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Spatial-temporal analysis of heat waves in Iran over the last three decades

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Abstract

The purpose of this research is to analyze heat waves characteristics in the warm period of the year as a climatic hazard in Iran. In this study, the daily maximum temperature is taken at 44 synoptic stations during the period 1981-2010. These temperature values were used to extract the intensity, frequency and duration of heat waves using percentile thresholds of 90, 95, and 98. The results showed that the average heat waves intensity is added between 3 to 4°C during summer more than spring. During spring and summer seasons, the most intense of heat waves is occurred on the southern coasts of Iran, and the most frequency of heat waves is occurred in the Zagros Mountains and eastern scattered mountainous of Iran. On average, the heat waves frequency is increased about 4 more heat waves during summer than spring. Furthermore, the seasonal average of the most duration of heat waves about 10 to 16 consecutive days has occurred in the southeastern of Iran. Generally, in the higher percentile thresholds heat waves frequency is reduced, but the intensity and duration are increased.

Keywords

climatic hazard, heat wave, Iran, percentile thresholds, warm period.

1. Introduction

Previous research shows that since the beginning of the Twentieth century, average Global temperature has been increased about 0.6°C (Easterling et al., 1997). Nowadays, climate change is one of the most serious hazards to human life (Confalonieri et al., 2007). The Fourth Assessment Report of the International Panel on Climate Change (IPCC) confirms that climate change can be caused by changes in the mean climate, and variability of its properties (Solomon, 2007). One of the signs of climate change is an increase in the risks of climate events such as heat waves. It can be said that the first step to control or at least to reduce the harm caused by these atmospheric phenomena are by definition, recognition and identification of its features with scientific methods. There is no comprehensive and universal definition of a heat wave (Folland et al., 2001; Frich et al., 2002; Stott et al., 2004; Tamrazian et al., 2008). In this regard, any temperature above a certain threshold as single, or one-day is not a heat wave so that a heat wave is different on its duration characteristics from a hot day. A group of key extreme indices such as hot days are defined with

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the cooperation of Commission for Climatology (CCL), World Meteorological Organization (WMO), and the Climate Variability and Predictability Program (CLIVER). In general, according to a simple definition of American Metrological Society (AMS), a heat wave is a period of abnormalities and unpleasant warms that is usually associated with the humidity (Kalkstein et al., 2008). In the field of heat waves, Barros began his studies in the late 19th century. Barros considered the heat wave as a period of three consecutive days and more where the average daily temperature is 32.2°C (Robinson, 2001). Then in the early twentieth century, Ward has defined a heat wave as an unpleasant period of high temperature during the warming seasons that lasting more than one day (Ward, 1925). Most recent study showed that 90th percentile of daily maximum temperature and its duration equal to or more than 6 days are suitable to determine a heat wave (Zhang et al., 2011). Krautmann (2012) considered some characteristics include duration, daily maximum and minimum temperature, atmospheric conditions, human health and location of the stations to detect a heat wave as a part of climatic hazards. In several studies, 10 relative based thresholds were applied to detect heat waves (Steadman, 1984; Meehl & Tebaldi, 2004; Anderson & Bell, 2010; Peng et al., 2011), and similarly 6 absolute value based thresholds were used to find out heat waves in many researches (Steadman, 1979; Rothfusz and Headquarters, 1990; Robinson, 2001; Tan et al., 2007) during last four decades. In comprehensive study considering these thresholds made by Smith et al. (2013), 16 various thresholds have been used to determine the characteristics of heat wave for the warm period of the year between 1979-2011. In another study, heat waves have been defined using a period more than two consecutive days and above percentile threshold of 90th in daily maximum temperature (Keellings & Waylen, 2014). The report of IRIMO (2012) showing effects on mitigation and adaptation to climatic extremes indicated that there is an increase in extreme climate events in Iran, particularly heat waves. Thus, the percentile thresholds were applied on daily maximum temperature time series of the 44 synoptic stations in Iran to detect heat waves in the warm period of the year between 1981-2010, and ultimately to understand the spatial distribution of the changes in terms of characteristics of heat waves over Iran. The obtained result will be benefit governmental planning studies in a broad range of society comprising health care, transportation, mitigation strategies, emergency services, energy and agriculture.

2. Study area

Iran covers a total area of 1.648 million $km^{2,}$ and is also located between 45°–63° Eastern longitude and 25°–40° Northern latitude near the center of the Middle East. Due to the high mountains and topographical diversity in Iran, spatial distribution of temperature does not follow a regular pattern. Hence, temperatures will increase from North to South and from West to East. This characteristic is mostly due to the presence of mountains in the North and West of the country along with a gradual reduction of radiation angle in northern latitudes. It is included the central plateau surrounded by two mountainous zones of Alborz in the north, and Zagros in the west with elevation ranges of –56 to 5415 masl, as well. The mountains prevent Mediterranean moisture-bearing systems from crossing through this region (Fig. 1). Therefore, most parts of Iran especially in the warm season are affected by the subtropical high pressure system which causes the existence of warm and dry summer in Iran (Mansouri-Daneshvar et al., 2013).

3. Materials and Methods

In present study, the daily temperature time series during the observation period (1981–2010) was prepared using data from 44 synoptic stations over Iran which was obtained from Iran Meteorological Organization (via http://www.irimo.ir). These selected stations with the most perfect records of daily temperature time series during the observation period are represent suitable spatial distribution over elevation range of Iran (Fig. 1).

There are numerous definitions of heat waves. In general, the definition of "heat wave" can be separated into two groups. In the first group, researchers define a heat wave based on region-specific absolute and numerical thresholds (Robinson, 2001). In the second group, researchers define a heat wave based on relative and percentile thresholds with a comprehensive vision (Hajat

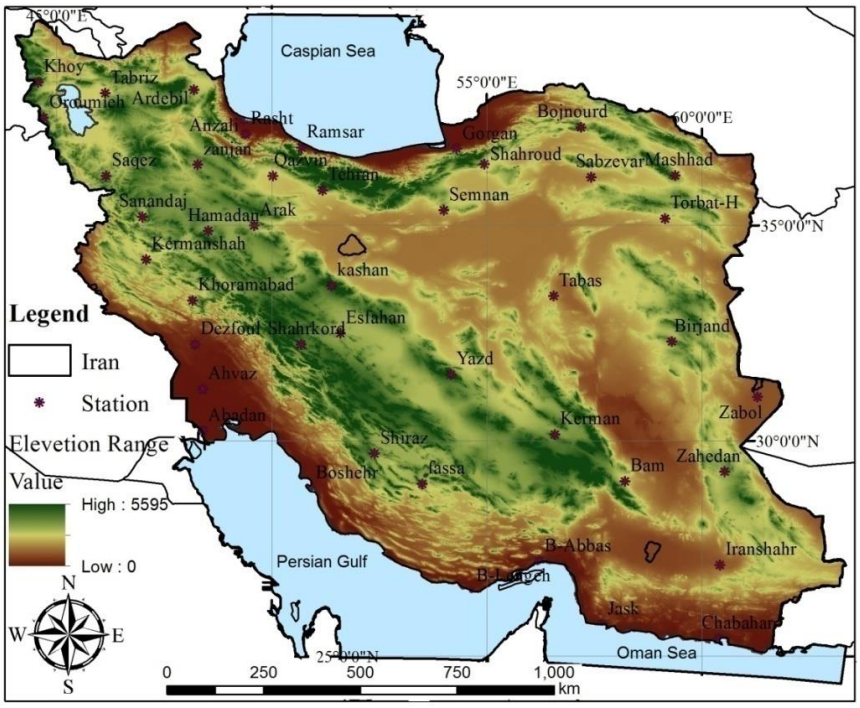

Fig. 1. Topography map of the study stations in Iran

et al., 2002; Gosling et al., 2007; Beniston & Diaz, 2004; Kuglitsch et al., 2010; Kent et al., 2014). Absolute numeric thresholds are typically used for areas with subtle elevation change and are insufficient for analyzing a large country with varied topography such as Iran. Therefore, the percentile threshold methods of Tryhorn and Risbay (2006) and the comprehensive definition of international climate change expert (CLIVER) were used in this study. In this method if the daily maximum temperature of a station is higher than the percentile thresholds of 90, 95 and 98 for a period of at least three consecutive days, then the event is considered a heat wave. To perform this study, observational data related to daily maximum temperature were obtained from The Iran Meteorological Organization (via http://www.irimo.ir) at 44 synoptic stations during the base period (1981 to 2010). Observational data in each station was tested for accuracy of data time series at a significance level of 95% by using of data adequacy test, homogeneity of Run Test, and normality *test of Kolmogorov-Smirnov*. After sorting and validating the observational data, daily maximum temperature time series for each study stations were prepared during the spring and summer months. Period of three consecutive days or more that daily maximum temperature is greater than selected percentile threshold as a Heat wave were extracted from these time series using the aforementioned percentile threshold. For this purpose, the percentile thresholds definition of heat wave was scripted via MATLAB software for identifying all periods of heat waves occurrence. After detecting heat waves in all study stations in Iran, its characteristics includes intensity, frequency and duration which were separately calculated for all percentile thresholds, study stations, and months during the warm period of year. Finally, with regarding to the elevation diversity, the spatial distribution of heat waves characteristics over the study area was mapped using the IDW interpolation method via Arc GIS software.

4. Results and Discussion

After detecting the heat waves, its characteristics comprises intensity, frequency and duration were separately calculated for the any percentile thresholds (90^{th}, 95^{th} & 98^{th}), and the any 6 months during the warm period of the year (April, May, June, July, August, and September). To respect the principle of shorthand, and similar features in extracted heat waves is between monthly with seasonal periods. Therefore, only the results of the analysis of seasonal heat waves in terms of percentile thresholds of 90, 95 and 98, in the warm seasons including spring and summer, will be developed and followed more.

The average heat waves intensity map displays a 3 to 4°C increase in the intensity of heat waves in summer versus spring (Fig. 2). The intensity of heat waves on the threshold of the 98th percentile to the 90 and 95 percentile thresholds shows an increase for about 1°C. In other words, the average of heat waves intensity is added in the higher percentile thresholds than the lower threshold percentiles. Based on the 98th threshold percentile, the most intense heat waves in Iran occur during the summer season. The seasonal variations in the intensity of heat waves during the study period showed that the strongest and weakest heat wave event in the spring has been approximately 49 and 25°C and about 50 and 30°C in the summer. In terms of seasonal patterns, heat waves during spring occur in the southern half of the country, especially in the southwest coast and south-eastern Iran. Spatial analysis of seasonal patterns and intensity zoning of heat waves during spring shows that heat waves occur in the southern half of the country. Heat wave intensity is reduced near the middle of the Northwest and Southwest coast of the Caspian Sea. The monthly trend analysis of the intensity of heat waves shows that at the end of spring and the beginning of summer (June & July), the intensity of heat waves increased, and at the end of the summer, heat wave intensity is reduced.

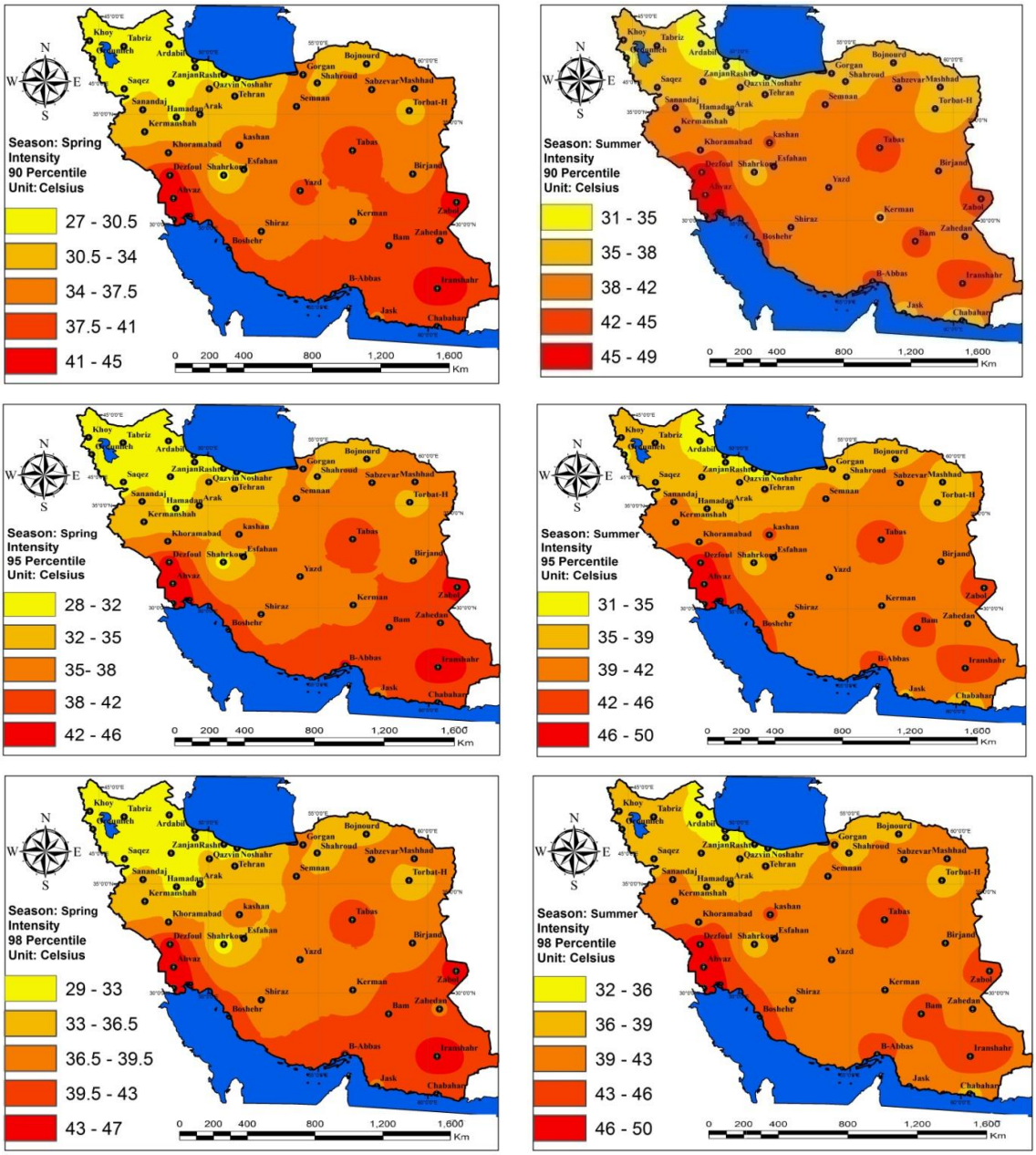

Fig. 2. The seasonal average of heat waves intensity during the warm period of year

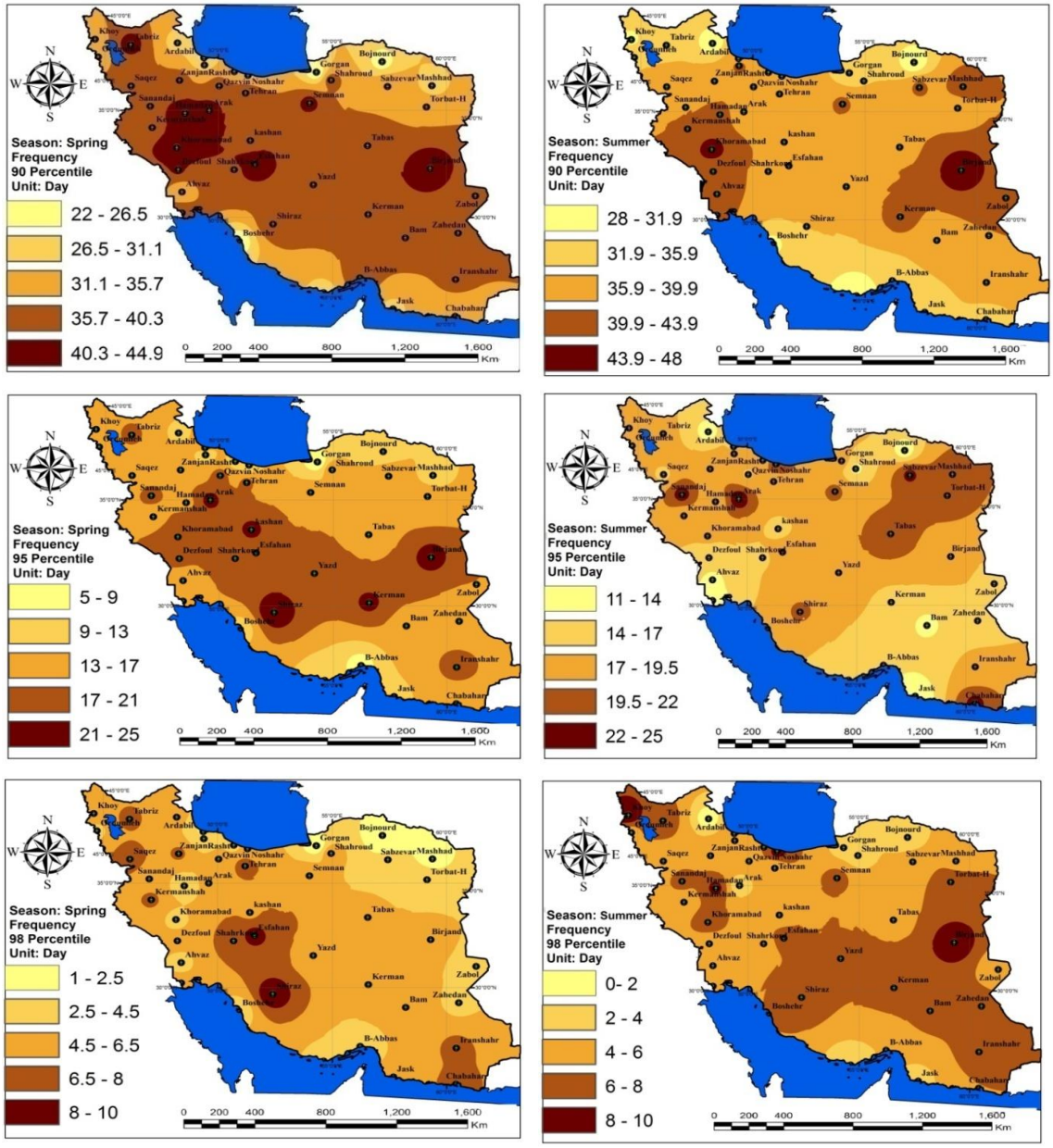

Fig. 3. The sum total of heat waves frequency during the warm period of year

After calculating the number of heat waves, spatial distribution of heat waves frequencies were mapped (Fig. 3). It should be noted that in this study, counting the frequency of heat waves in each period was subject to the definition of a heat wave, regardless of the number of days it has been sequenced. In the spring, the spatial distribution of most heat waves based on the 90th percentile threshold were observed in the middle half of the central latitudes, especially in the area of the western mountains of Iran. The lowest frequencies were observed in the high latitudes of the northern and southern half of the lower latitudes, especially along the coastal margin. The frequency of heat waves is added during the summer than the spring, but in terms of the spatial distribution of the heat waves frequency in the mid-latitude regions, especially in the mountain areas was reached the maximum due to the more frequency of short-waves occurrences in the mountainous areas than low-land. In other words, temperature fluctuations in most mountainous areas exhibit a greater frequency of shorter periods repeated than neighboring Central areas. On average, the frequency of heat waves in summer is about 4 heat waves more than the spring season. In general, the total frequency of heat waves on the percentile threshold of 98 is reduced to 1.3 and 1.2 less than percentile threshold of 90. Therefore, in higher threshold percentile, the occurrence of heat waves frequency is reduced but the intensity and continuity is increased. For this reason, the

spatial distribution pattern of the most frequent heat waves based on the 98 percentile threshold can be seen more in interior warm and semiarid areas in the eastern half of Iran. Also, examining the seasonal frequency of heat waves during the study period showed that the short-term heat waves were more frequent than long-term heat waves. On average, the duration of seasonal frequency variations of short-term heat wave occurrence is between 1-10 days and long-term heat waves between 1-5 days. Temporal analysis of monthly frequencies also showed in the first half of the spring season and the middle of summer, the frequency heat waves increased.

The overall pattern of spatial distribution of seasonal mean duration of heat waves displays the same similarities based on all percentile thresholds (Fig. 4). In other words, the average greatest seasonal duration in the central and eastern half, especially in the southeast coast of Iran in the value of consecutive 7 days, and the average smallest seasonal averages has been occurring in the area of the North East to the value of 4 consecutive days. Also, by monthly temporal analysis of durations, it was found that long-term occurrence of heat waves has been occurred more often in the early spring and mid-summer.

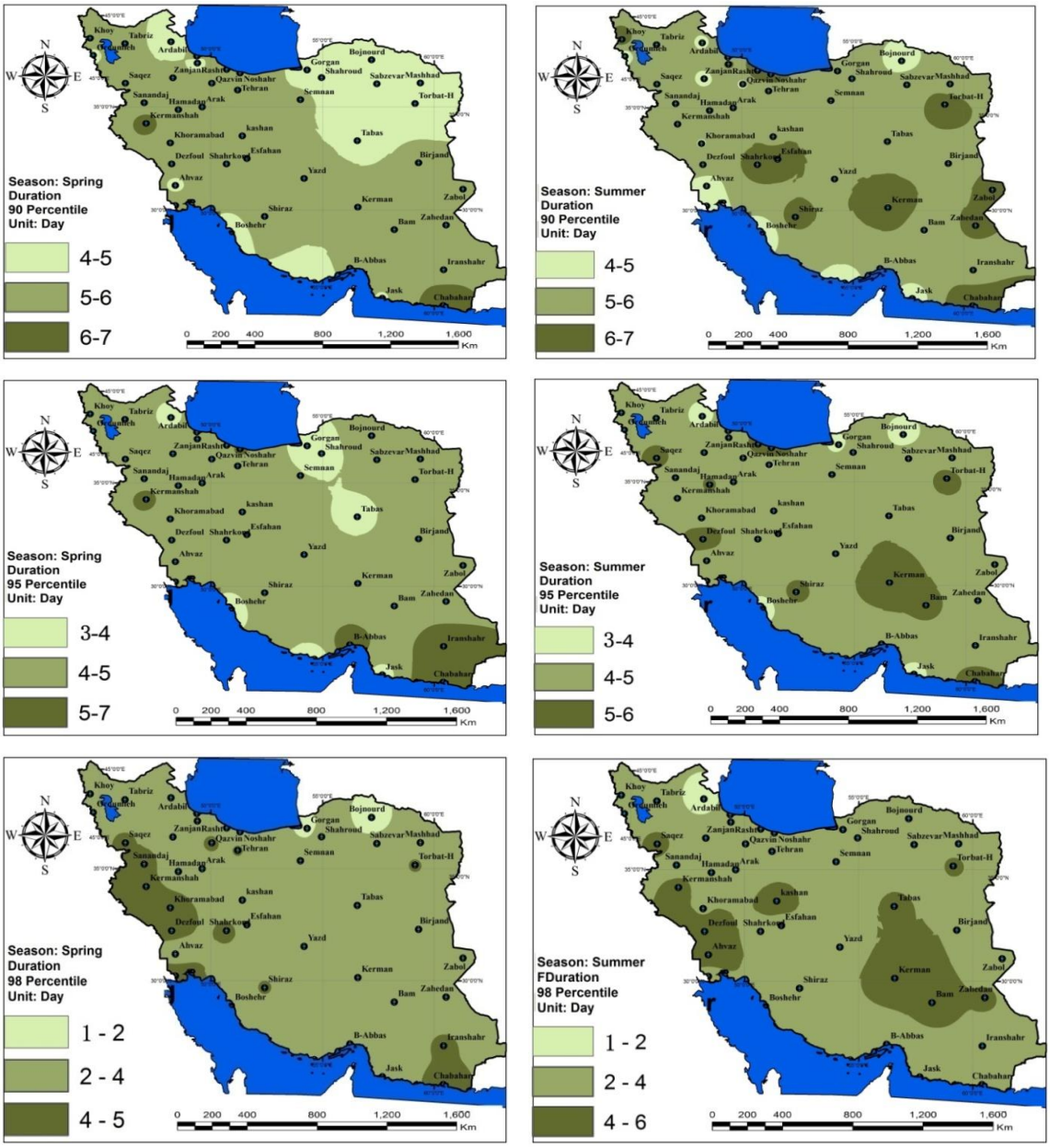

Fig. 4. The seasonal average of heat waves duration during the warm period of year

After examining the spatial distribution of seasonal mean of the heat waves duration, the largest and lowest heat waves on each of the 44 synoptic stations in Iran during the entire statistical period of the study were also extracted (Table 1). As the following table shows, the longest heat waves have been occurring with a value of about 10 to 16 days whereas the highest incidence was observed first in the half of southeastern Iran and then in the Caspian Sea and the western half of Iran. This is in terms of short-term spatial distribution of heat waves, in which no significant changes in the range of Iran were observed. Generally, short-term heat waves frequency occurring in 3-4 consecutive days in the summer is more than in the spring.

Table 1. Seasonal frequency of the longest and lowest of heat waves duration in the time period 1981 to 2010

Season→	Spring (Unit: Day)				Summer (Unit: Day)			
Stations ↓	Frequency	Lowest Duration	Frequency	Longest Duration	Frequency	Lowest Duration	Frequency	Longest Duration
Abadan	3	3	2	6	2	3	1	6
Ahvaz	2	3	1	8	2	3	1	7
Arak	3	3	1	8	4	3	2	8
Ardebil	2	3	1	6	3	3	1	5
B-Abbas	1	3	1	8	2	3	1	8
B-Anzali	3	3	1	8	2	3	1	9
B-Lengeh	3	3	4	4	3	3	1	6
Bam	3	3	1	8	1	3	1	8
Birjand	5	3	1	7	2	3	1	8
Bojnourd	2	3	1	6	3	3	1	6
Boshehr	2	3	1	5	4	3	1	5
Chabahar	1	3	1	13	2	3	1	10
Dezfoul	4	3	1	8	3	3	1	12
Esfahan	2	3	1	7	2	3	1	8
Gorgan	1	3	1	4	4	3	1	6
Hamadan	3	3	1	7	3	3	1	9
Iranshahr	2	3	1	9	3	3	1	8
Jask	3	3	1	7	2	3	1	6
kashan	2	3	2	8	2	3	1	9
Kerman	3	3	1	9	1	3	1	9
Kermanshah	2	3	1	9	2	3	1	6
Khoramabad	4	3	1	8	3	3	1	7
Khoy	3	3	1	8	2	3	1	9
Mashhad	2	3	1	6	5	3	1	7
Tehran	2	3	1	8	2	3	1	5
Noshahr	2	5	1	10	2	3	1	16
Oroumieh	3	3	1	8	4	3	1	8
Qazvin	3	4	1	8	3	3	1	6
Ramsar	2	3	1	10	3	3	1	11
Rasht	1	3	1	7	5	3	2	6
Sabzevar	3	3	1	6	4	3	1	8
Sanandaj	2	3	1	9	3	3	1	7
Saqez	5	3	1	9	2	3	1	13
Semnan	2	3	1	7	3	3	1	6
Shahrkord	2	3	1	7	2	3	1	11
Shahroud	3	3	1	6	2	3	1	8
Shiraz	2	3	1	8	3	3	1	9
Tabas	3	3	1	6	2	3	1	9
Tabriz	3	3	1	8	2	3	1	9
Torbat-H	2	3	1	8	4	3	1	12
Yazd	4	3	1	6	3	3	1	8
Zabol	3	3	1	8	2	3	2	6
Zahedan	3	3	1	7	3	3	1	12
Zanjan	1	3	1	8	4	3	1	8

5. Conclusions

At present, the phenomenon of extreme climate is at the center of attention for scientific community. The findings from the extraction and analysis of the characteristics of heat waves during the observation period (1981-2010) showed that intensity of heat waves in summer are more severe than in spring and extreme heat waves occurred across the southern coast of Iran. The frequency of heat waves in mid-latitudes of Iran and especially on the higher elevations display the maximum extent. The frequency distribution of heat waves is in the hotter part of the country due to temperature fluctuations in mountainous where there is a higher frequency of shorter repeated heat waves. On average, the frequency of heat waves is about 4 heat waves more in summer than spring. The frequencies of the most long-term of heat waves are observed in the middle of the southeastern Iran during midsummer. The results also showed in the comparative analysis of the characteristics of heat waves in Iran based on various thresholds, analyzed results also become more transparent in the 95 percentile threshold. Nowadays, due to adverse human and environmental consequence resulting from the occurrence of heat waves, it is necessary that the conditions and characteristics of heat waves be on the focus of planning in order to implement the best large scale programs, and managerial patterns.

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