipitation. *CI* is basically between 0 and 1, and geometrically shows the triangle between the line $X = Y$ and the exponential curve. When the share of each class to the total precipitation is the same, *CI* approaches 0, and when the share of precipitation is assigned to one class, the exponential curve changes into Y=0 line, and *CI* will equal 1. As it was mentioned in Section 2, in order to calculate the concentration index over the basin, first the recorded precipitation of the basin was classified into 1 mm classes. Finally, the value of the concentration index (*CI*) was obtained using Eq. (2) for each station. Similarly, the concentration index was calculated for all of the stations; the results are presented in *Table 3*. The results of studying the daily concentration index at seasonal scale are presented in *Table 4.*

Table 3. Results of calculation of the annual *CI* of rain gauge stations in the period 1984–2013

Station Number	Station	Latitude	Longitude	a	b	S	Annual *Ci*
1	Aghchekol	37.28	46.45	0.17	0.02	2969.68	0.41
2	Bashsisojan	37.80	46.77	0.1	0.02	2638.43	0.47
3	Basmenj	38.00	46.47	0.17	0.02	3053.47	0.39
4	Ghezelchehsadat	38.10	47.30	0.17	0.02	3053.47	0.39
5	Ghooshchisarab	37.78	47.27	0.16	0.02	3028.96	0.39
6	Herissarab	37.83	47.52	0.09	0.02	2526.12	0.49
7	Khooshehmehr	37.32	46.13	0.17	0.02	2969.68	0.41
8	Khormazard	37.42	46.17	0.14	0.02	2811.98	0.44
9	Mehraban	38.08	47.13	0.12	0.02	2697.35	0.46
10	Pardel	38.22	46.17	0.12	0.02	2654.22	0.47
11	Payam	38.35	45.80	0.12	0.02	2654.22	0.47
12	Saidabad	37.95	46.58	0.1	0.02	2638.43	0.47
13	Saray	38.22	46.93	0.06	0.03	2276.26	0.54
14	Sfahlan	37.98	46.12	0.1	0.02	2638.43	0.47
15	Shabestar	38.18	45.70	0.07	0.03	2391.7	0.52
16	Zarnaghheris	38.08	47.08	0.12	0.02	2697.35	0.46
17	Tasooj	38.32	45.37	0.12	0.02	2654.22	0.47
18	Zinjenab	37.85	46.27	0.14	0.02	2811.98	0.44
19	Afan	36.53	45.64	0.1	0.02	2606.73	0.48
20	Alasaghal	36.49	47.04	0.11	0.02	2628.00	0.47
21	Babarood	37.40	45.23	0.1	0.02	2606.55	0.48
22	Badamlu.xls	36.86	46.84	0.14	0.02	2896.44	0.42
23	Baghche-Misheh	36.48	46.77	0.13	0.02	2780.97	0.44
24	Chehreq	38.08	44.59	0.1	0.02	2585.03	0.48
25	Choblocha	36.88	46.40	0.15	0.02	2905.52	0.42
26	Dashband	36.65	46.17	0.11	0.02	2655.65	0.47
27	Gherdeyaghob	37.00	45.72	0.1	0.02	2538.01	0.49
28	Ghezel	36.42	45.97	0.13	0.02	2824.00	0.44
29	Ghezel-Ghaber	36.58	46.65	0.14	0.02	2896.44	0.42
30	Ghoshkhana	36.51	47.30	0.11	0.02	2628.00	0.47
31	Mosh Abad	37.73	45.20	0.11	0.02	2645.33	0.47
32	Naqade	36.96	45.39	0.12	0.02	2665.45	0.47
33	Pey Ghala	36.99	45.03	0.16	0.02	2912.26	0.42
34	Pole sorkhe	36.77	45.71	0.05	0.03	2163.22	0.57
35	Sari Ghamesh	36.48	46.49	0.14	0.02	2791.31	0.44
36	Sero	37.72	44.64	0.12	0.02	2675.28	0.46
37	Tamar	38.11	44.88	0.17	0.02	3053.47	0.39
38	Tapik	37.68	44.90	0.11	0.02	2704.35	0.46
39	Urban	38.35	44.72	0.16	0.02	2958.55	0.41
40	Zarrine	36.97	46.12	0.11	0.02	2660.5	0.47
41	Zereh Shoran	36.69	47.12	0.12	0.02	2743.48	0.45
42	Zhar Abad	37.23	44.96	0.13	0.02	2787.26	0.44

Table 4. Results of calculation of the seasonal *CI* of rain gauge stations in the period 1984–2013

Station Number	Station	Autumn *Ci*	Winter *Ci*	Spring *Ci*	Summer *Ci*
1	Aghchekol	0.39	0.42	0.41	0.40
2	Bashsisojan	0.48	0.47	0.45	0.48
3	Basmenj	0.4	0.41	0.38	0.40
4	Ghezelchehsadat	0.4	0.41	0.38	0.40
5	Ghooshchisarab	0.42	0.4	0.39	0.42
6	Herissarab	0.47	0.45	0.52	0.55
7	Khooshehmehr	0.39	0.42	0.41	0.40
8	Khormazard	0.43	0.40	0.44	0.43
9	Mehraban	0.46	0.46	0.46	0.46
10	Pardel	0.45	0.43	0.49	0.48
11	Payam	0.45	0.43	0.49	0.48
12	Saidabad	0.48	0.47	0.45	0.48
13	Saray	0.55	0.52	0.53	0.53
14	Sfahlan	0.48	0.47	0.45	0.48
15	Shabestar	0.50	0.51	0.52	0.56
17	Zarnaghheris	0.46	0.46	0.46	0.46
17	Tasooj	0.45	0.43	0.49	0.48
18	Zinjenab	0.43	0.40	0.44	0.43
19	Afan	0.46	0.48	0.48	0.56
20	Alasaghal	0.48	0.47	0.48	0.44
21	Babarood	0.47	0.47	0.48	0.54
22	Badamlu.xls	0.40	0.42	0.44	0.42
23	Baghche-Misheh	0.43	0.46	0.41	0.52
24	Chehreq	0.5	0.46	0.49	0.45
25	Choblocha	0.42	0.41	0.41	0.38
26	Dashband	0.46	0.47	0.46	0.45
27	Gherdeyaghob	0.51	0.47	0.50	0.48
28	Ghezel	0.44	0.45	0.41	0.52
29	Ghezel-Ghaber	0.40	0.42	0.44	0.42
30	Ghoshkhana	0.48	0.47	0.48	0.44
31	Mosh Abad	0.48	0.45	0.48	0.41
32	Naqade	0.47	0.46	0.42	0.40
33	Pey Ghala	0.44	0.40	0.42	0.40
34	Pole sorkhe	0.56	0.57	0.56	0.49
35	Sari Ghamesh	0.45	0.44	0.42	0.45
36	Sero	0.47	0.47	0.46	0.44
37	Tamar	0.40	0.41	0.38	0.40
38	Tapik	0.47	0.46	0.47	0.44
39	Urban	0.42	0.40	0.42	0.48
40	Zarrine	0.55	0.47	0.46	0.50
41	Zereh Shoran	0.53	0.46	0.44	0.34
42	Zhar Abad	0.44	0.46	0.42	0.42

To evaluate the accuracy of the coefficients *a* and *b*, function $Y = (a \times X)\exp(b \times X)$ can be employed along with the Lorenz curve. As examples, Lorenz curves of Stations 21 and 23 are presented in *Figs. 4* and *5*. In *Figs. 4* and *5*, Sum Ni (%) is the cumulative sum of the percentage of data frequency per each class, and Sum Pi is the subtraction of the cumulative sum of the frequency values of each class from the class mean.

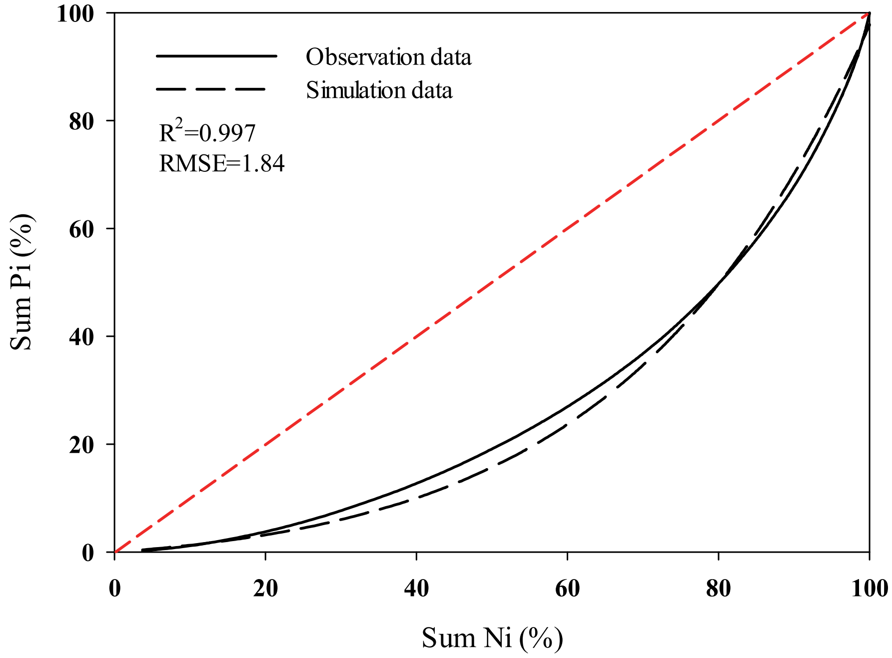

Fig. 4. Concentration (or Lorenz) curves for observed and estimated *CI* values of Babarood station (21)

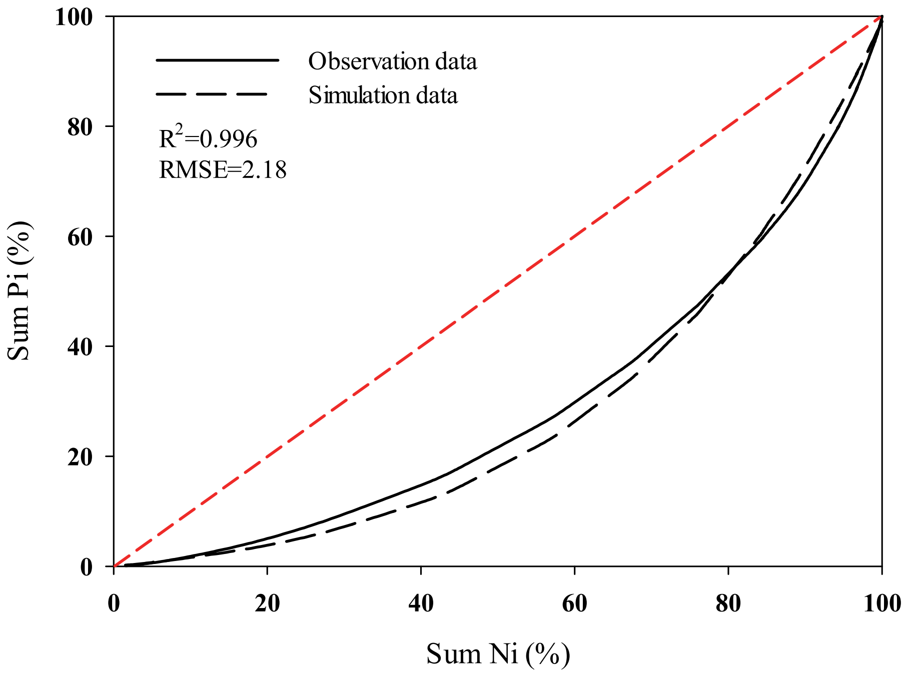

Fig. 5. Concentration, or Lorenz, curves for two observation and estimation *CI* values of Baghcheh-Misheh station (23)

The results of the studies of the concentration index showed that the average value of the index was obtained equal to 0.45 at annual and seasonal scales at all of the stations. On the annual scale, the lowest *CI* value was 0.39, and its maximum value was 0.57. A summary of the results of investigating stations in terms of daily precipitation concentration is presented in *Table 5*. According to the results, it can be concluded that the maximum value of *CI* on all the studied scales was 0.57 and 0.56.

Table 5. Summary of the results related to *CI* from 1984 to 2013

CI	**Annual**	**Autumn**	**Winter**	**Spring**	**Summer**
Max	0.57	0.56	0.57	0.56	0.56
Min	0.39	0.39	0.40	0.38	0.34
Average	0.45	0.46	0.45	0.45	0.45

According to the researches of Martin-Vide (2004), big values of *CI* (*CI* > 0.61) indicate a high concentration of daily precipitation, moreover, at stations with *CI*>0.6, the precipitation occurred on the 25 percent of rainy days. This indicates the possibility of highly aggressive and severe rainfalls at stations with *CI* > 0.61. *CI* < 0.61 values are more regularly distributed with regard to the daily rainfall, and the lower this number, the more regular station of interest is in terms of the number of rainy days and daily precipitation. In the present study, *CI* > 0.61 was observed at none of the studied stations. At annual scale, Stations 4, 3, 5, and 37 had the lowest *CI*, while the highest *CI* value was calculated for the Pole Sorkhe (34) station. To evaluate the concentration index regionally, *CI* values in the basin on different scales were zoned, and are presented as *Fig. 6*.

Based on the results of the studies of the concentration index (*CI*) in the period under review, no *CI* > 0.6 was observed in spring in any part of the study area. *CI* values were between 0.4 and 0.5 (the yellow parts) for most areas of the lake basin in this season (spring), while aggressive and severe precipitation was observed in none of the areas of the basin. In the northeast region of Lake Urmia and partly to the south of the lake, *CI* was 0.5 to 0.6, which represents irregular daily precipitation in these areas. The daily distribution of precipitation is more regular in the southern part of the basin, and a regular exponential distribution fits the rainfall data of the rainy days. As it was seen in spring, the daily precipitation in the southern basin of Lake Urmia is more regularly distributed. In autumn in the study area, like spring, *CI* > 0.6 was observed at none of the stations studied. Some areas in the eastern and southern, as well as the northeastern and southeastern parts of the basin of Lake Urmia, are more irregular than the others.

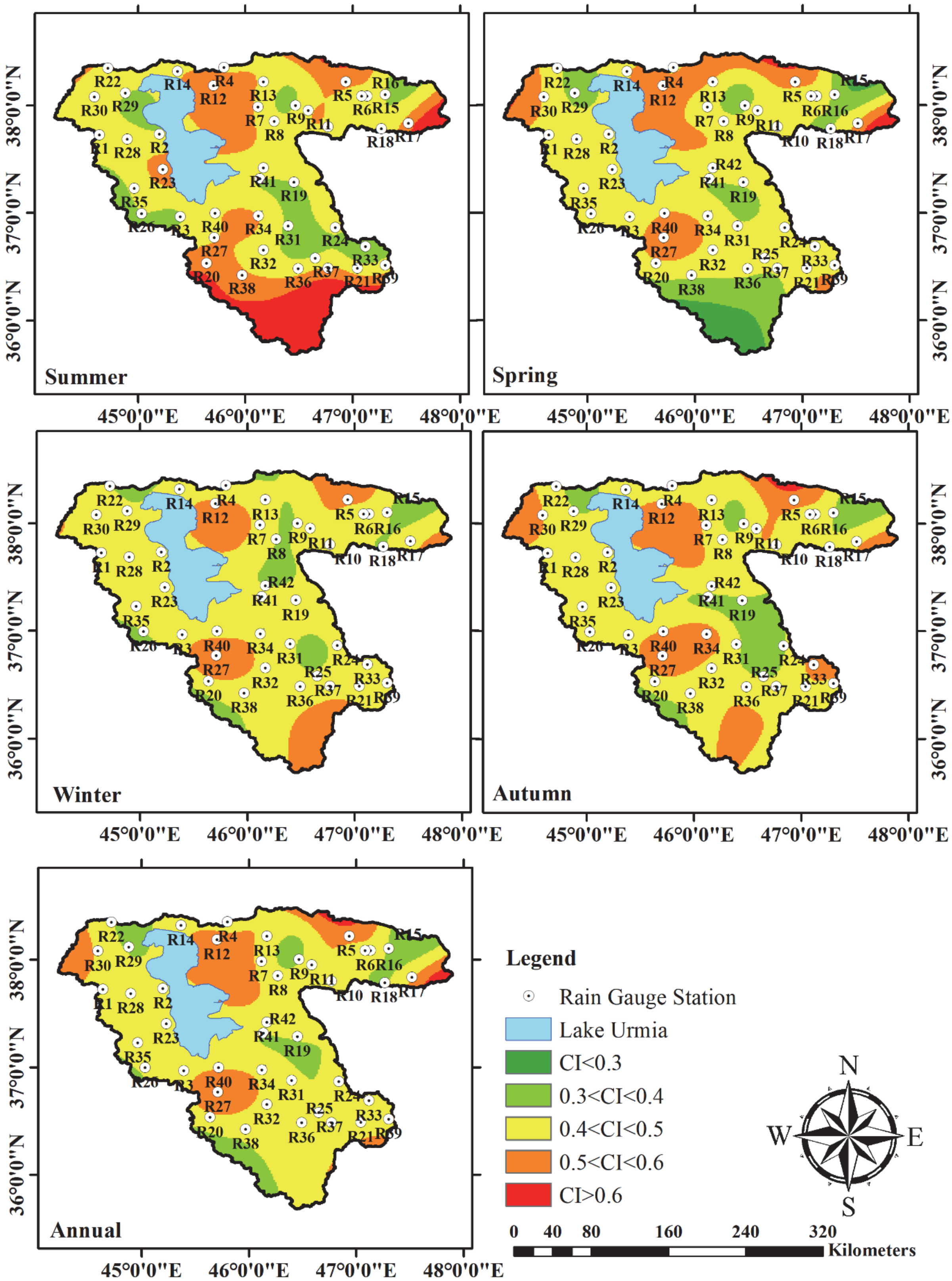

Fig. 6. Spatial distribution of *CI* index in annual and seasonal time scales in the period of 1984–2013.

The results showed that in both spring and autumn, these areas have severe and thunder-like rainfalls on days with precipitation, and the precipitation distribution in the rainy days is of less regularity than in the other regions. Areas in the eastern and northeastern parts of the basin (the areas colored green) are also relatively regular in terms of daily precipitation distribution. Other regions (colored yellow) deal with a moderate distribution of daily rainfall. Regular concentration was not observed in this season either. In winter, similarly to spring and autumn, areas to the south and northeast of Lake Urmia, as well as a region in the northeastern part of the basin in the period studied have an average *CI* value between 0.5 and 0.6, indicating strong concentration of daily precipitation and irregularity in the daily precipitation distribution in these areas. Also, it can be concluded that the amount of daily rainfall in the abovementioned areas is not divided regularly among the days with precipitation. Most areas of the basin have a *CI* between 0.4 and 0.5. In this season, neither regular distribution ($CI < 0.3$) nor irregular distribution ($CI > 0.6$) of daily rainfall was observed. Some small areas in the eastern part of the basin of Lake Urmia had *CI* values between 0.3 and 0.4, indicating a regular distribution of daily rainfall in winter days. In other words, the amount of precipitation is distributed fairly regularly in this season among the days with precipitation in the abovementioned areas. There is strongly irregular precipitation in summer in the southern parts of the lake basin, so that it can be concluded that 70 percent of the precipitation in this season has occurred only on 25 percent of the rainy days (days with precipitation).

In this season, the northeastern and southern regions of the lake, an area in the northeastern, and also a station in the southwestern region of the lake are of irregular concentration distributions of summer precipitation. In this season (summer), the regular distribution of daily rainfall was not observed in the basin. Some stations to the northwest of Lake Urmia and also to the southeast and west of the lake were of relatively regular daily precipitation. On an annual scale, most areas of the lake basin fell within the moderate concentration class (*CI* between 0.4 and 0.5). On this scale (annual), similarly to the seasonal scales, the northeastern and southern regions of Lake Urmia basin had more irregular concentration than the other areas. On an annual scale, regular daily precipitation distribution was observed at none of the stations studied throughout the basin of Lake Urmia. Moreover, the eastern part of the basin faces an increased precipitation irregularity in the time scales studied, though this change is not significant. Nonetheless, the reduction in precipitation reported by (*Asakereh* and *Razmi*, 2012; *Dinpashoh et al*., 2013; *Khalili et al.,* 2016) had a significant impact on the status of water resources of the region and can even be involved as an influencing factor on the drying up of Lake Urmia.

4. Conclusion

The results of the investigation of the annual precipitation concentration showed that in the basin of Lake Urmia, the precipitation distribution is generally irregular. The values of precipitation distribution index for the stations located to the east of Lake Urmia was 17.55 and for the stations to the west of the lake it was 16.37, indicating that precipitation is more irregular in the eastern parts of the lake than in the western parts. The irregularity of precipitation in the eastern parts of Lake Urmia basin will lead to more extreme rainfall events. The results also showed that during the period under review, the concentration index of precipitation at stations in the western and eastern parts of the lake had increased by 0.38 and 4.06 percent, respectively. Meanwhile in spring, the results indicated that precipitation distribution during the period under review became more regular. In summer, as in spring, a decrease in the concentration index of precipitation over the basin of Lake Urmia was observed, which represents a uniform distribution of rainfall in the months of summer. The concentration of autumn precipitation during the last 10 years of the study period in relation to the first 10 years has increased by about 20.54 percent. In this, the share of the western areas of Lake Urmia is about 19.91 percent, and the share of the eastern part of the lake is about 21.22. The increase in the concentration index over the basin of Lake Urmia in autumn depicts that the precipitation distribution has changed from moderate distribution to irregular distribution; this increase can increase autumn extreme precipitation events.

Based on the *PCI* index, winter precipitation at the basin studied is moderate and regular in terms of distribution, which demonstrates a uniform and moderate precipitation distribution in the months of winter. The results generally showed that the distribution of annual and autumn precipitation patterns of the basin of Lake Urmia, particularly in the eastern parts of the basin, became irregular from 1984 to 2013; this indicates the possibility of extent rainfall and flooding events in this season. The results of the studies of the concentration index throughout the basin showed that the daily rainfall of basin of Lake Urmia was within neither strongly irregular nor regular conditions at any of the stations. In the meantime, most of the stations studied were in the moderate concentration class in terms of daily precipitation distribution. In autumn, winter, spring, summer, and on the annual scale, 74, 90, 81, 74, and 84 percent of the rain gauge stations studied were respectively of moderate precipitation concentration. According to the results of the values of concentration index (*CI*), there is a possibility of severe and extreme precipitation in the southern and eastern parts of the basin of Lake Urmia; this possibility would increase over the course of time. Recent floods in the eastern part of the lake confirm these results. By analyzing and studying the concentration index and the precipitation concentration index, it is possible to investigate extreme events as well as the irregularity and inequality of daily, monthly, and annual precipitation. Hence, further researches should be considered to determine the correlation between the precipitation concentration index and the occurrence of extreme events such as floods, soil erosion, and drought.

Also the results of comparing two 10-year-long sub-periods indicated that *PCI* index of the second sub-period increased in the spring time scale that means that the irregularity of precipitation distribution has been increased, while in the other seasons significant variations were not observed. Also in the annual time scale, *PCI* index has been increased in the second sub-period because of the increasing trend of precipitation. These results showed the importance of applying techniques of water resources management in most parts of Iran, especially in the northwestern areas of Iran, where Lake Urmia and agricultural fields are located.

The evaluated indices, as statistical indicators, can specify different weights of precipitation, including distribution, share of extreme precipitation, and spatial distribution in relation to the total precipitation. One of the benefits of studying drought indices, such as the *PCI*, is the ability to observe the precipitation distribution among the months of a season and even a year, and also to distinguish the governing distributions. Therefore, the results may be utilized when facing droughts or extreme rainfall conditions.

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