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Studying spatial and temporal changes of aridity in Iran

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Abstract Optimum use of water in agriculture, drinking, and industry is necessary in arid and semi-arid regions like Iran, which face serious water tensions. Since studying aridity and its trend of changes has a significant role in water resources management and urban planning, this research has investigated spatial and temporal changes and trend of aridity changes in Iran as an arid country. To study the issue, 51 weather stations of Iran which covered a 30-year statistical period (1981–2010) were selected. Climatic variables, namely precipitation, vapor pressure, local pressure, temperature, maximum temperature, and relative humidity and required data to calculate the potential evapotranspiration were extracted from Iran meteorology organization data. In next step by applying A_i, I_m, and I_q aridity indices, zoning of the aridity was done after studying the aridity traits and its change. Then the most compatible aridity index was introduced according to the values of correlation between climatic factors of aridity indices and the magnitude of each main climatic area of Iran. Furthermore, in order to recognize aridity changes in Iran during the selected 30-year period, Mann-Kendal nonparametric test was used. Correlation analysis results showed that 35.4 and 64.6 % of Iran arid areas show more compatibility with I_m and A_i, respectively, which means that these indices are more appropriate to study aridity in arid regions of Iran. Also, it was revealed that 5.6 and 94.3 % of Caspian south plain region has more compatibility with A_i and I_q indices, respectively. As a matter of fact, 77.8, 0.75, and 21.4 % of the country area can be studied better by A_i, I_q, and I_m, respectively. Also, the results of Mann-Kendal nonparametric test confirmed that aridity is developing in Iran. In other words, 80.4 % of Iran area had increasing trend of aridity during the selected period and in just 19.6 % of the area, aridity trend was not significant or decreasing.

Keywords Aridity · Aridity index · Zoning · Trend of aridity changes · Iran

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Introduction

Vast areas of Iran and a third of world area have arid condition. These regions face shortages to fulfill water requirements of plants naturally (Rodrigues 2004). Although there are different factors associating with the aridity definitions, the most common of all is the lack of precipitation in comparison with potential evapotranspiration which causes problems for water requirement of plants (Bannayan et al. 2010). Agnew and Anderson (1992) defined aridity as a situation in which the amount of humidity is less than its average in a region which is a permanent climatic characteristic of a region.

Climatologists have suggested various climatic indices to investigate aridity intensity and traits, as nowadays different kinds of indices and aridity coefficients are used to study the aridity conditions. Nastos et al. (2013) studied spatial and

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temporal variations in Greece in which spatial and temporal traits of A_i aridity index were investigated. These traits were among 28 meteorology stations during a 50-year period from 1951 to 2000. The results showed that there was a gradual change from a humid region, as a wide region of Greece, to a semi-arid region; the most important change was from 1991 to 2001.

Liu et al. (2013) investigated temporal and spatial changes of A_i arid index in northwest of China from 1960 to 2011. The analysis of meteorology data from 80 meteorology stations showed that annual aridity index decreased and it became more humid from 1960 to 2010.

Şahin (2012) offered a new aridity index, I_q, the ratio of precipitation to humidity. In this study, which was implemented in Turkey, three indices, A_i, I_q, and I_m, were studied throughout 7 climatic regions of Turkey in 211 meteorology stations from 1974 to 2008. Considering similarities and differences of these 3 indices throughout the 7 regions, it was proven that I_q index is the best index to indicate the degree of aridity and humidity in Turkey.

Quan et al. (2013) investigated the validation of temperature and precipitation, using Thornthwait humidity index, soil moisture index, near-ground atmospheric relative humidity, and five aridity indices. They reported that AI_{Koppen} is the most reliable index to evaluate world hydrologic condition in specific areas.

Huo et al. (2013) studied temporal changes of evaporation, reference evapotranspiration, and A_i aridity index and showed that annual temperature, moisture, and precipitation temporally had remarkable increasing trend during the last 50 years, while wind speed and radiation had decreasing trend. Both evaporation and reference evapotranspiration with 3 mm decrease per year and A_i index have decreasing trend. They believed that in spite of the wind speed which is the most sensitive metrological variables for potential evapotranspiration, since the amount of precipitation is the most significant meteorological variable for A_i, so precipitation increase led to A_i decrease during the recent 50 years.

Ashraf et al. (2014) studied temporal and spatial variation of aridity in Iran, using several reliable universal indices. Based on the applied aridity indices, they stated that at the beginning of twenty-first century, (2000–2008), there was a remarkable increase in temperature in all meteorology stations in Iran; also, the precipitation anomalies suggest the arid period during the initial years of twenty-first century in Iran.

Tabari et al. (2014) studied aridity phenomenon in Iran, applying de Martonne and Pinna indices. They believed that 88 and 96 % of Iran area, according to de Martonne and Pinna indices, respectively, are in arid and semi-arid regions. In addition, there is a significant decreasing trend in aridity index in the western and northwest areas of Iran.

Bannayan et al. (2010) have explored the relationship between arid index (AI) and the performance of dry crops (wheat and oats) during statistical period from 1985 to 2005 in Khorasan Province. The findings revealed that there is a significant relationship between AI and performance of crops in the center of the province. Moreover, correlation coefficient between the performance of AI and oats is stronger than the correlation coefficient between AI and wheat in the studied region.

Ahani et al. (2013) have investigated the trend of aridity index throughout the three large basins of arid and semi-arid regions of Iran. In their research, monthly trend of precipitation (P), potential evapotranspiration (PET), and A_i aridity index were studied for synoptic meteorology stations among the three large basins of Iran during recent 50 years. They used Mann-Kendal nonparametric test for trend analysis, and their results revealed that in the northern parts of the studied basins, aridity condition was decreasing, while it was increasing across southern parts of Iran.

Shifteh Some'e et al. (2013) studied the process of temporal-spatial aridity index of arid and semi-arid regions of Iran among 22 synoptic weather stations from 1966 to 2005, using Mann-Kendal test and Theil-Sen estimator. The results showed a decreasing trend of aridity in 55 % of the whole studied stations.

Zare Abyaneh et al. (2011) have studied the trend of aridity index changes in southern parts of Iran, using Mann-Kendal nonparametric test. In order to evaluate the trend, 10 synoptic stations with a 40-year statistical period were selected. The analyses showed that the climate of the most stations, 80 %, tended to have a humid condition.

Ensafi-moqadam (2005) has studied arid index in the basin of salt lake of Qom, using Demarton method. Arid index average of the salt lake is 11/092 during a 40-year statistical period revealing semi-arid-dominant climate during the studied period.

Teymouri et al. (2011) have focused on the process of the arid index in Iran. In this study, climatic changes of 36 meteorology stations of Iran were studied by humidity/aridity index during a statistical period from 1976 to 2005. Thornthwaite method was used to estimate evaporation. Dividing Iran into six climatic levels, the aforesaid index was considered as climatic changes and the amount of real humidity/aridity of the regions.

Reviewing the previous researches, dedicated to the features and changes of environmental phenomenon of aridity in Iran, were mostly based on the A_i index. In this study, we aimed at not only investigating aridity status in Iran, using I_q index which is considered to be an appropriate index to study aridity in Iran but also comparing the results with the results of I_m and A_i indices. In addition, after determining the trend of aridity based on the mentioned indices, the most appropriate index to study the aridity of each part of Iran will be introduced.

Data and methodology

In order to evaluate aridity in Iran, 51 synoptic stations were chosen. They had more complete data of a 30-year period from 1981 to 2010. The features and conditions are presented in Fig. 1. The data, including monthly total precipitation, air vapor pressure, local pressure, temperature, maximum temperature, average relative humidity, maximum and minimum temperature, maximum and minimum of relative humidity, wind speed, and daily sun shining hours, were received from IRIMO.[1] Figure 1 shows the topography map of Iran and location of the 51 selected synoptic stations in Iran.

Methodology

The following indices were applied to study the climatic features of aridity and its trend during selected period in Iran.

A_i index

The values of this index (Table 1) are used to find the aridity of an environment which is calculated by precipitation variable divided with potential evapotranspiration (UNEP 1992) which is

$$A_i = \frac{P}{\text{PET}} \tag{1}$$

Where P is long-term average of precipitation and PET is long-term average of evapotranspiration in the synoptic station.

Calculating evapotranspiration is necessary to determine the values of A_i aridity index which can be found by several methods. In this research, FAO Penman-Monteith method has been used.

As a matter of fact, the optimality of Penman method is due to using more effective meteorology parameters in the amount of evapotranspiration. Moreover, other researchers have proven the accuracy of Penman-Monteith method and other methods based on Penman method (Dehghani Sanij et al. 2004; Jensen et al. 1990; Rahimi Khoob 2008).

FAO Penman-Monteith method

This equation is used to calculate potential evapotranspiration based on FAO Penman-Monteith method (Allen et al. 1998).

$$\text{ET}_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T + 273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34\, u_2)} \tag{2}$$

Where ET_0 is reference evapotranspiration (mm day^{-1}), R_n is net radiation at the crop surface (MJ m^{-2} day^{-1}), G is soil heat flux density (MJ m^{-2} day^{-1}), T is mean daily air temperature at 2 m height (°C), u_2 is wind speed at 2 m height (m s^{-1}), e_s is saturation vapor pressure (kPa), e_a is actual vapor pressure (kPa), $e_s - e_a$ is saturation vapor pressure deficit (kPa), Δ is slope vapor pressure curve (kPa °C^{-1}), and γ is psychometric constant (kPa °C^{-1}).

I_q index

The values of this index are determined by long-term average of the annual precipitation total (mm) divided into specific humidity in which specific humidity is calculated by (S_h), from (q_e) formula (Gill 1982). Different climatic regions found by P/S_h are presented based on Sahin classifying pattern (Sahin 2012).

$$I_q = \frac{P}{S_h} \tag{3}$$

$$S_h = q_e \quad q_e = \frac{0.622 e_a}{p_a - 0.378 e_a} \quad e_a$$

$$= \text{rh}10^{\left[\left(0.7859 + 0.03477\,\text{Ta}\right) / \left(1.0 + 0.004212\,\text{Ta}\right) + 2\right]} \tag{4}$$

Where S_h is specific humidity and for its calculation, q_e equation is used. In fact S_h is equal to q_e.

$$q_e = \frac{0.622 e_a}{P_a - 0.378 e_a} \tag{5}$$

Where p is long-term average of the annual precipitation total (mm), S_h is long-term average of the annual mean specific humidity (g/kg), q_e is specific humidity (kg/kg), e_a is vapor pressure of the air (Pa), P_a is local pressure (Pa), R_h is monthly mean relative humidity (%), and T_a is monthly mean temperature (°C).
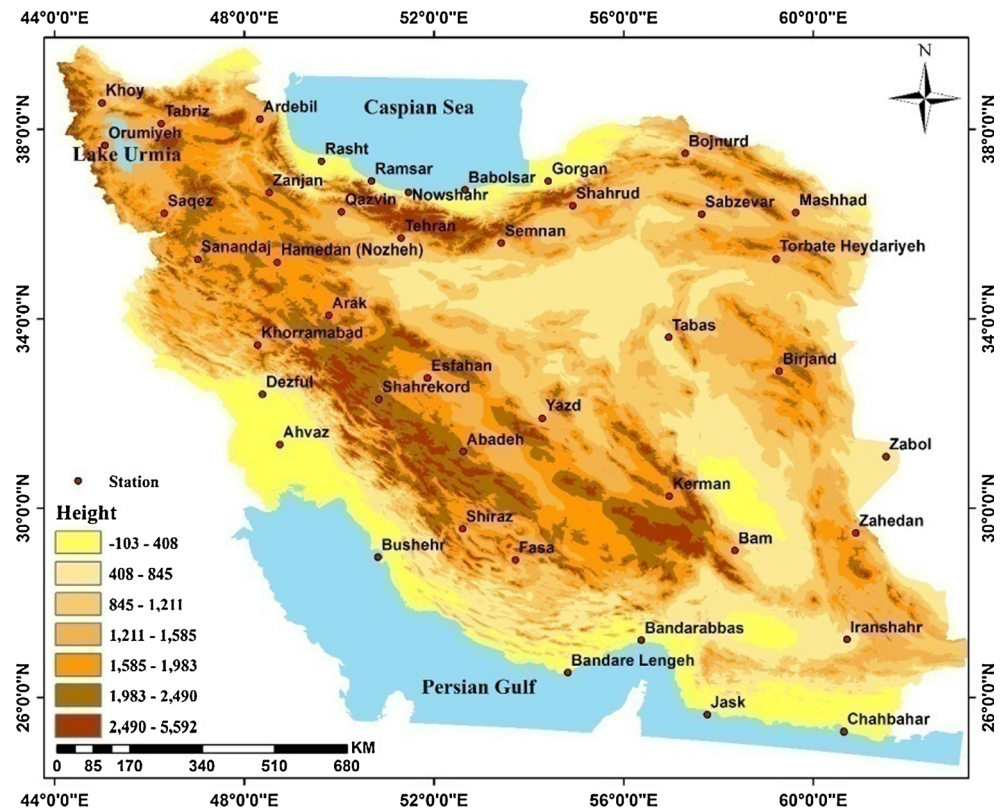
Climatic regions which are obtained from $\frac{P}{S_h}$ ratio are classified (Table 2) according to Sahin classification (Sahin 2012).

I_m index

The value of this index is defined by precipitation dividing with maximum temperature. Different climatic region, found by P/T_{max}, is shown based on Erinc classification (Erinc 1965).

$$I_m = \frac{P}{T_{max}} \tag{6}$$

Fig. 1 Topographic map of Iran and location of the selected synoptic stations in Iran

Where P is long-term average of the annual precipitation average (mm) and T_{max} is annual maximum temperature (°C).

Climatic regions which are obtained from $\frac{P}{T_{max}}$ ratio are classified according to Erinc classification (Erinc 1965; Table 3).

Aridity zoning in Iran

The results of statistical analyses of aridity during a 30-year period, based on the mentioned indices, using GIS[2] and RBF method, are presented in the zoning maps of the country aridity severity.

Radial basis functions (RBF) are of deterministic interpolation methods in which estimation level pass the observed values. This method is a kind of artificial neural network (Golmohamadi et al. 2009).

There is a basic kernel function which resembles modify in Kriging method. Basic kernel functions are defined as an optimal collection of applied weights to the related data of each point when a network node is interpolated (Chen et al. 2010).

Finding the aridity changes in Iran

I_q index is used to study the trend of aridity in Iran. Likewise, in this study, Mann-Kendal nonparametric test (Sneyers 1990) was applied to find the trend of aridity variation in Iran.

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[2] Geographical information system.

Results and discussion

Aridity intensity for each of the selected stations based on the applied indices is studied. Applying various interpolated methods for statistical spatial analyses in GIS environment helps to make aridity zoning maps and more precise spatial analyses of aridity phenomenon. The results of spatial analysis and methods for each index are presented below.

A_i index

Figure 2 shows Iran zoning based on the values of A_i index. According to the map, all five humidity conditions which are defined by UNEP (1992) are observable in Iran.

The confine of hyper-arid area is located in southeast of Iran and Lut plain, in which the most apparent characteristic is very low precipitation and extremely high temperature. As a

Table 1 Different climatic levels based on A_i

A_i	Climate type
<0/05	Hyper-arid
0/05–0/20	Arid
0/20–0/50	Semi-arid
0/50–0/75	Semi-humid
>0/75	Humid

Table 2 Different climatic levels based on I_q

I_q	Climate type
<20	Hyper-arid
20–35	Arid
35–60	Semi-arid
60–90	Semi-humid
90–120	Humid
>120	Hyper-humid

matter of fact very high evapotranspiration, over 2000 mm and very low precipitation led to decrease of values of A_i index. The area of this region is 285,442 km^2 (16.78 %), while the area of arid region is 782,812 km^2 (46.02 %) which covers vast areas of central parts of Iran and south to the Persian Gulf and Oman coasts.

Alborz and Zagros mountain ranges play a significant role in the temporal and spatial distribution of precipitation throughout Iran. These two mountain ranges prevent humid air masses to reach central parts of Iran; therefore, the center of Iran is the driest part (hyper-arid area) of the country. The semi-arid region with the area of 560, 323 km^2 (32.94 %), like arid region, covers a vast part of Iran, including areas in th northeast, center, southwest, and west of Iran.

Semi-humid climate, covering 53,159 km^2 (3.13 %), is located more in northern and western mountainous regions of Iran. In fact, various factors are engaged in this distribution, including higher precipitation, which is caused by adjacency to the Caspian Sea, high altitude, which attracts high snowfall, and low temperature.

Humid climate, the smallest climatic area of Iran about 19, 234 km^2 (1.13 %) according to the aforesaid indices, is mainly located in western coasts of the Caspian Sea. So unlike arid and hyper-arid regions, in semi-humid regions, evapotranspiration decreases, while rainfall increases, and as a result, A_i index values increase. This situation can be observed in humid and semi-humid regions of Iran.

According to UNEP (1992), hyper-arid, arid, semi-arid, semi-humid, and humid regions receive around 73.9, 169, 328, 499.4, and 1287.2 mm precipitation per year, respectively.

Table 3 Different climatic levels based on I_m

I_m	Climate type
<8	Hyper-arid
8–15	Arid
15–23	Semi-arid
23–40	Semi-humid
40–55	Humid
>55	Hyper-humid

I_q index

Figure 3 shows the value of I_q index in the frame of zoning map. According to this map, all six humidity conditions which are defined by Sahin (2012), are observable in Iran. The confine of hyper-arid region, with the area over 342,455 km^2 (20.08 %), is seen in southeast and parts of southern coasts of Iran. In spite of higher specific humidity in southern coast regions of Iran, it is considered as hyper-arid region, because of its low precipitation amounts. In fact, the synoptic stations which have more specific humidity (S_h) and less precipitation are considered hyper-arid, since I_q index values decrease considerably.

Arid regions cover a vast area of central and southern parts of Iran. This confine is 580,390 km^2 (34.4 %). In other words, in addition to low specific humidity in these regions, there is less precipitation. Simultaneous decrease of these two factors leads to aridity of these regions. The area of semi-arid region is 523.176 km^2 (30.68 %). This region covers a considerable area in Iran, including the northeast, northwest, center, and southwest parts. Like A_i index, this index proves that most area of Iran is in arid and semi-arid regions.

Semi-humid climate, 222,631 km^2 (13.06 %), covers vast areas of west of Iran; moreover, some parts of west and northwest have similar precipitation conditions similar to humid regions. In fact, more precipitation marks higher I_q values which lead to milder climate in these regions. Humid climates, covering 30,607 km^2 (1.8 %), have the same quality of extreme humid region, although there is a slight variation in precipitation and specific humidity. Extreme humid regions, covering 5778 km^2 (0.34 %) of Iran, are the smallest region of the country. This region shows the highest values of I_q value. Unlike southern coasts, the amount of specific humidity in northern coast decreases. This decrease of specific humidity with an increase of precipitation leads to an increase of I_q index. As a matter of fact, these regions with more moisture and less precipitation experience more aridity. As a result, I_q index values decrease. However, the region with less stable moisture and more precipitation has better moisture conditions as I_q value increases.

I_m index

Figure 4 shows the value of I_m index distribution throughout Iran which reveals that all six humid conditions, defined by Erinc (1965), are observable in Iran. According to both I_m formula, achieved by precipitation divided into maximum temperature, and dryness of Iran plateau, the vast area is located in hyper-arid region. This climate include 917,658 km^2 (53.70 %) of Iran's area which covers the central parts, southeast, and south of Iran.

Fig. 2 Climatic zoning of Iran, based on A_i index
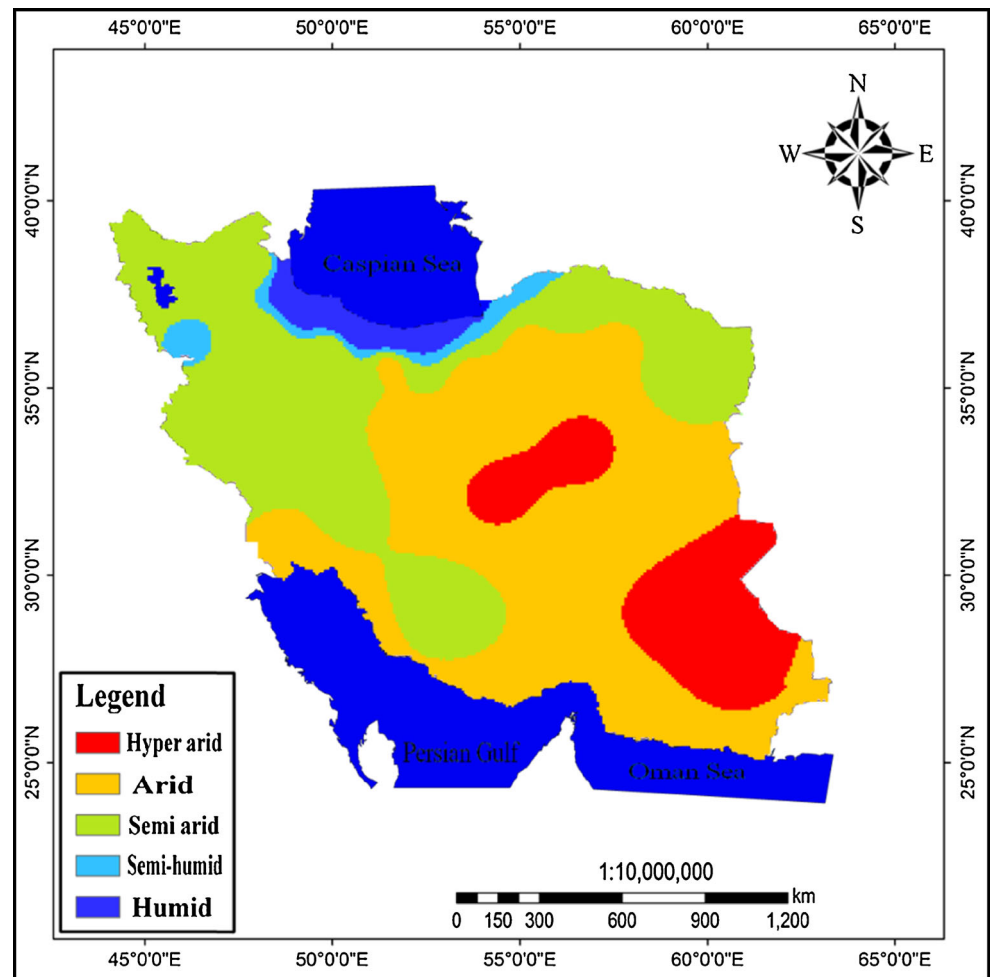
This condition is resulted from higher temperature average, more frequency of maximum temperatures, and low precipitation amounts. Vast area of arid region, over 442, 134 km^2 (25.87), covers the northwest and southwest of Iran. One of the most effective parameters on the aridity of the region, despite high maximum temperatures is receiving very low precipitation in comparison with semi-arid regions.

Semi-arid regions, 275,436 km^2 (16.12 %), covers parts of the northwest and west of the country. These regions have less temperature average (13 °C) and less frequency of maximum temperatures. Semi-humid and humid areas cover 22,210 km^2 (2.47 %) and 13,230 km^2 (0.77 %) of Iran, respectively. In fact, lower temperature and more precipitations lead to these climate conditions.

As expected, vast area of hyper-humid regions are located in south and southwest coasts of the Caspian Sea. Due to high moisture, the temperature ranges are very small. Moreover, these regions, affected by blowing precipitation and westerly winds, receive more precipitation. So these factors affect I_m index, and this region is classified in hyper-humid climatic class. The area of this region

is over 18,270 km^2 (1.07 %). Generally, as the distance from Caspian coasts and Zagros mountain range increases, precipitation decreases, while thee maximum of temperature increases which leads to arid climate in the central areas of Iran.

Finding the appropriate aridity index for Iran climatic regions

Examining zoning maps of A_i, I_q, and I_m indices shows similarities and differences in aridity trait of Iran meteorology stations. Generally, it can be said that about 58 % of Iran arid area is ranked as arid according to each aforesaid indices. In the other words, all stations of this region have arid condition, based on these three indices; for example, stations like Ahvaz, Abadan, Kashan, Kerman, and Semnan are all located in arid climate class.

Likewise, there are apparent differences among A_i, I_q, and I_m indices in zoning maps. For example, the area of hyper-arid region differs greatly on the basis of the following three indices, that maximum area and minimum area can be seen in I_m and A_i indices, respectively, which

Fig. 3 Climatic zoning of Iran according to I_q index
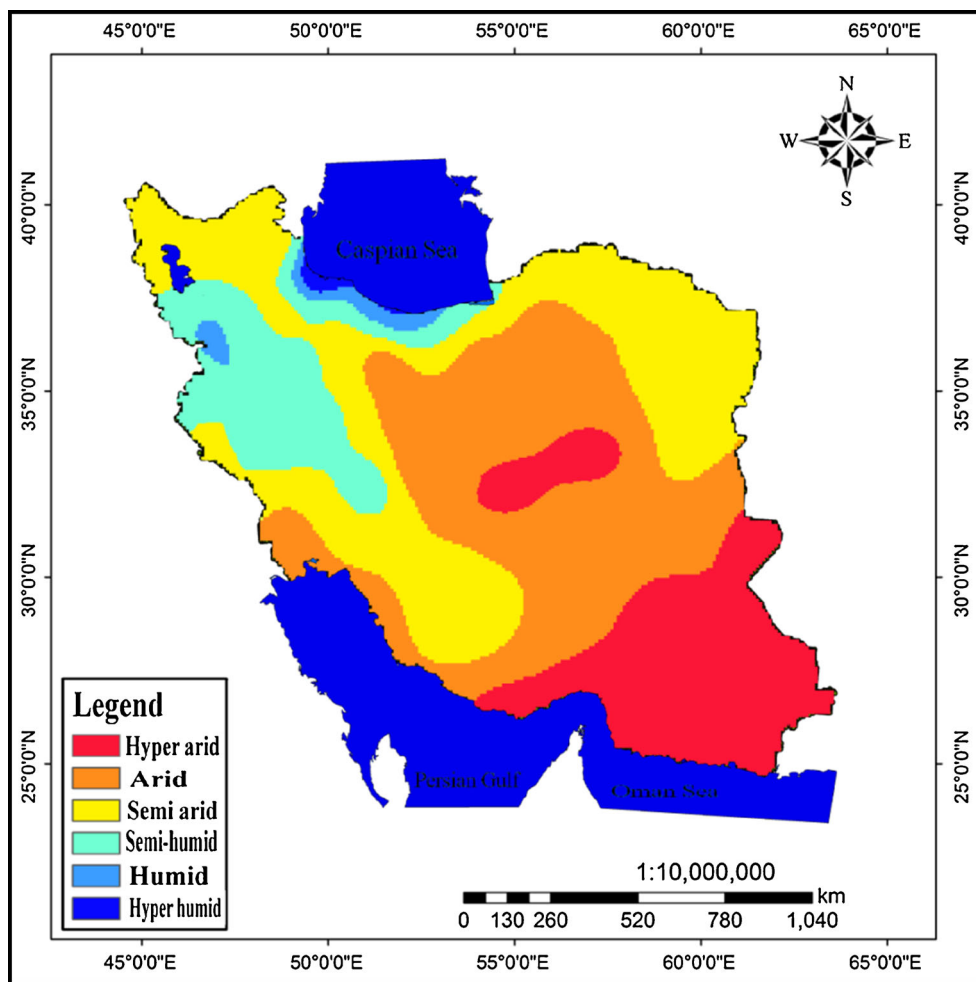
may be the result of higher temperature average impact on this climatic region. In fact T_{max} has more focus among the stations of the region. By studying the quality and quantity of zoning maps, it can be said that an index is more suitable than others to determine the aridity of a climatic region. Although none of these indices are recognized suitable enough for all parts of Iran, it seems that more suitable index for each climatic region can be recognized. So to find the suitable index for each region, correlation coefficients of climatic parameters of the indices among the stations were determined. In other words, a correlation was established between 30-year outputs of A_i, I_q and I_m and precipitation amount, maximum temperature, evapotranspiration, and specific humidity.

Table 4 shows the correlation analysis. The results show that from 985,761 km^2 of the arid area (57.6 % of the Iran area), 35.4 % of the area shows stronger correlation with I_m index, while 64.6 % of this region shows stronger correlation with A_i aridity index. Thus, it can be concluded that A_i index corresponds with arid region of Iran and can be a better index of aridity. Besides, by observing zoning maps of these three indices, it becomes clear that A_i shows arid climate much

better than other indices, as hyper-arid climate is distinguished well from the arid region.

In fact hyper-arid regions show rare precipitation and the highest annual evaporation and transpiration. However, by other indices, I_m and I_q, this separation is not the same as real climatic regions of Iran. For example, based on the results of I_m and I_q, the stations like Tabas, Bam, and Iranshahr and coastal stations of Chabahar and Bandarabas are categorized in the same class, hyper-arid climatic class, which is different from the climatic reality of these regions. Since Tabas, Bam, and Iranshahr stations have the lowest amounts of precipitation and the highest amounts of evapotranspiration, coastal stations of Chabahar and Bandarabas do not have the aforesaid conditions and cannot be included in hyper-arid class. In addition to correlation results, zoning maps show that A_i index can distinguish hyper-arid boundary from arid boundary which confirms that A_i index is a better index to show aridity in these regions.

Analyzing the results of correlations and zoning maps revealed that I_q aridity index separates the boundary between west and east climates of Caspian Sea in a precise way, as the stations like Anzali, Nowshahr, and Rasht are in hyper-humid

Fig. 4 Climatic zoning of Iran, based on I_m index
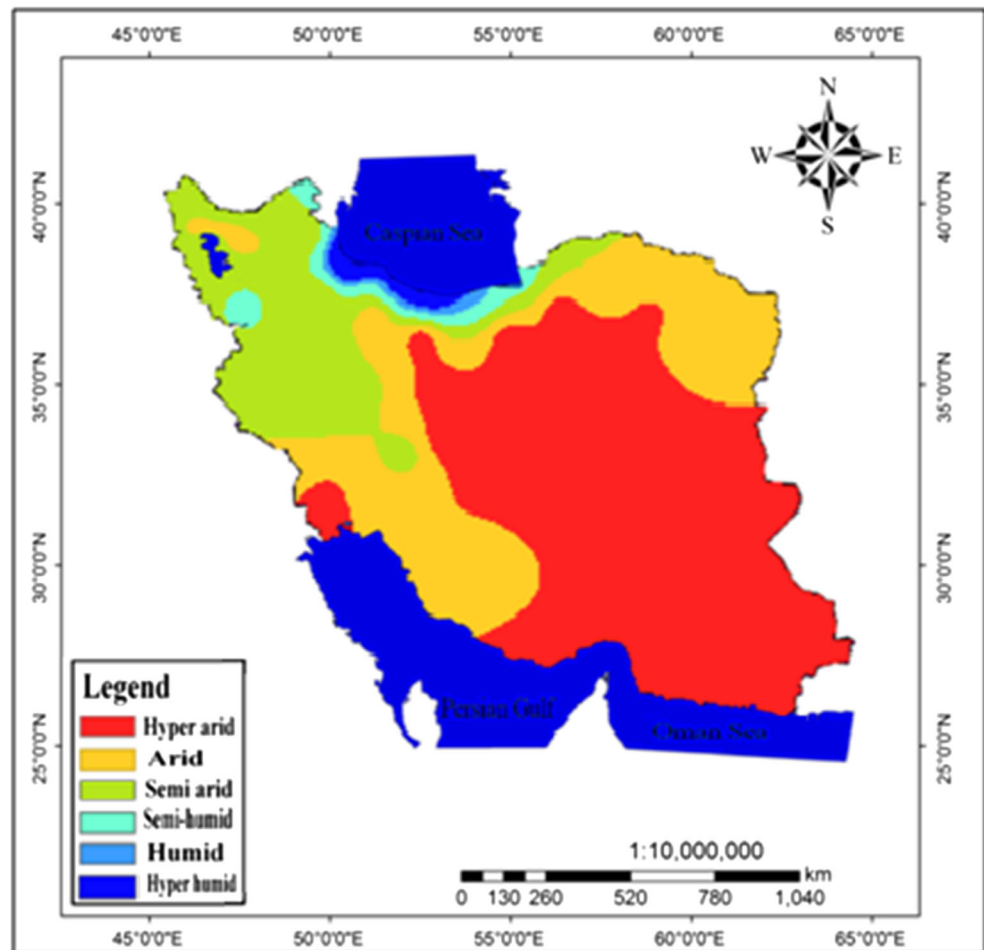
class, while stations such as Babolsar and Ramsar are in humid and Gorgan is classified in semi-arid classes, respectively. Moreover, correlation results, presented in Table 5, also confirm this fact. The highest correlation coefficients among I_q index, precipitation and specific humidity are observed in Caspian region stations, especially southwest of the Caspian Sea. Examining the area of this region shows that from 6131.8 km^2 of the Caspian region (0.35 % of the Iran area), 5.6 % of this region area has stronger correlation with A_i, while 94.3 % of this region has stronger correlation with I_q. In fact, the stations are distinguished from each other from west and southwest of the Caspian Sea to its easterly parts, as Caspian region climate changes from hyper-humid class to humid and semi-arid from station of Anzali with 1722.5 mm precipitation and 10.4 gr/kg specific humidity to Gorgan with 526 mm precipitation and 9.4 gr/kg specific humidity. Its output results of I_q index correlations and zoning maps also confirm these facts; therefore, the role of precipitation and specific humidity to determine Caspian region climate is significant and shows aridity degree much better.

Generally, results of correlation test revealed that 77.85, 0.75, and 21.4 % of the Iran area has strong correlation with A_i, I_q, and I_m, respectively. Likewise, evapotranspiration is an effective factor in calculating A_i index. A lot of parameters were applied to calculate potential evapotranspiration. Based on the aforesaid reasons, it is claimed that A_i aridity index, according to regional width, has more validity to explain aridity in Iran.

The analysis of aridity changes trend in Iran

It was considered suitable to analyze trend of aridity changes in Iran based on I_q aridity index, since it has been revealed that I_m and A_i not only do not show a lot of differences in explaining aridity intensity of arid and semi-arid regions of Iran but also cannot present acceptable results for humid region, especially the Caspian region. Mann-Kendal nonparametric test was applied in which Mann-Kendal statistic Z for certain level was 95 % which is shown in Table 6.

As can be seen in Table 6, except for 10 stations, namely Abadeh, Dooshantapeh, Isfahan, east of Isfahan, Hamedan, Hamedan (airport station), Iranshahr, Kashan, Shahrkord, Zanjan, and Khoramabad, where an insignificant increasing trend can be observed, there is a slight decreasing trend among other stations; it is not significant in any level. This negative trend shows gradual precipitation decrease but temperature and specific humidity increase. In other words, as numeral

Table 4 Correlation values among climatic parameters of A_i, I_q, and I_m indices in arid stations

Stations	Climatic parameter index	Precipitation	Maximum temperature	Evapotranspiration	Specific humidity
Zahedan	I_m	0.999**	−0.649**	0.026	0.382*
	A_i	0.987**	−0.649**	0.143	0.400*
	I_q	0.955**	−0.562**	−0.055	0.141
Zabol	I_m	0.998**	−0.637**	−0.169	0.578**
	A_i	0.984**	−0.659**	−0.247	0.568**
	I_q	0.964**	−0.517**	−0.120	0.408*
Iranshahr	I_m	0.998**	−0.564**	−0.153	0.433**
	A_i	0.973**	−0.498**	−0.298	0.236
	I_q	0.954**	−0.477**	0.023	0.405*
Tabas	I_m	0.988**	−0.186	0.114	−.0.34
	A_i	0.992**	−0.194	0.172	0.144
	I_q	0.954**	−0.032	0.280	0.112
Bam	I_m	0.998**	−0.685**	−0.375*	0.361
	A_i	0.989**	−0.693**	−0.464**	0.398*
	I_q	0.957**	−0.617**	−0.258	0.152
Yazd	I_m	0.997**	−0.502**	−0.193	0.295
	A_i	0.992**	−0.421**	−0.270	0.337
	I_q	0.975**	−0.678**	−0.078	0.132
Kerman	I_m	0.997**	−0.678**	0.313	0.321
	A_i	0.988**	−0.678**	−0.409*	0.356
	I_q	0.961**	−0.517**	−0.207	0.048
Isfahan	I_m	0.986**	−0.328	−0.313	0.152
	A_i	0.972**	−0.350	−0.383*	0.169
	I_q	0.956**	−0.077	−0.111	−0.135
Semnan	I_m	0.979**	−0.305	0.065	0.298
	A_i	**0.969	−0.218	−0.090	0.333
	I_q	**0.958	−0.242	0.150	0.099
Kashan	I_m	0.992**	−0.281	0.026	0.224
	A_i	0.975**	−0.264	−0.089	0.266
	I_q	0.952**	−0.243	0.175	−0.003
Shahrood	I_m	0.990**	−0.642**	0.048	0.270
	A_i	0.983**	−0.592**	−0.046	0.297
	I_q	0.967**	−0.616**	0.089	0.151
Abadan	I_m	0.998**	−0.363*	0.031	0.285
	A_i	0.969**	−0.447*	−0.152	0.377*
	I_q	0.976**	−0.303	0.109	0.117
Ahwaz	I_m	0.992**	−0.507**	−0.275	0.373*
	A_i	0.967**	−0.565**	−0.419*	0.390*
	I_q	0.932**	−0.479**	−0.143	0.112
Jask	I_m	**0.998	−0.319	−0.331	−0.221
	A_i	**0.990	−0.317	*0.393	−0.240
	I_q	**0.994	−0.342	−0.344	−0.257
Chabahar	I_m	**0.997	−0.172	0.012	−0.312
	A_i	**0.983	−0.146	−0.099	−0.304
	I_q	**0.996	−0.135	0.051	−0.286
BandarAbbas	I_m	**0.999	−0.566**	−0.334	0.174
	A_i	**0.987	−0.593**	−0.451*	0.178
	I_q	**0.998	−0.563**	−0.338	0.152

Table 4 (continued)

Stations	Climatic parameter index	Precipitation	Maximum temperature	Evapotranspiration	Specific humidity
Bandar-e-Lengeh	I_m	**0.999	−0.655**	−0.217	−0.204
	A_i	**0.920	−0.721**	−0.490**	−0.349
	I_q	**0.994	−0.667**	−0.237	−0.340
Boshehr	I_m	**0.997	−0.107	0.121	0.193
	A_i	**0.980	−0.087	0.10	0.125
	I_q	**0.978	−0.122	0.070	0.083
Kish	I_m	**0.999	−0.571**	−0.220	−0.173
	A_i	**0.992	−0.589**	−0.293	−0.196
	I_q	**0.999	−0.576**	−0.219	−0.180
Birjand	I_m	**0.983	−0.733**	−0.530**	−0.008
	A_i	**0.964	−0.712**	−0.632**	0.046
	I_q	**0.938	−0.766**	−0.493**	−0.203
Sabzevar	I_m	**0.995	−0.649**	−0.329	*0.456
	A_i	**0.981	−0.610**	−0.426*	**0.480
	I_q	**0.954	−0.608**	−0.302	0.275
Doushantappeh	I_m	**0.977	−0.508**	−0.371*	0.340
	A_i	**0.895	−0.488**	−0.580**	**0.463
	I_q	**0.894	−0.350	−0.079	−0.021
Tehran	I_m	**0.979	−0.493**	−0.099	0.148
	A_i	**0.951	−0.471**	−0.269	0.071
	I_q	**0.926	−0.469**	−0.186	−0.108

*Significant in level at 0.05

**Significant in level at 0.01

Table 5 Correlation values among climatic parameters of A_i, I_q, and I_m indices in the Caspian Sea southern coasts stations

Stations	Climatic parameter index	Precipitation	Maximum temperature	Evapotranspiration	Specific humidity
Rasht	I_m	0.980**	−0.595**	−0.212	−0.524**
	A_i	0.947**	−0.464**	−0.515**	−0.397**
	I_q	0.989**	−0.529**	−0.260	−0.543**
Noushahr	I_m	0.983**	−0.500**	−0.129	−0.432*
	A_i	0.936**	−0.482**	−0.350	−0.422*
	I_q	0.980**	−0.455**	−0.082	−0.496**
Bandar-e-Anzali	I_m	0.941**	−0.398*	0.064	−0.255
	A_i	0.755**	−0.163	−0.593**	−0.063
	I_q	0.942**	−0.326	−0.012	−0.472
Ramsar	I_m	0.991**	−0.400**	−0.051	−0.273
	A_i	0.907**	−0.318	−0.411**	−0.253
	I_q	0.992**	−0.335	−0.049	−0.371**
Babolsar	I_m	0.992**	−0.313	0.061	−0.243
	A_i	0.894**	−0.308	−0.442**	−0.278
	I_q	0.985**	−0.289	−0.087	−0.312
Gorgan	I_m	0.975**	−0.482**	0.059	−0.336
	A_i	0.852**	−0.085	−0.423*	−0.139
	I_q	0.977**	−0.412*	0.045	−0.375*

*Significant in level at 0.05

**Significant in level at 0.01

Table 6 The value of Mann-Kendal statistic Z

No.	Stations	Mann-Kendal statistic Z	No.	Stations	Mann-Kendal statistic Z
1	Abadan	−0.267	27	Kerman	−1.116
2	Abadeh	0.965	28	Kermanshah	−0.305
3	Ahvaz	−0.12	29	Khoramabad	0.23
4	Anzali	−0.483	30	Khooy	−1.024
5	Arak	−0.597	31	Kish	−0.388
6	Ardebil	−0.388	32	Mashhad	−0.777
7	Urmia	−0.543	33	Noshahr	−0.306
8	Babolsar	−1.079	34	Ramsar	−0.37
9	Bam	−0.213	35	Rasht	−0.682
10	Bandarabas	−0.175	36	Sabzevar	−0.305
11	Bandar Lengeh	−0.179	37	Saqez	−0.278
12	Birjand	−0.726	38	Sanandaj	−0.856
13	Bojnoord	−0.201	39	Semnan	−0.996
14	Booshehr	−0.125	40	Sahrekord	0.496
15	Chabahar	−0.231	41	Shahrood	−0.267
16	Dezfool	−0.032	42	East of Esfehan	0.566
17	Doushantapeh	0.02	43	Shiraz	−0.292
18	Isfahan	1.029	44	Tabas	−0.032
19	Fasa	−0.44	45	Tabriz	−0.711
20	Qazvin	−50.6	46	Tehran	−0.292
21	Gorgan	−0.935	47	Torbat Heydariye	−0.34
22	Hamedan	0.297	48	Yazd	−0.05
23	Hamedan Nowzheh	−0.942	49	Zabol	−0.089
24	Iranshahr	0.001	50	Zahedan	0.225
25	Chamak	−0.121	51	Zanjan	−0.526
26	Kashan	0.524			

value of the index is lower, the station is dryer. The results of trend analyses for all studied stations show that arid condition was increasing in 80.4 % of the stations, while only in 19.6 % of them, it was decreasing. Studying the trend of I_q arid index explains that aridity intensity of Iran climate has increased during the last 30 years from 1980 to 2010. Moreover, the extent arid region is increasing in Iran.

Conclusion

Based on aridity indices, Ashraf et al. (2014), Tabari et al. (2014), and Ahani et al. (2013) have claimed that there has been a considerable increase of aridity among the stations at the beginning of twenty-first century (2000–2008) leading to an increasing area of arid and semi-arid regions. The amount of aridity during a period from 1981 to 2010 was studied in this research. The findings of A_i, I_q, and I_m in various regions clearly have proven the increase of aridity severity in recent years.

Several climatic indices are used to study and determine aridity severity in geographical regions. According to a remarkable climatic variation and spatial differences in climatic element distribution of Iran, it is believed that applying a specific index to study the traits of aridity phenomenon is insufficient. Previous studies were mainly about finding climatic aridity based on precipitation and temperature, since it was traditionally believed that temperature and precipitation are effective factors in explaining the environment aridity. However, the fact is that studying bio-climatic indices, considering potential evapotranspiration, precipitation, specific humidity, and maximum precipitation, and temperature simultaneously, are more important in agriculture and natural resources. Furthermore, these indices have significant importance in biogeographical planning, water resources, and agriculture.

This research studied aridity temporal-spatial changes in Iran. In fact, different indices were applied and their results were analyzed to achieve a more complete view toward aridity phenomenon and its changes in Iran; therefore, several valid aridity indices like A_i, I_q, and I_m were used. After zoning in GIS environment and analyzing the differences and similarities of the indices, correlation coefficients of all used climatic parameters in the indices were found. The results, got from zoning and correlation, showed that A_i index is more suitable and efficient than other indices to study aridity condition throughout Iran. I_q

index can also show aridity degree and traits of southern coasts of the Caspian sea region better.

Shifteh Some'e et al. (2013) showed that there was negative trend in annual aridity index among 55 % of stations in the arid and semi-arid regions. The findings of this research confirmed the findings of Shifteh Some'e et al., which also showed that more than 90 % of arid and semi- arid stations of the country have a negative trend during the studied period which expresses the increase of aridity severity in these regions.

Trend of aridity changes among the stations were studied by Mann-Kendal nonparametric test. The results revealed that aridity is increasing in most (80 %) of meteorology stations. In fact during last 30 years, environmental condition was changing to aridity, while the remaining 20 % of meteorology stations were moving to humidity or showed no significant changes.

Studying the trend of aridity index (A_i) by Zare Abyaneh et al. (2011) proved that the climate of 80 % of the studied stations tend to have a humid climate. While the present study, the trend of aridity index (I_q) showed that climate aridity degree of most southern stations of Iran has increased during the selected period from 1981 to 2010. This increase can be as a result of a gradual decrease of precipitation or temperature increase.

All previous studies have used aridity index (A_i) to explore temporal-spatial variability of aridity in all various regions of Iran, and the whole country of Iran in previous studies was not studied.

Due to various climatic and ecologic conditions, applying an only one index for all regions of Iran cannot be an appropriate solution to analyze aridity severity.

In present study, three different aridity indices of A_i, I_q, and I_m were applied to analyze the amount of aridity in different regions of Iran in order to choose the appropriate aridity index for each climatic region of Iran so all synoptic stations which had at least 30-year meteorological observations were selected in order to cover all regions of Iran.

Unlike all previous studies which used aridity index A_i to find aridity trends in Iran, this study used the new aridity index I_q to find aridity temporal trends. Some of the advantages of this study to other similar studies is concurrent studying precipitation and evapotranspiration changes, special humidity and precipitation, and also maximum temperature and precipitation, while most previous studies in Iran mostly focused on precipitation and temperature.

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