Climate vulnerability index fluctuation: a case of Iran

Hakimeh Hatef, Mahmoud Daneshvar Kakhki, Mohammad Reza Kohansal, Mohammad Bannayan and Naser Shahnoushi Froshani

ABSTRACT

Climatic fluctuations have severe effects on water and soil resources and economy as a whole. It is hence important to study the fluctuations of climatic parameters in different regions in order to recognize the source and type of parameter that have led to fluctuating climatic parameters. To achieve this goal, the current study attempts to address the following issues: what are the different sources of fluctuations in climate parameters? Do different regions have the same degree of vulnerability and what is the most fluctuating parameter in each region? To answer these questions, the study suggests climate vulnerability index fluctuation. Calculating the index requires data provided by weather stations, so 115 weather stations were divided into 12 climatic zones based on the availability of data. This index considered permanent and frequent temperature, precipitation, storm and aridity shocks. The results indicated that the maximum rank of index has occurred in hot semi-mountainous and very hot desert. Also, temperature fluctuation was the major factor in five regions, whereas wind fluctuation was the major factor in three regions. Generally, the northern and western parts of the country experienced minimum climatic changes. Moving towards southern regions of the country, more climatic changes were observed.

Key words | climatic factor fluctuations, Iran climate, progressive shocks, recurrent shocks, vulnerability index

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INTRODUCTION

Various studies and investigations conducted by the Intergovernmental Panel on Climate Change (IPCC) indicate that climatic parameters are drastically changing. For instance, study results indicate that by 2100, land surface temperature will increase to 3.5° due to greenhouse gas emissions (IPCC 2014). These changes, along with management issues, influence plant growth and yield, as well as conditions of resources and natural habitats. Therefore, it would be beneficial to study whether or not different regions are damaged by changes in climatic factors. Also, the damage may be estimated in order to better control and manage chaotic situations. Already, the damage caused by changes in climatic factors has been studied from analytical perspectives. However, the risks, which constantly change due to rising temperatures, reduced precipitation, aridity, and storm or flood of natural-animal habitats and agricultural production, have been rarely considered. Similarly, there are an inadequate number of studies in the Iranian context.

Guillaumont & Simonet (2011) designed an index (physical vulnerability to climate change index) to investigate the damage of climatic changes in different regions. In their index, the fluctuations in temperature, precipitation, aridity, and rising sea levels for Africa, and in another study for other countries of the world, were considered. In other similar studies regarding the damage caused by climatic changes, researchers have often focused on a single meteorological parameter. The following studies are only some of

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the previous attempts to determine the damage of climatic changes.

Using Reed's frameworks presented in 2013, Keshavarz *et al.* (2017) studied drought vulnerability in the villages of Fars Province in Iran. Also, Farhangfar *et al.* (2015) investigated the vulnerability of wheat and corn to climate change and drought in five cities of Iran. They considered vulnerability as a function of three components, namely, sensitivity, initial position to damage threshold, and exposure. In another study, Rufat *et al.* (2014) reviewed a number of studies about flood damage and proposed certain strategies for countering the issue. Ahsan & Warner (2014) focused on the index of social-economic vulnerability to climate change in Bangladesh by studying 60 families.

Various climatic parameters have changed over time due to changes in the climate. For instance, in Iran, the average temperature has risen, while precipitation has reduced by 10% (Mousavi Baygi *et al.* 2016). Temperature increase would, in turn, lead to a significant increase of annual evapotranspiration level (Deschenes & Greenstone 2007). Several studies have shown that Iran's semi-arid climate is highly vulnerable to future changes in climate. For instance, Farajzadeh & Razi (2011) studied the storms at three stations in Mashhad, Sabzevar, and Torbat-e Heydariyeh. In another study, Vafakhah *et al.* (2012) analyzed the degree of rainfall in northeastern regions of Iran. Also, Azarakhshi *et al.* (2013) studied the process of seasonal variations in precipitation and temperature in 24 synoptic stations with about 50 years' statistics (1956–2005). Ghoddosi *et al.* (2013) studied the trends in 19 thermo-control stations in the south of Iran. Climate change causes drought and water shortage. Drought itself has significant effects on the living conditions of animals, plant growth in natural habitats and production yield. Another important point with regards to Iran's climate is the wide temperature range, which varies from −20 to +50 °C. Severe drought is another feature of Iran's climate. In the past few years, Iran has suffered a lot of damage due to severe drought conditions (Iran Second National Communication to UNFCC 2010). Most notably, Lake Urmia and Zayanderood have been severely damaged in recent years, while many other natural habitats have been almost completely destroyed (AghaKouchak *et al.* 2015). The destruction of these natural habitats imposes extensive damage on the economy. Thus, identifying the vulnerable areas is necessary to help the adjustment procedure (IPCC 2014). So far, many studies have investigated the unique fluctuations of each climatic parameter, but there are inadequate numbers of studies that have investigated different parameters and fluctuations simultaneously.

In the climatic program of the World Meteorological Organization, 'defining characteristics of human societies at different levels of development which makes them flexible and vulnerable in the face of diversity or climate change' is of particular significance. Vulnerability to climate change can be considered as vulnerability to environmental shocks caused by climate change. These shocks occur due to climate changes and/or fluctuations and are measured through droughts, floods, storms, and rising sea levels. They are significantly affected by changes in climatic variables (temperature and precipitation) and the fluctuations of these variables.

Assessing the vulnerability indicators may serve as a tool for calculating the vulnerability of a country or region to climate fluctuations or climate change factors. Given that all regions of a country are not equally affected by the same conditions and fluctuations of climatic factors, it is mandatory to calculate and examine the vulnerability of these regions separately. Accordingly, the purpose of the current study is to investigate the fluctuations in climatic factors by analyzing the different aspects of vulnerability index of fluctuating climatic parameters, which may in turn lead to a lack of economic growth. The vulnerability index of fluctuating climatic parameters indicates the degree of vulnerability to drought, desertification, and storms in the study region. Therefore, calculating the vulnerability of different countries and regions to climate change is a proper measure for making policies in order to adopt appropriate programs for the allocation of resources.

The significance of this study arises from the fact that it aims to present a series of strategies for coping with or adapting to climate change so as to reduce the harmful effects of this phenomenon. To choose the right and effective strategy, the dominant parameters of weather fluctuations have to be specified in each region. Coping or adaptation strategies vary depending on the source of fluctuations. For instance, strategies for coping with temperature fluctuations may change due to the day of planting, choosing a variety of products, changing harvest time, and the patterns of cultivation that are less sensitive to temperature fluctuations. Strategies for coping with reduced rainfall may include choosing modern irrigation methods, improving irrigation efficiency, and water recycling in agriculture. Thus, recognizing the source and type of parameter that has led to fluctuating climatic parameters is very important. To fill this gap, this study tries to answer the following questions: 1) what are the different sources of fluctuations in climate parameters? 2) Do different regions have the same degree of vulnerability to fluctuations of climate parameters? 3) What is the most fluctuating parameter in each region? This study was conducted for Iran, but according to the information recorded at weather stations, it is possible to do it for other parts of the world, in different countries and regions.

MATERIAL AND METHODS

Study region

The study area covered different regions in Iran. These are located in the range of 25° 3′ and 39° 47′ north latitude and 44° 5′ to 63° 18′ east longitude. Iran is one of the widest countries in the world with a diverse climate and an area of 1,648,198 square kilometers. Iran is located in the west of Asia and in the Middle East and Central Asia. The country is located in the northern dry temperate zone and average latitudes in the region next to tropical and equatorial climatic zones. Air flow makes Iran's climate dry, but due to its vast area, Iran has a large variety of climates. The average altitude of Iran is approximately 1,200 meters above sea level and it is located in arid and semi-arid areas in terms of global climatic zoning. The average rainfall in Iran is about 250 mm annually, which is less than one-third of the world's rainfall (860 mm) (Iran Second National Communication to UNFCC 2010).

Meteorological data

The data pertaining to the weather stations included in the study were received from official meteorological organizations. Since the study years cover a wide time interval, some of the recently established weather stations were removed from the calculations. Ultimately, 115 weather stations with wider time intervals of information were taken into consideration. Table A1 in the Appendix presents the names, established year, and geographical coordinates of the study stations from their establishment up until 2014.

To calculate the components of vulnerability index and climatic factor fluctuations, the data of weather stations regarding temperature, precipitation, and wind were received on a daily basis. Also, potential evaporation index and other components were used to calculate the aridity index. The most vulnerable areas of the country and the most important factors causing fluctuations in climatic factors have been determined according to the obtained results.

Vulnerability definition

Vulnerability is the degree of sensitivity of a system and its potential to cope with the effects of climate change. Timmerman (1981) defines vulnerability as 'the degree to which a system may react unfavorably to the occurrence of a hazardous event'. Vulnerability is a function of the characteristics, magnitude, rate, and diversity that a system is facing and the sensitivity and adaptation capabilities are defined accordingly (IPCC 2007).

Components

The purpose of this study is to investigate the components of the vulnerability index which is caused by fluctuations in climate factors. In general, vulnerability index is made up of three main parts: shocks, exposure, and flexibility. Shock is a totally unexpected and external event (e.g., tornado, hurricane, earthquake, and drought). Exposure is related to the direct effects of shock. As for flexibility, it refers to the capacity to respond to unexpected shocks (Miller *et al.* 2010).

To achieve the goal of the study, in line with the framework provided by Guillaumont (2015), the factors considered in this study did not depend on national volition and policies (they are embedded in the structure of the country and are hence affected by fluctuations in climatic factors). With regards to calculating the index, sea level was not considered as a potentially damaging threat, since many regions of Iran are not in the vicinity of the sea and sea level is not a significant issue. Based on previous studies, storms and aridity were considered as repeated threats (Bannayan et al. 2010; Farhangfar et al. 2015; Keshavarz et al. 2017). Index components are shown in Figure 1.

As seen in Figure 1, this index is based on the reflective components of climate change consequences and it may potentially affect the community welfare and activities. The index consists of two components, each having two parts and each part in turn being composed of two sub-sections. In other words, the components of this index consider two types of threats caused by climate change: risks of increasing frequent shocks (such as drought, floods, and storms) and the risks of permanent shocks (such as increasing temperatures and decreasing rainfall) (Guillaumont 2009).

The risks of permanent shocks refer to the likely consequences of climate change and they are studied by increasing or reducing the temperature and precipitation. Thus, negative shocks are considered for rainfall and positive shocks for temperature. Since there are no seas in the study area and there is no history of major flooding in the region, frequent shocks were removed from the analysis. Based on the study area, storms and aridity were studied as fluctuations of climatic factors for frequent shocks.

Calculation method

As seen in Figure 1, the index consists of two components and four sub-components. The components of risks cover climate change and its consequent risks and reflect the possible size and exposure to shocks. To achieve the study objective and calculate the vulnerability index of fluctuations in climate parameters, the researchers had to analyze the fluctuations of temperature, precipitation, wind, storms, and aridity. Therefore, different climatic parameters and their trends were first studied. Then, climatic factors, the fluctuations of which caused more damage to natural resources such as agricultural products, were analyzed. Then, a rank was determined for each of the climatic factors with higher fluctuations in each weather station. Ultimately, the most vulnerable parts of the country were identified.

Given that in the long term, lower rainfall levels or a higher proportion of aridity exposed an area to risk of higher temperature and/or lower rainfall, it is of high significance to analyze the fluctuations of these two parameters. As an alternative to an increased risk of drought, which may show the average level of rainfall or the area of dry land in a country, aridity was considered as an index of desertification risk. The aridity index is used for calculating the intensity aridity in the studied stations.

This index was presented by the United Nations Environment Program in 1992. It represents the simultaneous changes in rainfall and potential evaporation and is calculated by the following formula:

$$AI = \frac{P}{PET} \tag{1}$$

in which, P is the cumulative precipitation (mm) and PET is potential evaporation (mm) at a given time scale. The aridity index ranges between zero and one. Numerical values less than 0.05 indicate very dry conditions, while values more than 0.75 show humid conditions (Bannayan et al. 2010).

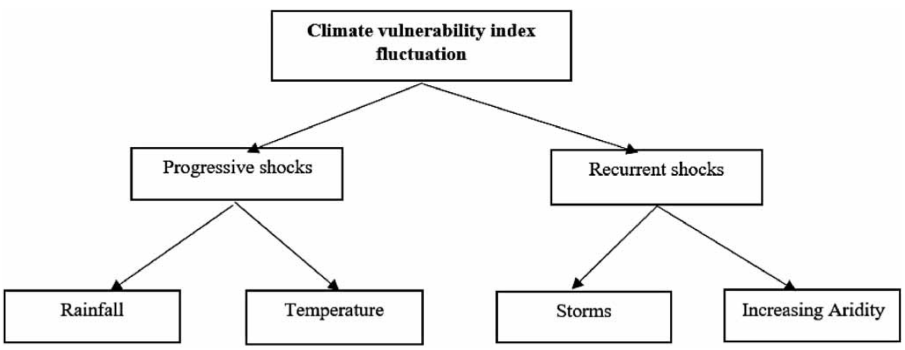

Figure 1 | Components of the vulnerability index (adapted from Guillaumont & Simonet (2011) with minor changes).

According to international standards, storm refers to winds with speeds of over 30 knots (15 meters per second) and horizontal visibility less than 1 km. The amount of potential evaporation was calculated by analyzing the data provided by the weather stations using REF ET software. Of course, the appropriate method to determine the potential evaporation in each region depends on climatic conditions, requirements data, and associated costs. REF ET software requires information on solar radiation, net radiation, average minimum temperature, average maximum temperature, sunshine, wind speed, and relative humidity. This survey employed the FAO Penman–Monteith potential evaporation method, since it has been introduced as the most accurate method both in dry and wet weather conditions. Subsequently, the aridity index was estimated (Sharghi *et al.* 2010).

To calculate the rainfall index, it was assumed that the average increase of global temperature will continue as in recent decades; R_t is the amount of rainfall in year t, and IR is the rainfall index.

$$IR = \sum \frac{\left|R_t - \hat{R}_t\right|}{\hat{R}_t} \tag{2}$$

where $\hat{R}_t$ is the trend level of rainfall.

To calculate the rainfall index, the recorded data of weather stations were adjusted and the calculations were carried out using the ordinary least squares method. The most common method for analyzing meteorological time series is to use statistical tests. As time series trends of meteorological variables influence the analysis and evaluation of their effects on the related procedures, it is necessary to evaluate the trends first. Then, if required, detrending could be done. Investigation of trending and detrending may have a significant role in the evaluation and quantification of the extent and impact of meteorological variables. Several methods have been presented for analyzing time series trend, but they are mainly divided into two categories, namely, parametric and nonparametric methods. Nonparametric methods, especially Mann–Kendall, have been used more commonly, because climatic elements have a nonlinear behavior and they are not a function of significant statistical distributions (Ghoddosi *et al.* 2013). Thus, for each of the four components of the vulnerability index presented in Figure 1, the trending and instability of trending were calculated by the Mann–Kendall test.

After calculating the components, their weight had to be determined. Previous research studies have used the following methods to determine the weight of components: weighted arithmetic average, geometric average, reversed geometric average, modified geometric average, and analysis of main components (Guillaumont 2009). In this study, following Guillaumont & Simonet (2011), the same weights were selected for the indices due to the difference between regions and climatic characteristics.

Finally, in order to have the possibility of comparing different parts of the index components and calculate the vulnerability index to fluctuations of climatic factors, each of the components were normalized according to the various units of index components in the following way:

$$CN = \frac{(C - min_c)}{max_c - min_c} * 100 \tag{3}$$

where CN is the normalized component and C is the component value.

Therefore, based on the obtained results from the index, the most vulnerable regions should be identified for proper policy-making and target-oriented planning to adapt to climate change. There are different political, geographic, and climatic divisions based on one or a number of different climatic parameters. Since this study investigated various climate parameters, it was necessary to employ climate division which used various climate parameters comprehensively. Therefore, the study conducted by Heidari & Alijani (1999) was considered as the basis for climate division.

RESULTS

After calculating the index, it was indeed possible to analyze the results for all the stations (N = 115) across Iran. However, in order to summarize the results, the climatic divisions of the country, as shown in Figure 2, were used.

In Heidari & Alijani's (1999) study, various parameters were considered by using multivariate statistical methods (as shown in Table 1). They divided Iran into six climate zones, namely, wet and temperate climate (zone A),

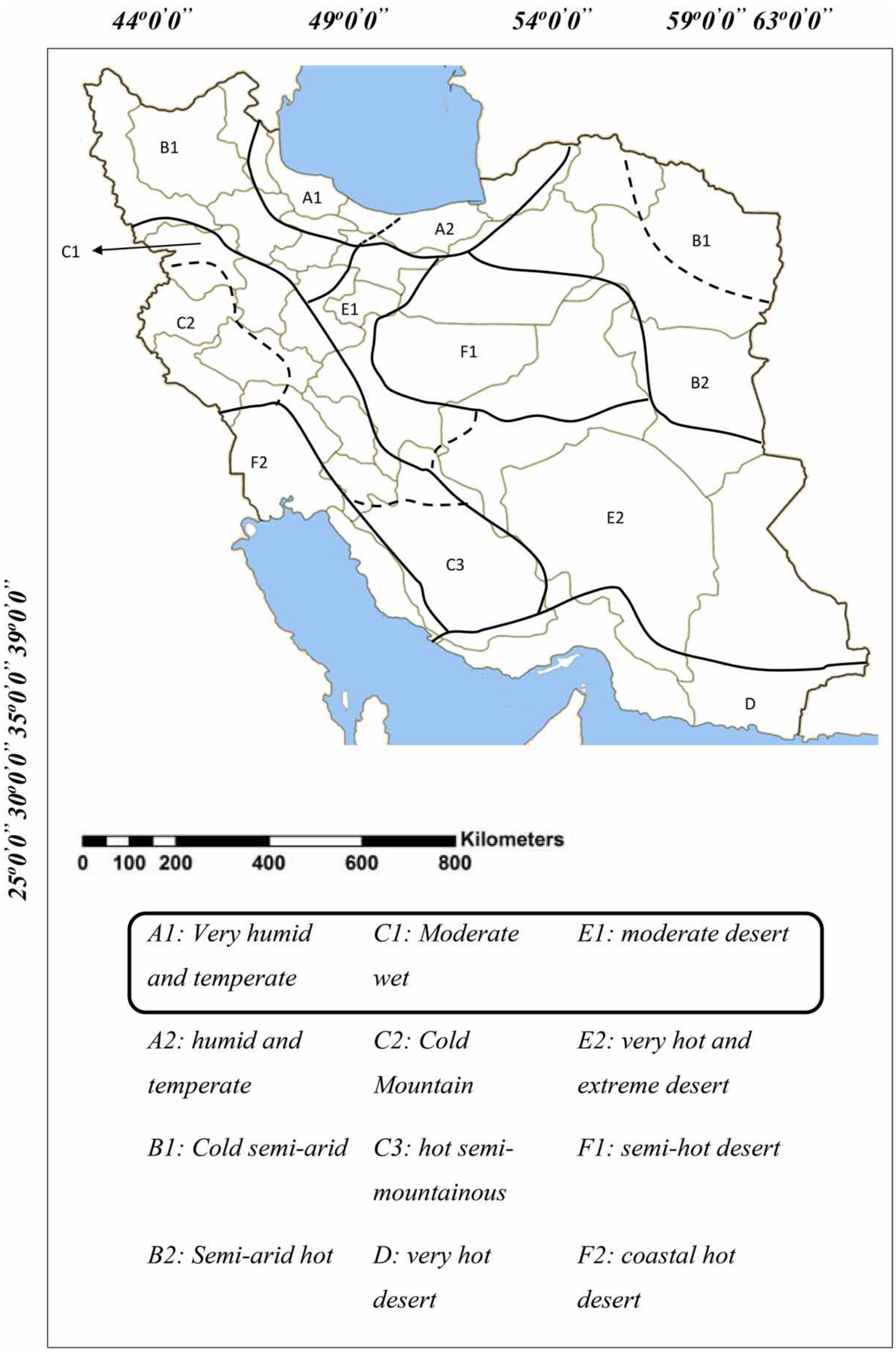

Figure 2 | The climatic divisions of the country.

Table 1 | Details of the division climates

Station	Climate	Symbol	Station	Climate	Symbol
A1	Very humid and temperate	Bandar Anzali, Ramsar, Rasht	C3	Hot semi-mountainous	Fasa, Shiraz
A2	Humid and temperate	Babolsar, Gorgan	D	Very hot desert	Bandar Lenge, Bandar Abas, Jask
B1	Cold semi-arid	Mashhad, Tabriz, Urmia, Zanjan	E1	Moderate desert	Esfahan, Tehran
B2	Semi-arid hot	Birjand, Sabzevar, Shahrod	E2	Very hot and extreme desert	Kerman, Zabol, Zahedan, Yazd
C1	Moderate wet	Kermanshah, KhoramAbad, Sanandaj	F1	Semi-hot Desert	Kashan, Semnan, Tabas
C2	Cold mountain	Arak, Saqez, Hamedan, ShahreKord	F2	Coastal hot desert	Abadan, Ahvaz, Bushehr

Source: Heidari & Alijani (1999).

semi-arid climate (zone B), Zagros climatic region (zone C), desert climate and very hot coastal area (zone D), moderate desert to severe hot area (zone E), and semi-hot to hot desert climatic (zone F) (1999). These climates have been displayed in Table 1.

Based on this classification, the results were analyzed in terms of 12 climatic groups. Accordingly, the results obtained from calculating the index of fluctuations of climatic factors for various stations in Iran are presented from their establishment until 2014 and later analyzed. As presented in Tables 2–4, each component of the index has been calculated separately and has a rank which shows the conditions of the corresponding station in terms of the vulnerable component. Then, the vulnerability rank of each station was determined and its rank compared to other stations for frequent and permanent risk.

Climate A, including northern areas, consists of two parts, namely, A1 and A2. As shown in Figure 2, A1 climate zone covers the northern parts of Iran and the south strip of the Caspian Sea to the west. This zone has a very humid and temperate climate. The data were taken from nine stations which were established from 1951 to 1987.

The rank related to fluctuations in temperature parameters listed in Table 2 shows that the temperature fluctuations in this region ranked between 30 and 105,

Table 2 | Results obtained from the variability of the climate vulnerability index in climate A1

Station	Tem	rain	wind	Aridity	Risk1	Rank	Risk2	Rank	Index	Rank
Ardebil	80	68	72	67	26.66	75	28.07	68	54.72	72
Astara	74	9	21	9	24.76	54	23.00	12	47.76	24
Bandar Anzali	105	1	38	1	19.46	1	20.29	1	39.75	1
Parsabad	30	63	32	62	24.21	45	25.14	45	49.35	45
Khalkhal	47	17	17	18	23.59	30	23.22	16	46.80	16
Ramsar	50	13	19	12	23.58	29	23.07	13	46.65	13
Rasht	35	47	22	44	23.78	33	23.98	27	47.77	25
Sarab	87	37	61	45	26.49	73	26.29	59	52.78	67
Noshahr	62	57	11	52	25.21	61	23.56	18	48.77	42

Note: Rank of fluctuations in temperature (tem), rank of rainfall fluctuations (rain), rank of wind fluctuations (wind), and rank of aridity fluctuations (Aridity) are named in the table. The progressive and recurrent risks and index of climatic factor fluctuations (Index) and the rank of each station (115) are shown. Thus the rank is 1–115. Lower numbers show less fluctuations or more stability and the higher numbers show more fluctuations or less stability.

Table 3 | Results obtained from the variability of the climate vulnerability index in climate E2

Station	tem	rain	wind	Aridity	Risk1	Rank	Risk2	Rank	Index	Rank
Anar		104	75	107	28.94	86	31.88	90	60.81	84
IranShahr	94	71	113	72	28.67	85	35.08	105	63.74	94
Bam	79	109	115	109	29.91	94	39.28	115	69.19	110
Khash	70	43	85	49	25.47	65	29.00	71	54.47	71
Zabol	65	108	101	108	29.18	87	35.22	106	64.40	99
Zahedan	113	114	106	113	39.87	114	36.97	113	76.84	115
Saravan	83	18	60	13	25.54	66	25.47	51	51.01	61
Sirjan	93	112	80	112	31.90	100	33.30	97	65.20	102
Kerman	101	99	78	100	32.32	103	31.14	84	63.46	92

with the most fluctuating station being Bandar Anzali and the lowest Pars-Abad station up to 2014.

The rank of rainfall fluctuations is 1–68 across the stations in the country; Bandar Anzali had the lowest, or in other words, the highest stability of rainfall compared to other parts of the country. The rank of wind fluctuations is 11–72 with the lowest Noshahr station and the highest Ardabil station. The aridity fluctuation rank is 1–67, Bandar Anzali having the lowest and Ardabil station the highest. Analyzing the rank of Bandar Anzali station's temperature fluctuations (105), it can be concluded that the low fluctuation in desertification is because of rainfall stability. These results are in accordance with the findings of Shirgholamy & Ghahraman (2005), who found an incremental fluctuation of temperature parameters in 34 stations across Iran. The study prognosticates that this trend will increase in the coming years.

The rank of frequent risks (wind and aridity fluctuations) in this climate is 1–68 and permanent risks (temperature and rainfall) are 1–75. Generally, Ardabil had the highest fluctuations in parameters of temperature and rainfall, wind and aridity which led to its being ranked 72 in terms of climatic parameters' fluctuations. In the development of this index for Ardabil station, permanent risks (75) were more than frequent risks (68) and temperature fluctuations had the most important role. The results regarding frequent risks confirmed the results obtained by Afshari Azad & Shabanzadeh (2010), who pointed to a

Table 4 | Results obtained from the variability of the climate vulnerability index

Zone	tem	rain	wind	Aridity	Progressive	Rank	Recurrent	Rank	Index	Rank
A1	63.3	34.7	32.6	34.4	24.2	45	24.1	29	48.3	34
A2	42.0	39.8	41.5	41.3	24.4	40	25.2	44	49.6	42
B1	60.5	55.0	62.2	55.9	26.6	57	28.2	60	54.8	58
B2	77.1	63.7	75.3	62.1	28.8	75	29.6	73	58.4	75
C1	39.7	41.5	33.5	42.4	24.5	35	25.1	33	49.6	30
C2	44.1	55.0	55.3	53.4	25.2	47	27.1	55	52.3	51
C3	51.9	74.0	53.7	75.3	27.4	66	28.1	63	55.6	66
D	59.6	76.4	76.4	72.7	28.3	67	29.5	75	57.8	76
E1	52.5	51.3	56.3	56.7	25.3	54	26.8	57	52.1	55
E2	87.3	86.4	90.3	87.0	30.2	89	33.0	92	63.2	92
F1	72.6	63.4	68.2	57.8	28.0	73	28.9	63	56.9	67
F2	58.9	63.6	54.8	63.0	27.0	65	27.9	60	54.9	62

significant decrease in wind speed in this climatic region of Iran.

According to the results of Table 2, the vulnerability index of climatic parameters' fluctuations in Bandar Anzali had the least fluctuations in the country. In other words, this region was more stable than other regions which is due to rainfall stability and aridity not increasing. Temperature fluctuation was the main damaging factor for Bandar Anzali station. This is shown in Figure 3.

In climate A2, which covers the northern parts of Iran and the south strip of the Caspian Sea to the east, and is characterized by the humid and temperate climate, four stations were investigated. This region ranks second in terms of stability. Generally, in climate A, temperature had the highest fluctuation and was the main vulnerability factor of the region. The results pertaining to climatic zone A confirm the results of the study by Sabouhi & Soltani (2008). By studying the parameters of precipitation, temperature, relative humidity, and wind, those authors pointed to an increasing and decreasing trend in the parameters of climatic factors.

Climate B, which includes the northern area, is made up of two parts, namely, B1 and B2. In climate B1, which is cold and semi-arid, 15 stations were investigated, covering the northeast and northwest regions of Iran. In the northwest stations, Urmia, with a rank of 109, is the most vulnerable. Comparison of the frequent and permanent risks indicates that temperature and rainfall fluctuations were less than wind and aridity fluctuations. Frequent risks were ranked at 114 due to high fluctuations of wind and storm. In this region, in addition to rainfall fluctuations, wind and storm fluctuations (40–90 km per hour) lead to increased aridity (causing drying of the Urmia Lake). Generally in climate B1, frequent risks are greater than permanent risks, while storms and aridity are two reasons for the instability of the climate. However, temperature fluctuation is the most important factor of climatic change in climate B2. The results obtained from region B are in line with the findings of Rezaei *et al.* (2011), pointing to an increasing and decreasing trend in analyzing the trend of changes in wind speed. Also, the results of this study are in line with the findings of Ghoddosi *et al.* (2013), who compared the detrending methods in the time series of temperature and precipitation and found temperature fluctuations and temperature rises in the Aji Chai Basin. Also, Vafakhah *et al.* (2012) analyzed the rainfall trend in the Kashafrud catchment area by studying 13 stations with increasing trend and decreasing trend in rainfall data.

Climatic region C was divided into three parts and covers areas with proximity to Iran's western border towards the center. In climate C1, which contains moderate wet regions, the rank of index is 3–95. Generally, in this area, aridity is the most effective factor of the index. In stations with C2 cold mountainous region, which cover western regions towards the center of the country, 16 stations were investigated. In seven stations of the C3 climate (hot semi-mountainous), high temperature fluctuation was the most important reason for the instability of climatic parameters. The results of the study carried out by Arsalani *et al.* (2012) in restoring maximum temperature changes indicate that the maximum temperature fluctuation due to climate change is a limiting factor for the growth of trees in climatic zone C, which confirms the results of climatic parameters' fluctuations in the current study. As for area C3, Keshavarz & Sharifan (2014) studied the trend of wind speed changes in this climatic region and demonstrated a decreasing trend in wind speed variations. The results of

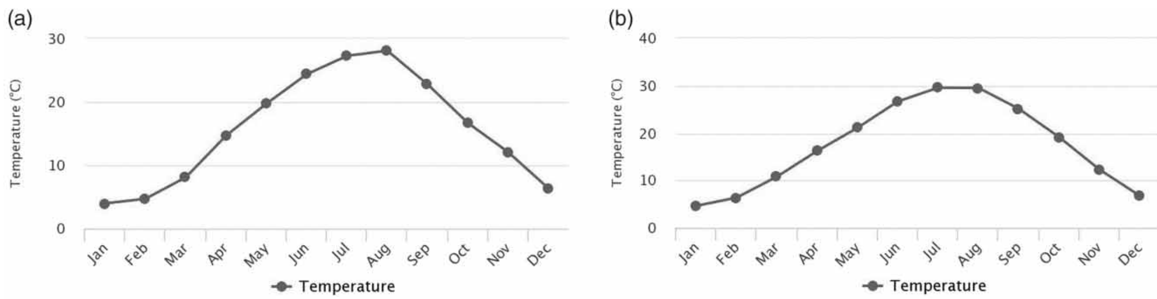

Figure 3 | (a) Average monthly temperature 1961–1990 and (b) average monthly temperature 1991–2015. Source: World Bank Climate Change Knowledge Portal.

the study conducted by Farajzadeh & Razi (2011) also indicate a trend in average wind speed at most stations in Iran.

Climate D includes very hot desert and the coastal region in the northern strip of Oman and the Persian Gulf, where nine stations were investigated. Temperature fluctuation is the most effective factor of the index in this zone. A study on the temperature trend in Bandar Abbas, carried out by Salari & Gandomkar (2012), also indicated a decreasing trend of minimum temperature and an increasing trend of maximum temperature, which confirms the results obtained from calculating the vulnerability index of climate fluctuations in this area.

In 12 stations of the E1 zone (moderate desert region), rainfall and aridity fluctuation are the most effective factors of the index. Similar to the current study, the results of the drought study conducted by Abbasian & Delavar (2012) pointed to the occurrence of drought in this region. A study by Sabouhi *et al.* (2009), which investigated climate change and its correlation with air pollution in Isfahan, indicated a significant negative trend in the number of rainy days in this part of the country.

Climate E2, very hot and extreme desert, covered nine stations for investigating and calculating the index. The ranking of the index was 61–115 (as shown in Table 3), which was the most fluctuating station in the country in terms of climatic parameters. Temperature and aridity fluctuation are high in this region and it has the third ranking of instability nationwide. Thus, rainfall fluctuation is the most effective factor of the index in this region.

The Zahedan station index was 76.8 (rank of 115), permanent risks were 114 and frequent risks 113, which indicates the high fluctuation of all four factors. The rainfall fluctuation in permanent risks was more unstable than frequent risks which rank second in terms of rainfall fluctuation in the country. The temperature and increasing aridity fluctuation are high in this region and it has the third ranking in terms of instability in the country. Thus, rainfall fluctuation (as shown in Figure 4) is the most effective factor of the vulnerability index of climatic parameters' fluctuations in this region.

The lowest ranking index in this region was recorded for Saravan, which had the highest recorded fluctuations related to temperature stress. The highest fluctuation of wind parameter in the whole country was recorded in Bam station. Weather data also recorded the highest heavy winds and wind-driven vision loss in Zahedan – Bam road. In this climate zone, Karimi Nazar *et al.* (2009) conducted a study to identify the factors affecting drought. The results of their study indicated that rainfall and severe droughts have significantly decreased in this area. As stated, the results of calculating the climate change fluctuation index also emphasize the major role of precipitation fluctuations in this area. The results of the study conducted by Ahmadi *et al.* (2016) are contradictory to the results of the calculation of the index in this study. They concluded that the precipitation trend in the northwest of Iran is more severe than the central and eastern regions. The results of the climatic fluctuation index indicate the importance of precipitation fluctuations in this area, while the results of the study by Razeai *et al.* (2005) show that in recent years, southeastern regions of Iran have suffered from a shortage of rainfall and temperature rise, and the precipitation trend has undergone a significant decline. Also, it has been concluded that successive droughts in this area can be attributed to the decreasing trend of precipitation and temperature rise.

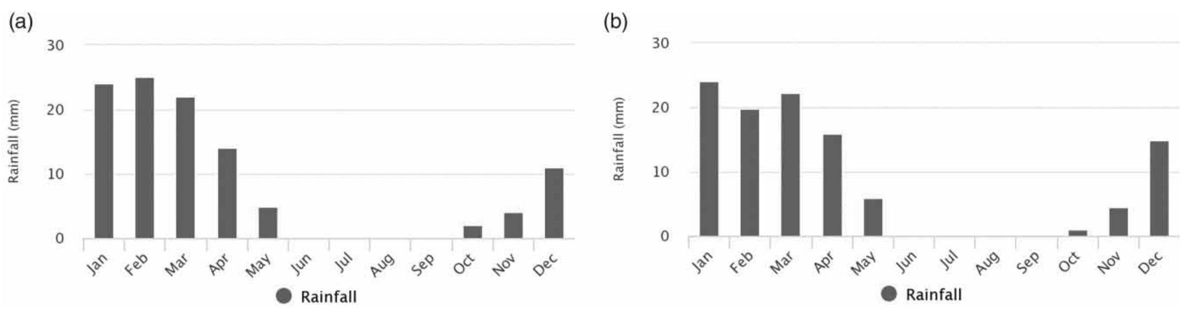

Figure 4 | (a) Average monthly rainfall 1961–1990 and (b) average monthly rainfall 1991–2015. Source: World Bank Climate Change Knowledge Portal.

As for the stations of the F1 climate, semi-hot desert or a central region of the country, the highest fluctuation was recorded in Tabas station (rank 111). In this station, permanent risks were more than frequent risks and wind fluctuation was the most effective factor of the index. Ghahreman & Ghareh Khani (2010), also studying the time variation process in wind speed, concluded that the increasing trend of wind speed has been greater than its decreasing trend, which is in line with the results obtained from calculating the climate change fluctuation index. Mirabasi & Din Pajouh (2015) also studied the trend of wind speed changes in Iran and found a certain trend in the studied stations.

As for climate F2 (coastal hot desert region), frequent risks were found to be higher than permanent risks, and wind and aridity fluctuation were the most effective factors of the index. Azarakhshi *et al.* (2013) studied the trend of annual and seasonal changes in rainfall and temperature parameters, concluding that rainfall data have a combination of increasing and decreasing trends.

DISCUSSION

The purpose of this study was to investigate the climate vulnerability index fluctuation. In other words, the study aimed to investigate the fluctuations in climatic factors by analyzing the different aspects of vulnerability index of fluctuating climatic parameters. Generally, among the 12 studied climates, temperature fluctuation was the main damaging factor in very humid and temperate, humid and temperate, semi-arid hot, hot semi-mountainous, and very hot desert zones, whereas wind fluctuation was the major factor in semi-hot desert, cold semi-arid, and cold mountain zones. In very hot and extreme desert, precipitation change was the major factor that increased the index. In moderate desert and coastal hot desert zones, rainfall and aridity fluctuation simultaneously were the main factors of index and effective factors of higher index.

Weather data confirm results in the B1 region Mashhad station, located in the east of country, where, based on the SPI index, there was severe drought, or wind with speeds of 40 km/h in Urmia. Generally, during the course of the study, the north and northeast of the country experienced minimum climatic changes, and moving towards the southeast and south of the country there were more climatic changes.

The results indicate that the maximum rank of index has occurred in hot semi-mountainous, very hot desert, and very hot and extreme desert, respectively. Also, temperature fluctuation was the major factor in five regions, whereas wind fluctuation was the major factor increasing the index in three regions. Generally, the northern and western parts of the country experienced minimum climatic changes during the timespan of the study.

As mentioned in the previous sections, other studies have merely focused on one of the parameters and exclusively studied the impact of parameters such as floods, drought or heat stress on crop production, income level and/or household welfare, but this study shows that due to different sources of vulnerability in different parts of a region or country, it is necessary to study the vulnerability index by determining the main source of fluctuation in the region. In this way, research findings would prove useful for planners and policy-makers.

Therefore, related organizations such as the Environmental Protection Agency (EPA) are recommended to use the index results to allocate budgets in order to cope with the negative effects of fluctuations of climatic factors. Ignoring the negative effects of such fluctuations of climatic factors would impose heavy costs and irreparable damage to renewable and unrenewable resources, particularly in developing countries. Moreover, the compensation cost (like Urmia Lake or habitat degradation of natural species, animals, and plants in Iran) would be significant for the economy. It should be noted that the ranking of vulnerability index was based on the current situation of stations, and in the future, the effects of climate change conditions can change area ranks. This index has to be calculated for other developing countries which are similarly vulnerable to climate change.

CONCLUSION

The climate vulnerability index fluctuation indicates the available features within the region which are damaged by changes or fluctuations of climatic factors. Generally, this indicator is useful for assessing channels and vulnerability in the studied areas. Thus, the vulnerability characteristics are analyzed with regards to climate change in each specific area.

The results indicated that climates C3 (hot semi-mountainous), D (very hot desert), and E2 (very hot and extreme desert) had the highest index value in Iran. Also, one can conclude that northern and western parts of the country have been less exposed to the fluctuations of climate factors. Moving towards the southeastern and southern areas, more fluctuations in climatic factors are recorded.

Other studies were based on one or a number of different climatic parameters, whereas this study investigated various climate parameters for various stations of the country. Other studies have focused on one or two parameters in terms of economic or structural vulnerability, etc. So far, a similar study has not been carried out on the structure of this study in Iran. Guillaumont (2015) and Guillaumont & Simonet (2011) studied this index for African countries and in another study for different countries in the world (calculated on average for the country); however, those authors studied the indicator for different regions and stations of the country separately.

The results of calculating the vulnerability index in this survey confirmed Guillaumont & Simonet's (2011) study, which calculated the index for all the countries of the world. They found the index value to be 55.58 for Iran. It needs to be mentioned that in Guillaumont & Simonet's study, sea level was also considered as an effective part of climate change.

In Guillaumont (2015) study, the physical vulnerability index of climate change for developing countries was 46.72, and the same index for the developing countries of Africa was 51.07. This index was 55.58 for Iran, which points to the high vulnerability of Iran compared to other developing countries. In general, developing countries receive more damage caused by global warming. Since these areas have a lower capacity to adapt to changing conditions, they are more vulnerable when facing climate change. High levels of vulnerability, limited financial and organizational ability to adapt, low per capita GDP, and widespread poverty are the main factors which aggravate the consequences of climate change.

The results obtained for this index may be used as a guideline for allocating national resources in order to adapt to the consequences of fluctuations of climatic factors. Also, this index may prove to be useful for obtaining loans from international agencies, and it helps in allocating funds and resources to areas that are more vulnerable to the vagaries of climatic factors.

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REFERENCES

Abbasian, A. & Delavar, A. 2012 Investigation of the relationship between drought and number of days of dust and wind speed in Isfahan. In: *Third National Conference on Integrated Water Resources Management*, University of Agricultural Sciences and Natural Resources.

Afshari Azad, M. & Shabanzadeh, F. 2010 Investigate the trend of wind speed changes at Rasht station. *Geographic Outlook* **5** (11), 1–11.

AghaKouchak, A., Norouzib, H., Madanic, K., Mirchid, A., Azarderakhshe, M., Nazemif, A., Nasrollahia, N., Farahmanda, A., Mehrana, A. & Hasanzadeh, E. 2015 Aral Sea syndrome desiccates Lake Urmia: call for action. *Journal of Great Lakes Research* **41** (1), 307–311. http://dx.doi.org/10.1016/j.jglr.2014.12.007.

Ahmadi, F., Radmanesh, F. & Najafi, R. 2016 Analysis of the trend of the northern part of the country's rainfall in the last half century. *Journal of Water and Soil Science* **26** (2), 171–186.

Ahsan, N. & Warner, J. 2014 The socioeconomic vulnerability index: a pragmatic approach for assessing climate change led risks–A case study in the south-western coastal Bangladesh. *International Journal of Disaster Risk Reduction* **8**, 32–49. http://dx.doi.org/10.1016/j.ijdrr.2013.12.009.

Arsalani, M., Azizi, Gh. & Khosh Akhlagh, F. 2012 Reconstruction of maximum temperature changes in Kermanshah province using tree rings. *Geography and Environmental Hazards* **1**, 27–41.

Azarakhshi, M., Fazadmehr, J. & Eslah, M. 2013 Investigating annual and seasonal changes in precipitation and temperature parameters in different climate zones of Iran. *Pasture and Watersheds Journal* **1**, 1–16.

Bannayan, M., Mohamadian, A. & Alizade, A. 2010 On climate variability in north-east of Iran. *Journal of Water and Soil* **24** (1), 118–131.

Deschenes, O. & Greenstone, M. 2007 The economic impacts of climate change: evidence from agricultural output and random fluctuations in weather. *American Economic Review* **97** (1), 354–385.

Farajzadeh, M. & Razi, M. 2011 Investigation of temporal and spatial distribution of severe storms and winds in Iran. *Watershed Research (Research and Construction)* **91**, 22–32.

Farhangfar, S., Bannayan, M., Khazaei, H. & Mousavi Baygi, M. 2015 Vulnerability assessment of wheat and maize production affected by drought and climate change. *International Journal of Disaster Risk Reduction* **13**, 37–51. http://dx.doi.org/10.1016/j.ijdrr.2015.03.006.

Ghahreman, N. & Ghareh Khani, A. 2010 Investigation of changes in time of wind speed in Iran's climatic range. *Iranian Journal of Irrigation and Drainage* **1** (4), 31–43.

Ghoddosi, M., Morid, S. & Delavar, M. 2013 Comparison of detrending methods for the temperature and precipitations time series. *Journal of Agricultural Meteorology* **1** (2), 32–45.

Guillaumont, P. 2009 An economic vulnerability index: its design and use for international development policy. *Oxford Development Studies* **37** (3), 193–227.

Guillaumont, P. 2015 *Measuring Vulnerability to Climate Change to Allocate Funds for Adaptation*. Joint Research Center Seminar, Brussels.

Guillaumont, P. & Simonet, C. 2011 *To What Extent are African Countries Made Vulnerable to Climate Change? Lessons from a new Indicator of Physical Vulnerability to Climate Change*. Ferdi Working Paper.

Heidari, H. & Alijani, B. 1999 Iran climate classification using multivariate statistical techniques. *Geographical Research* **37**, 57–74.

IPCC 2007 *Fourth Assessment Report of the Intergovernmental Panel on Climate Change Glossary Climate Change: Climate Change Impacts, Adaptation, and Vulnerability*. Cambridge University Press, Cambridge.

IPCC 2014 *Fifth Assessment Report-Impacts, Adaptation and Vulnerability*. Cambridge University Press, Cambridge and New York.

Iran Second National Communication to UNFCC 2010 *Climate Change Office*. Department of Environment, Islamic Republic of Iran.

Karimi Nazar, M., Mosaedy, A. & Fakhrieh, A. 2009 Investigation of climate factors affecting drought, a case study of Zabol. In: *5th National Conference on Watershed Management Sciences and Engineering*, Gorgan University of Agricultural Sciences and Natural Resources.

Keshavarz, M. & Sharifan, R. 2014 Investigation of the process of changes in average wind speed in selected synoptic stations of Fars province. In: *Third National Conference on Agriculture and Sustainable Development*, Islamic Azad University of Shiraz.

Keshavarz, M., Maleksaeidib, H. & Karami, E. 2017 Livelihood vulnerability to drought: a case of rural Iran. *International Journal of Disaster Risk Reduction* **21**, 223–230. http://dx.doi.org/10.1016/j.ijdrr.2016.12.012.

Miller, F., Osbahr, H., Boyd, E., Thomalla, F., Bharwani, S., Ziervogel, G., Walker, B., Birkmann, J., Van der Leeuw, S., Rockström, J., Hinkel, J., Downing, T., Folke, C. & Nelson, D. 2010 Resilience and vulnerability: complementary or conflicting concepts? *Ecology and Society* **15** (3), 11.

Mirabasi, R. & Din Pajouh, Y. 2015 Investigating the trend of wind speed changes in selected stations in Iran. *Geography and Planning Journal* **19** (52), 59–73.

Mousavi Baygi, M., Bannayan, M., Ashraf, B. & Asadi Oskuei, E. 2016 Assessment of climatic indices limiting rainfed wheat yield. *Ecological Indicators* **62**, 298–305.

Razeai, T., Danesh Kar, P. & Saghafian, B. 2005 Annual precipitation trend in arid and semi arid regions of central and eastern Iran. *Water and Wastewater* **54**, 27–36.

Rezaei, M., Javan, Kh. & Zeinali, B. 2011 Investigating the trend of wind speed changes in northwest of Iran. *Natural Geography Quarterly* **4** (13), 750–764.

Rufat, E., Tate, G., Burton, C. & Maroof, A. S. 2014 Social vulnerability to floods: review of case studies and implications for measurement. **14** (4), 470–486. http://dx.doi.org/10.1016/j.ijdrr.2015.09.013.

Sabouhi, R. & Soltani, S. 2008 Analysis of the trends of climatic factors in large cities of Iran. *Science and Technology of Agriculture and Natural Resources* **12** (46), 303–321.

Sabouhi, R., Soltani, S. & Yaghmaee, L. 2009 Investigation of climate change and its relation with air pollution in Isfahan. In: *Third Conference on Environmental Engineering*, Tehran.

Salari, A. & Gandomkar, A. 2012 Investigating the trend of temperature changes in Bandar Abbas and Qeshm Island using my non-parametric Kendal test. *Quarterly Geographic Survey* **9** (35), 77–92.

Sharghi, T., Abarghoye, H., Asadi, M. A. & Kosary, M. 2010 Estimating reference evapotranspiration using the FAO-Penman-Monteith and zoning in Yazd Province. *Arid Biome Scientific and Research Journal* **1** (1), 25–33.

Shirgholamy, H. & Ghahraman, B. 2005 Investigating the trend of annual average temperature changes in Iran. *Science and Technology of Agriculture and Natural Resources* **9** (1), 9–24.

Timmerman, P. 1981 *Vulnerability, Resilience and the Collapse of Society, Environmental Monograph 1*. Institute for Environmental Studies, University of Toronto, Toronto.

United Nations Environment Program/Global Resource Information Database 1991 *Global Digital Data Sets for Land Degradation Studies: A GIS Approach, GRID Case Study Series No. 4*. UNEP/GEMS and GRID.

Vafakhah, M., Bakhshi Tirgani, M. & Khazaee, M. 2012 Rain and rain analysis in Kashfrud watershed. *Geography and Development* **29**, 77–90.

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