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Quantification and assessment of effective of global warming on the occurrence of heat and cold waves in some selected stations in Iran

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Abstract
One of the atmospheric hazards that seriously affect human life and health is the occurrence of thermal tensions and stress in the form of heat and cold waves. Iran is one of the areas of the planet that has climate variability due to its geographical characteristics; therefore, consequently, its different regions are not immune to heat and cold waves. On the other hand, Iran's climate variability is the factor causing the difference between thresholds of heat and cold wave occurrence for its different regions. Therefore, in this study, based on three different thresholds, spatial analysis of the frequency of occurrence of heat and cold waves has been done. Thus in this work, using average daily data from 1960 to 2014, PET (Physiological Equivalent Temperature) was used to monitor heat and cold waves of four stations in Iran. Results of this study showed that in the context of global warming, although significant differences in the frequency of cold waves cannot be seen, these changes are significant and increasing for the frequency of occurrence of heat waves of selected station.

Keywords: Global warming, frequency of occurrence, duration, thermophysiologic indices, temperature stress, Iran.

1. Introduction
Ecosystems and a variety of human activities are strongly influenced by extreme climate phenomena that heat waves (HW_S), cold waves (CW_S), wind chill, floods and droughts are some of these extreme bioclimatic events. The IPCC (2007) defines an extreme event as follows: "an extreme weather event is an event that is rare within its statistical reference distribution at a particular place". Definitions of 'rare' vary, but an extreme weather event would normally be as rare as or rarer than the 10^{th} or 90^{th} percentile" (Unal et al., 2013).

HWs and CWs are harmful to the biophysical systems and can create danger on human health, especially on elderly people, children, and people who have serious health problems (World Health Organization, 2003; Ding and Ke, 2013). Global mean surface temperature has increased since the late nineteenth century, and warming has led to changes in temperature extremes, including heat wave (HW) and cold wave (CW) since the mid twentieth century (IPCC 2013; Unal et al. 2013; Ding and Ke; 2015). Global warming is one of the most prominent climate changes of the current century, which has been addressed by researchers in the regional and planetary scale. The second half of the twentieth century in the northern hemisphere was found to be warmer than any other 50-year period in the last 500 years with the greatest warming documented during winter and spring (Schär et al. 2004). In several studies (Robeson, 2004), a general increase in warm extremes and a decrease in cold extremes have been seen in the regional and global scale, although this increase in temperature has not occurred uniformly around the earth (Frich et al., 2002). Since the past few decades in the Europe, the rise in temperature has started in the twentieth century (Klein Tank et al, 2003; Ramos et al., 2011). Climate change projects show that the intensity and frequency of heat waves of Europe will increase for decades to come. This increasing trend is also visible in the current observational data and approves the increasing trend of this climatic hazard for the coming decades (Karl and Trenberth, 2003). Although the results of temperature increase are not unique to Europe, an increase in the minimum temperature in East Asia (Zhao et al., 2003) and the trend of a rise in annual temperature with decade changes up to 0.7 degrees Celsius in the majority of Africa (Manfred and El-Tantawi Attia, 2005) are also significant. Analyses of

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trends in extreme climate conditions found decreases in the diurnal temperature range, frost days, ice days, cool days and cool nights for the majority of stations across Iran (Rahimzadeh et al., 2009). For the arid to semi-arid regions of Iran, winter temperatures have been found to increase (Tabari and Hosseinzadeh Talaee 2011). The capital city of Tehran has additional heat stresses from the urban heat island, which has worsened over recent decades due to urban sprawl (Roshan et al., 2009; Roshan et al., 2010). The confirmation of 2 degrees Celsius increase in temperature of Iran in the last hundred years (Masoodian, 2004) is another finding of increasing temperature changes for Iran. Besides, projects of simulation of future climate change indicate that Iran will face temperature increase in the coming decades. In a study it was found that temperature have been increasing for the winters of North West Iran and in total, temperature rise of these areas will reach by 1.35 ° C until late 2100s (Roshan and Orosa 2015). On the other hand, the observed data also shows that the trend of cold extremes has been decreasing in recent decades. This decreasing trend is not only seen in the observed data, but projects of climate change forecast for the twenty second century confirm the decrease of frequency of frost days across Europe (Heino et al., 1999; Meehl et al., 2004). Despite this, although a decreasing trend in cold extremes is seen for the coming decades, the climate change modeling indicates greater severity of cold extremes for the coming decades compared to the current period (Vavrus et al., 2006; Kodra et al., 2011).

During the past years, some studies analyzed the physical basis of cold waves on the basis of human health effect and mortality rates (Aylin et al. 2001; Ballester et al. 2003; Bøkenes et al. 2000; Fitchett et al. 2014). On the other hand, the studies either analyzed the relation between heat waves and atmospheric circulation (Kyselý, 2002; Makrogiannis et al., 2008) or physical basis of heat waves such as thermal and air quality conditions (Giles and Balafoutis, 1990; Roshan et al., 2018a; Matzarakis and Mayer, 1991), heat-related mortality and morbidity (Pantavou et al., 2008; Dolney and Sheridan, 2006; Fouillet et al., 2006; Basu and Samet, 2002) and the calculated human discomfort indices (Giles et al., 1990; Matzarakis and Mayer, 1997; Matzarakis and Nastos, 2011). Several high impact of HW events have occurred in recent years, e.g. in Europe in 2003 (Beniston, 2004; Levinson and Waple, 2004; Christoph and Gerd, 2004) and Russia in 2010 (Barriopedro et al., 2011; Dole et al., 2011; Trenberth and Fasullo, 2012; Twardosz and Kossowska-Cezak, 2013). Heat and cold waves in Serbia have been analyzed based on the daily maximum air temperature during the summer season (June, July and August). The frequency and distribution of heat waves were also studied, as well as the relationship between the longest heat waves and atmospheric circulation (Unkašević and Tošić, 2009, 2011, 2013, 2014). The study of Esmaeelinejad (2012) is one of the most comprehensive studies on heat waves in Iran. The results showed that short had waves have more continuity and winter was the focus of maximum monthly heat waves. The outputs of the study also revealed that their occurrence was more frequent in recent years.

In a study, Darand (2014), identified and spatiotemporally analyzed heat waves in Iran. In this study, using data from the maximum and minimum temperature and on the basis of three indices of the 90^{th}, 95^{th} and 99^{th} percentiles, the occurrence of heat waves was monitored. The findings showed that the frequency of the occurrence of heat waves was rising in Iran. According to the Meteorological Organization report, Tehran, in the summer of 2013 (July and August) after the domination of heat waves and having a temperature over 40 degrees Celsius, reached the record of the hottest days in the past 60-years (Sanaee et al., 2013). On the other hand, the Iranian population is exposed to severe cold waves. Reviewing cold extremes in the Iranian cities Kerman, Khanjani and Bahrampour (2013) found that an increase in cardiovascular (0.6 % per °C) and respiratory (average of 2.5 % per °C) mortality was associated with decreasing air temperature and cold wave occurrence. In the following, given the subject of the study that is determining thresholds for heat and cold waves, a suggestion regarding the extreme thresholds of PET has been made for selected Iranian cites. Besides, due to the problem of global warming, the effect of this phenomenon on the changes of heat and cold waves for a few selected stations in Iran with a longer period has been evaluated.

1-1. Different views on the concept and methodology for monitoring of the heat and cold waves

One of the problems that researchers face in the study of heat (cold) waves is lack of comprehensive and accurate definitions for them. Considering the definitions of heat (cold) waves provided by researchers, institutions and research centers, it is understood that their fundamental discrepancy is over the definition of two terms; wave and heat (cold). The term of 'wave' is indicating durability of the phenomenon that is expressed by number. Durability is one of the main and inherent features of the heat (cold) waves that is obvious in all the definitions of heat (cold) waves. Heat (cold) is either expressed as a number (numerical threshold) or a percentile (percentile threshold) that would eventually have been presented based on numbers. In a general categorization, the existing definitions of heat (cold) waves can be placed in three groups. In the first group, researchers provide a numerical threshold for the definition of heat (cold) waves. In different countries, different thresholds have been introduced by researchers for heat wave. In this group, for example, the following studies can be cited. In China, heat wave has occurred in every day of the year when maximum temperature has reached above 35 degrees Celsius (Liu et al., 2008). Moreover, this situation should occur for at least three consecutive days (Roshan et al., 2018b; Zhang et al., 2005; Hua et al., 2006). While in the UK, the thresholds of minimum and maximum temperatures vary from one region to another and the condition for its occurrence is that it persists for more than two days. The Netherland's Meteorological Agency, for health warning system update considers the heat wave when the maximum temperature for at least five consecutive days reach over 25 degrees Celsius provided that at least three days of those five days, the temperature is critical and over 30 °C (Darand, 2014). For Athens, the numerical threshold has been PET> 35 °C to determine and monitor the heat wave if this situation is continued for at least three consecutive days (Matzarakis and Nastos, 2011); or for Novi Sad in Northern Serbia, the threshold occurrence of cold wave has been used based on numerical PET ≤0°C, and if this situation continues for at least six consecutive days, it will be known as cold wave (Basarin et al., 2015).

The second group involves the studies that have defined heat (cold) wave based on percentile thresholds. For instance, the maximum temperature during three days is more than 90th summer long-term percentile (Beniston and Diaz, 2004), 3-day lasting of maximum temperature more than 95th percentile (Gosling et al., 2007) and 3-day lasting of the average temperature more than 97th percentile (Hajat et al., 2002); or for Turkey, the threshold of 90th percentile of apparent temperature or heat index when it occurs in at least three consecutive days, have been defined as the measure of heat wave (Unal et al., 2013). Furthermore for China, the threshold of 90th percentile of daily maximum temperature is the measure for detecting heat wave (Yan et al., 2002; Zhai and Pan, 2003; Hua et al., 2006; Fang et al. 2008; Ding et al., 2009). For Novi Sad in Northern Serbia, the occurrence threshold of cold wave is defined as cold wave based on the 5% percentile of PET with duration of at least six days (Basarin et al., 2015). The third category of the definition of heat (cold) waves has been presented by the help of research teams and experts for detecting climate change and extreme indices. They are a team of climate change scientists from around the world. The purpose of this definition is to compare the incidence of heat (cold) wave as a sign of climate change in different regions of the world.

One recommendation of the Intergovernmental Panel on Climate Change (IPCC) is to use the heat wave duration index (HWDI). This index has been defined as a period of five or more consecutive days with a maximum daily air temperature (Tmax) 5°C or more above the mean maximum daily temperature _Tmax_ for the normal climatic period 1961–1990 (IPCC 2001).

Based on this view, some define heat (cold) wave as when at least for six consecutive days, the maximum (minimum) temperature is greater than the 90th percentile (less than 10th percentile) of the baseline period of 1961 to 1990 or 1971 to 2000 (Zhang et al., 2005). Although the purpose of providing such a definition was its comprehensiveness and sufficient precision to detect heat (cold) waves across the globe, it does not apply to areas outside the Middle latitudes (Frich et al., 2002).

2. Materials and methods

To analyze the thermal comfort conditions and heat and cold waves of case studies, the PET bioclimatic indices was used. Mean daily air temperature, precipitation, relative humidity, vapour pressure, wind speed and cloud cover data were obtained for four Iranian synoptic stations of Bandar Abbas, Mashhad, Tabriz, Tehran spanning the period 1960-2014 from the Meteorological Organization of Iran.

Table 1. Thresholds of thermal perception according to PET (after Matzarakis and Mayer, 1996).

Class	PET (°C)	Thermal perception
1	<4	Very cold
2	4-8	Cold
3	8-13	Cool
4	13-18	Slightly cool
5	18-23	Comfortable
6	23-29	Slightly warm
7	29-35	Warm
8	35-41	Hot
9	>41	Very hot

To account for acclimatization of human beings to either heat or cold, the Health Related Assessment of the Thermal Environment (HeRATE) was applied to consider adaptation to thermal stress. The HeRATE system (Koppe and Jendritzky, 2005) combines thermal stress calculations with an evaluation of short-term adaptation to thermal stress. The system modifies the PET thresholds given in Table 1 by accounting for the perception of thermal stress in recent years. The HeRATE procedure has the advantage that the resulting modified PET (PET_a) can be applied without further modification to different climate regions and during different times of the year (Jendritzky and Tinz, 2009; Matzarakis and Nastos, 2011; Zaninović and Matzarakis, 2014; Basarin et al., 2015). Introducing zones for thermal comfort and applying a Gaussian low pass filter according to Koppe (2005) to PET, PET_a was calculated as:

$$PET_a = TH + (PET_f - TH) \times 1/3 \qquad (1)$$

where TH is the predefined threshold, and PET_f is the Gaussian filtered PET. In order to evaluate the acclimatization for different defined PET thresholds, the HeRATE model was calculated for every threshold values of HW and CW according to Basarin et al. (2015).

Three approaches were chosen to study heat wave and cold wave occurrences and characteristics:

- First, the 95th and 5th percentiles of the distribution of PET values were used to detect extreme hot and cold days at all stations. Following Unal et al. (2013), HW was defined as period of three and more consecutive days with PET values being above the 95th PET percentile (HW_p); CW was defined as an episode of three and more consecutive days below the 5th PET percentile (CW_p). An HW occurrence was valid only if the station-specific 95th percentile of PET was above 29.0 °C (HW_p) and a cold wave was counted only if the station-specific 5th percentile of PET was below 13.0 °C (CW_p).

- Second, 95th and 5th percentiles of PET were evaluated against thresholds. An HW occurrence was valid only if the station-specific 95th percentile of PET was above 29.0 °C (HW_{tr}), i.e. in PET classes 7 to 9. A cold wave was counted only if the station-specific 5th percentile of PET was below 13.0 °C (CW_{tr}), i.e. in PET classes 1 to 3. Therefore, the lower (upper) threshold of the desired bioclimatic class was determined as the criterion for detecting the heat (cold) waves.

- Third, 95th percentiles of PET were assigned to PET classes 7 to 9. 5th percentiles of PET were assigned to PET classes 1 to 3. Hence, the lower (upper) threshold of the desired bioclimatic class was determined as the criterion for detecting the heat (cold) waves. Although the third method is quite similar to the second method, the class 1 is just divided into two classes of 4> PET≥ 0 C°

and PET <0 C° (CW_{rcl}). Besides, class 9 is divided into two new classes of 46 ≥ PET> 41 ° and one PET > 46 C° (HW_{rcl}).

Since the analysis of trend of heat and cold waves changes is a main basis for this study, Mann-Kendall non-parametric test, were used to detect and monitor the trend's changes for the frequencies of occurrence of these atmospheric hazards. Detail of Mann-Kendall non-parametric test method is available by some climatic studies (Matzarakis and Nastos, 2011, Basarin et al., 2015, Roshan et al., 2016a; Roshan et al., 2016b).

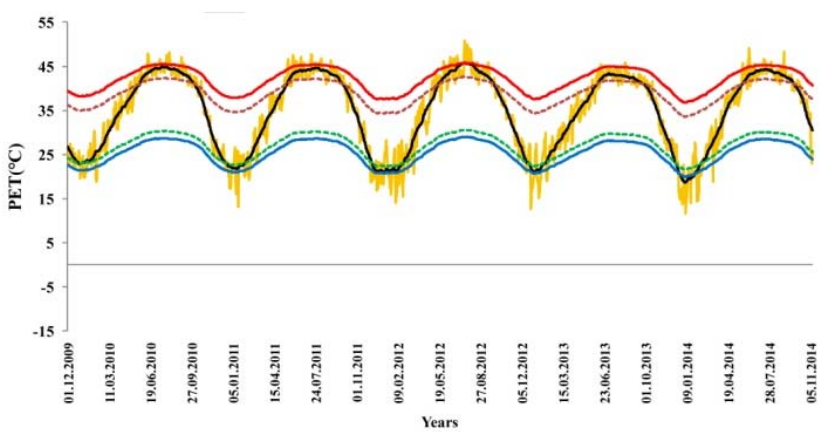
3. Results

3-1. Assessment of spatial-temporal changes of the occurrence of heat-cold wave of some sample stations

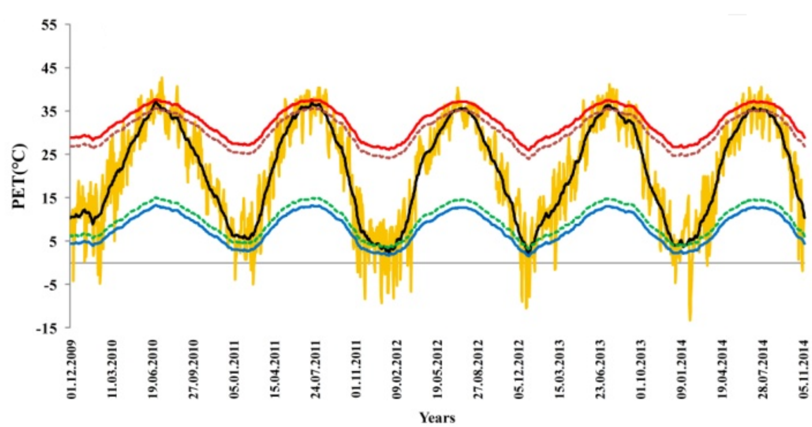
In present work, four samples of the country's stations with different climate including Bandar Abbas, Mashhad, Tabriz and Tehran were been selected and evaluated. Bandar Abbas station on Iran's southern coasts has very hot and humid summers and relatively mild winters. Mashhad has a cold and rough weather in the cold period of the year that is affected by Siberian high pressure; however, hot summers are among its characteristics. Tabriz is a station with colder and more humid winters compared to Mashhad that due to being located in the North West of Iran is the entrance gate of weather systems to Iran. On the other hand, summers are milder compared to other stations in middle and lower latitudes of Iran. Of course, Tehran considering coldness severity is milder compared to Mashhad and Tabriz stations but its summer heat is more intense compared to those two stations. First, according to Figure 1, based on three approaches, a sample of heat and cold wave occurrence are shown for the study period of 02.01.2009 to 11.05.2014. According to figure (1a), the CW_p threshold of PET index is 20.6 °C for Bandar Abbas station also based on the method of CW_{tr} and CW_{rcl} this threshold is jointly 23 °C. Therefore, based on the conditions set formerly, the threshold of PET> 13 °C cannot be the criterion of determining the occurrence of cold wave. Hence, based on the CW_p threshold, the minimum threshold of cold wave occurrence belonged to Tabriz with -2.7 °C and Mashhad and Tehran station with values of 1.4 and 5.1 °C. Nevertheless, based on the method of CW_{tr}, the criterion for occurrence of cold wave PET = 4 °C for Tabriz and Mashhad but for Tehran PET = 8 °C that after reviewing threshold of classes on base of CW_{rcl} , these values have been PET = 0 °C for Mashhad and Tabriz (Figure 1f, 1g) and it PET = 8°C for Tehran (Figure 1h). The output of Figure 1 shows that the maximum of HW_p threshold of PET index for monitoring of heat waves belonged to Bandar Abbas with PET = 46.2°C and Tehran with 42.8 °C, Mashhad with 38 °C and Tabriz with 35.9°C were in the next rankings. On the other hand, by applying method of HW_{tr} for two stations of Tehran and Bandar Abbas, these stations has been 41 °C shared and it has been 35 °C for two stations of Mashhad and Tabriz. However, by applying the method of HW_{rcl}, the only change observed has been for Bandar Abbas station with new threshold of 46 °C (6e) though no changes are observed for other stations (Fig. 1f-1h). However, the results of this section showed that in total, the behavioral pattern of three different thresholds of heat wave (cold wave) have been the same for different stations, but what makes the major difference among these stations is the difference in monitoring of frequency, duration and intensity of heat (cold) wave occurrences. In a way that in most stations, frequency and duration of heat (cold) wave occurrences are based on the method of HW_p (CW_p), are less than the method of HW_{tr} (CW_{tr}) and HW_{rcl} (CW_{rcl}). In other words, considering the second and third methods, more periods being affected by bioclimatic occurrence of heat and cold waves were identified compared to the first method. In the wake of the heat wave, temperature in the summer of 2013, according to the report of Meteorological Agency of Iran reached the record of the hottest days of the year in the past 60 years. According to reports from news agencies, the extent of the heat wave occurred was not limited to Iran, but high temperatures have been reported in China and most of European countries, which shows the dominance of heat wave in these regions. These conditions resulted in high temperatures in Tehran so that the maximum temperature in July reached 40.5 and in August to 42.5 °C that compared with last year, it increased 1.2 to 3 degrees Celsius in July and August. This value compared with the temperature of a decade ago in July and August has increased 2.5 to 6.5 °C respectively. According to the monthly report of the General Directorate of Meteorology of Tehran, this increase in temperature compared to the long-term average has been 2 degrees in July and 0.5 °C in August (Sanaee et al., 2015). As it can be seen from the outputs of Figure 1, not only in the station of Tehran but also in two stations of Tabriz and Mashhad the summer of 2013 has been associated with the occurrence of significant heat wave. However, these conditions have not been considerable for Bandar Abbas so that it can be imagined this heat wave has affected middle and high-latitude areas of Iran more than its areas with low latitudes.

3-2. Thermal Index

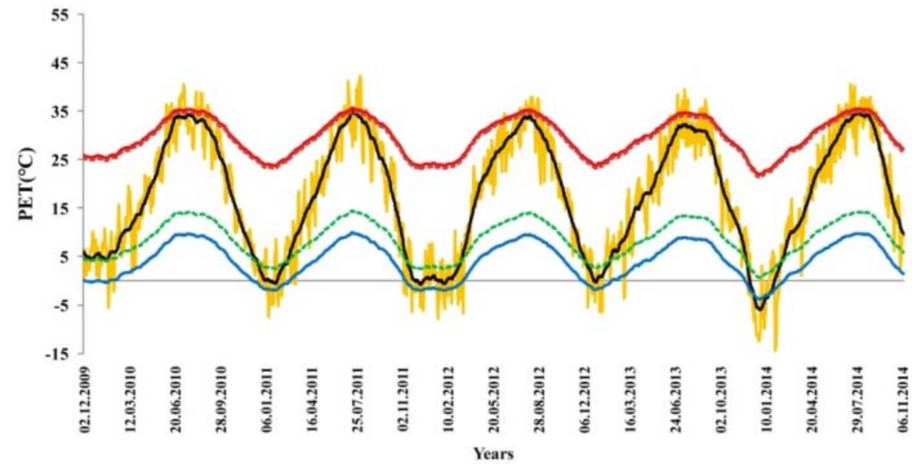
PET allows for a physiologically significant assessment of thermal conditions. Daily PET values were calculated using the RayMan model (Matzarakis et al. 2007a). RayMan's PET calculation is based on the solution of the human energy balance with the MEMI model (Höppe, 1993). The thermo-physiological parameters heat resistance of clothing (in clo units) and activity of humans (in W) required to run RayMan, were set to the values 80 W and 0.9 clo, which are values related to a standardized male person of 1.75 m of height, 75 kg of weight and 35 years of age. Using these values, the standard person is characterized by a working metabolism of light activity in addition to basic metabolism and heat resistance due to the clothing. The PET values were then assigned to grades of thermal perception by human beings and physiological stress on human beings (Table 1) according to Matzarakis and Mayer (1996). PET was used to analyze HW and CW at the meteorological stations.



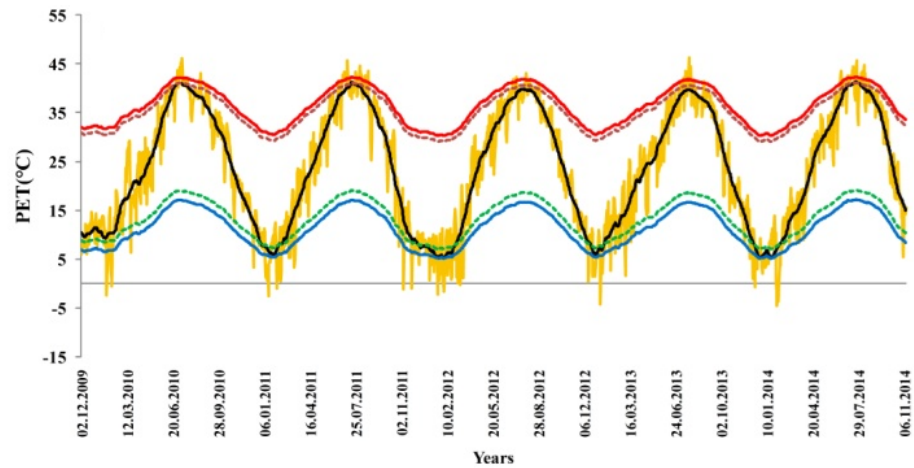
(a)



(b)


PET(°C)
55
45
35
25
15
5
-5
-15
02.12.2009
12.03.2010
20.06.2010
28.09.2010
06.01.2011
16.04.2011
25.07.2011
02.11.2011
10.02.2012
20.05.2012
28.08.2012
06.12.2012
16.03.2013
24.06.2013
02.10.2013
10.01.2014
20.04.2014
29.07.2014
06.11.2014
Years

(c)


PET(°C)
55
45
35
25
15
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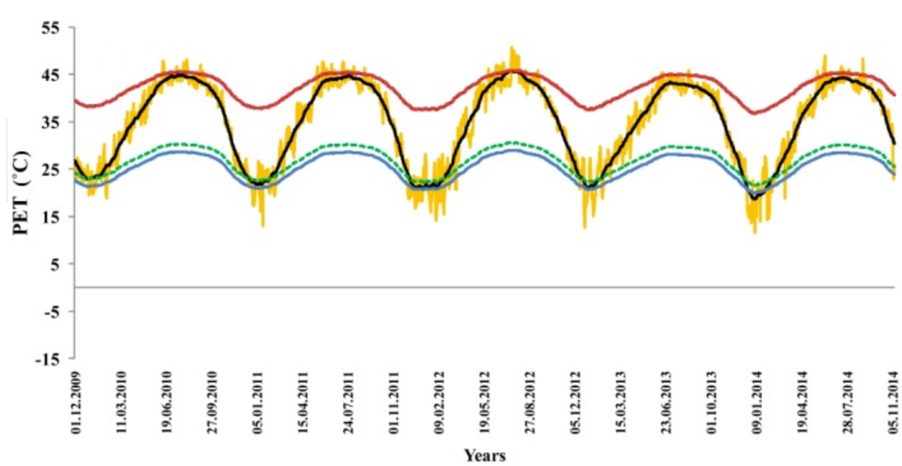
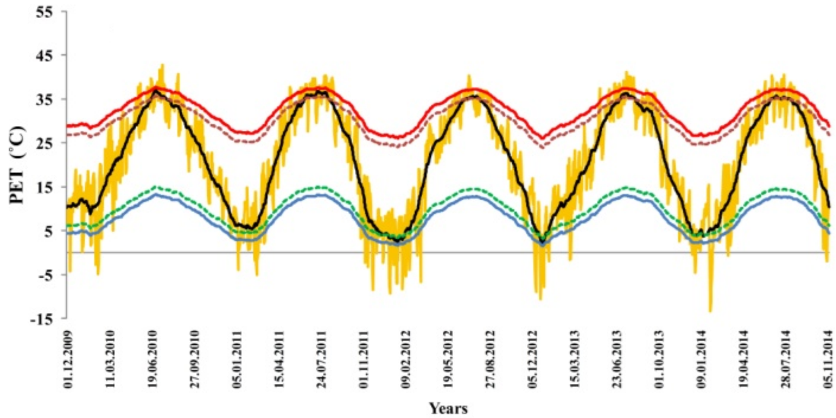
-5
-15
02.12.2009
12.03.2010
20.06.2010
28.09.2010
06.01.2011
16.04.2011
25.07.2011
02.11.2011
10.02.2012
20.05.2012
28.08.2012
06.12.2012
16.03.2013
24.06.2013
02.10.2013
10.01.2014
20.04.2014
29.07.2014
06.11.2014
Years

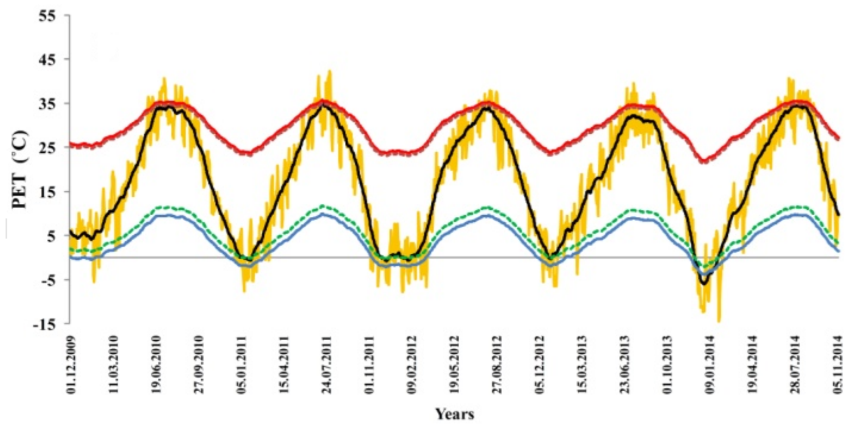
(d)


PET (°C)
55
45
35
25
15
5
-5
-15
01.12.2009
11.03.2010
19.06.2010
27.09.2010
05.01.2011
15.04.2011
24.07.2011
01.11.2011
09.02.2012
19.05.2012
27.08.2012
05.12.2012
15.03.2013
23.06.2013
01.10.2013
09.01.2014
19.04.2014
28.07.2014
05.11.2014
Years

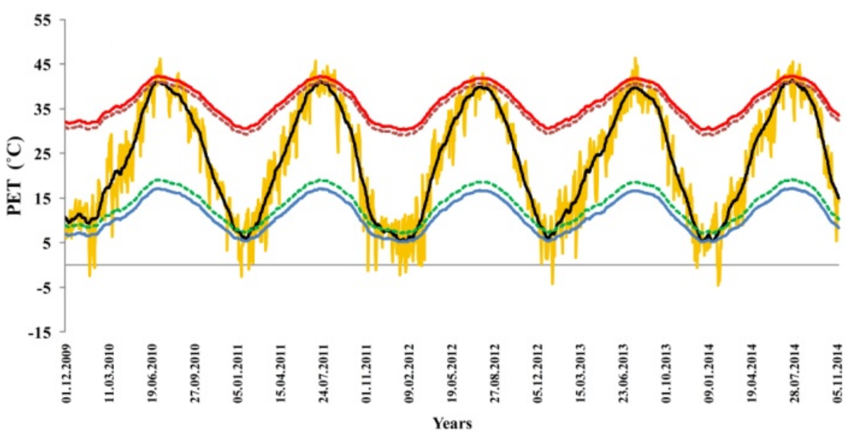
(e)



(f)

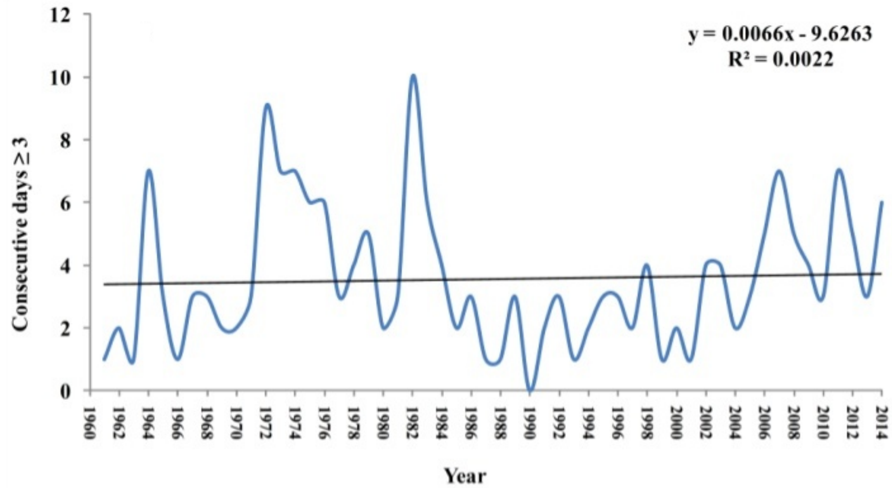


(g)

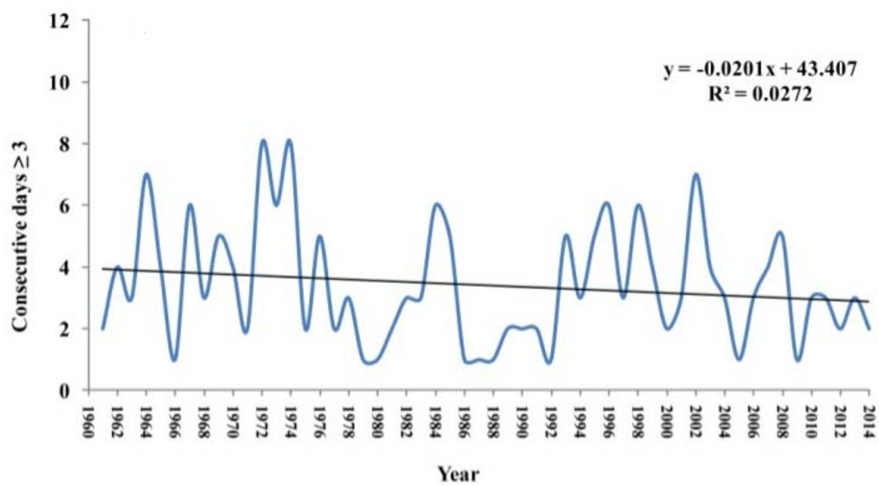


(h)

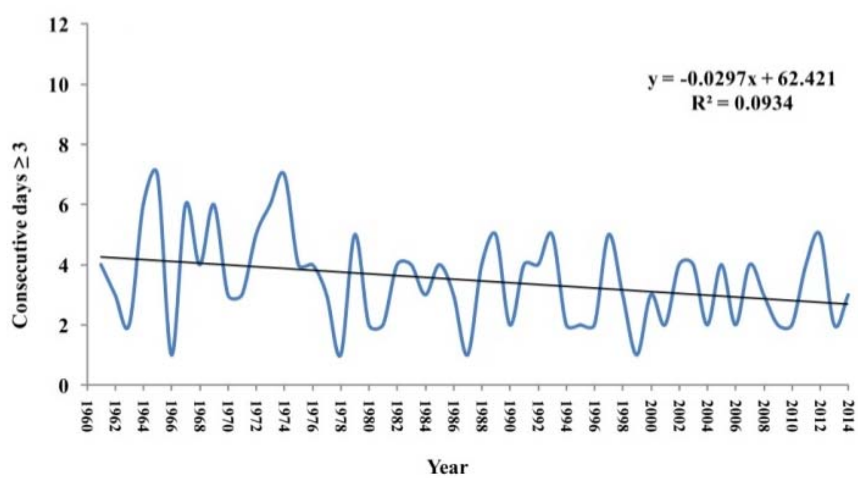
Figure 1. Interannual variability of thermal adaptation based on PET for 2009 to 2014 (yellow line = PET; black line = Gaussian filtered PET; stipple pink line = heat wave based on the HW_{tr}; red line = heat wave based on the HW_p; stipple green line=cold wave based on the CW_{tr}; blue line = cold wave based on the CW_p). a: Bandar Abbas; b: Mashhad; c: Tabriz; d: Tehran. Interannual variability of thermal adaptation based on PET for 2009 to 2014 (yellow line = PET; black line = Gaussian filtered PET; stipple pink line = heat wave based on the HW_{rcl}; red line = heat wave based on the HW_p; stipple green line = cold wave based on the CW_{rcl}; blue line = cold wave based on the CW_p). e: Bandar Abbas; f: Mashhad; g: Tabriz; h: Tehran.


y = 0.0066x - 9.6263
R² = 0.0022
Consecutive days ≥ 3
Year

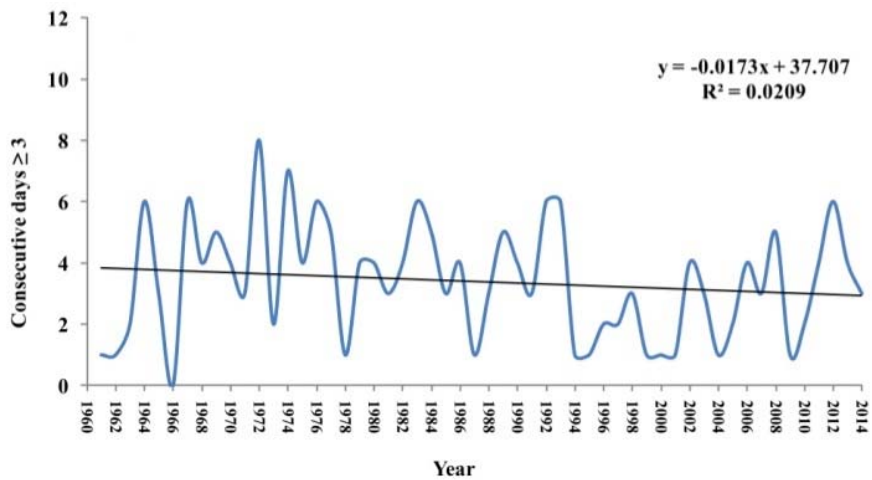
(a)


y = -0.0201x + 43.407
R² = 0.0272
Consecutive days ≥ 3
Year

(b)

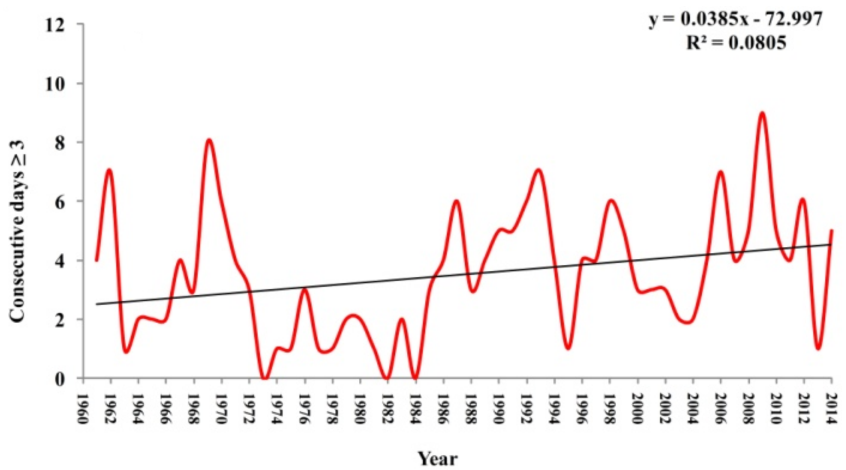

y = -0.0297x + 62.421
R² = 0.0934
Consecutive days ≥ 3
Year

(c)



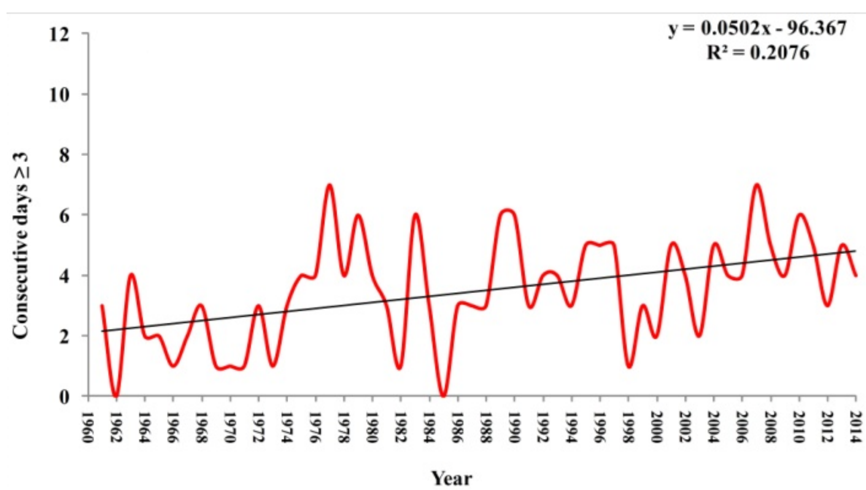
y = -0.0173x + 37.707
R² = 0.0209
Consecutive days ≥ 3
12
10
8
6
4
2
0
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
Year

(d)



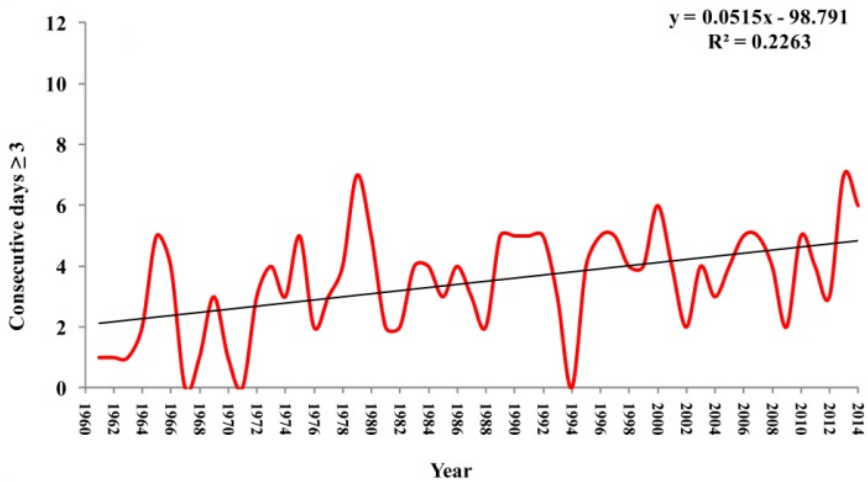
y = 0.0385x - 72.997
R² = 0.0805
Consecutive days ≥ 3
12
10
8
6
4
2
0
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
Year

(e)

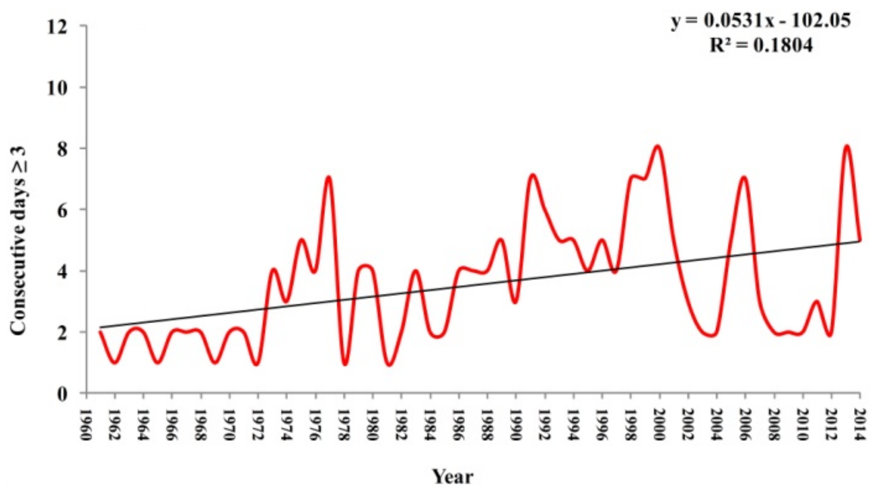


y = 0.0502x - 96.367
R² = 0.2076
Consecutive days ≥ 3
12
10
8
6
4
2
0
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
Year

(f)



(g)



(h)

Figure 2. The frequency of occurrence of cold waves based on the CW_p threshold for the study period from 1960 to 2014. a) Bandar Abbas, b) Mashhad, c) Tabriz, d) Tehran. The trend of frequency of occurrence of heat waves based on the HW_p threshold for the study period of 1960 to 2014. e) Bandar Abbas, f) Mashhad, g) Tabriz, h) Tehran.

One of the most important parts of this paper is to analyze the effects of global warming on changes of the frequency of heat and cold waves. However, due to the limited space of this article, only the changes of heat and cold waves regarding the threshold occurrence of HW_p (CW_p) using nonparametric Mann-Kendall method has been analyzed. As it can be seen in Figures 2a to 2d, although in three stations of Mashhad, Tabriz and Tehran the trends of frequency of cold waves are decreasing, this trend is increasing for Bandar Abbas, based on the outputs of the Mann-Kendall method. According to the significant threshold of $-0.19 \geq t0 \geq +0.19$ it is observed that Mashhad with t = 0.10, Tabriz with t = 0.02, Tehran with t = -0.02, and Bandar Abbas with t=0.18 do not have significant trends. The noteworthy point is that the trend for changes of cold waves for Bandar Abbas has experienced three palpable changes over time. Thus from 1960 to 1972 it has had an increasing trend but its trend has been decreasing after that until 1980. Then again the trend has slowly been rising for the past two decades (Figure 2 a). In the following, as it can be seen from Fig. 2e to 2h, changes in the frequency of heat waves have had an increasing trend for these four stations. Mann-Kendall statistics for

Mashhad with t = 0.47, Tabriz and Tehran with values of t=0.44 and t = 0.45 respectively, and, ultimately, for Bandar Abbas with t = 0.29 shows a significant trend with a confidence level of 95 percent. Besides, the outputs show that the behavior and frequency pattern of heat and cold waves are reversed during the statistical period. Hence, times that coincide with the minimum of cold (heat) waves are at the same time with the maximum of heat (cold) wave occurrence.

4. Discussion

The use of single parameters or factors is not the only way by which the implications of heat waves on humans can be assessed (Matzarakis and Nastos, 2011).This paper, for the first time, uses the thermal indices under the name of PET and includes an analysis of consecutive days, as well as statistical filters to measure thermal adaptation of humans to extreme temperature events. This study represents a valuable first step for the quantification of cold waves and cold stress as well as heat waves and heat stress Iran. Despite this issue, most of the works done for Iran (Masoodian and Darand, 2012, Esmaeelinejad, 2012, Karimi et al., 2012, Darand, 2014, Sanaee et al., 2013), have identified and studied solely on the basis of the components of minimum and maximum temperature for heat and cold waves. In addition, nonmeteorological elements such as acclimatization, clothing, activity level and fitness, and physiologic adaptation to a particular environment also influence the whole heat balance of the human body (Robinson, 2001). Thus, the analysis of cold and heat waves can be carried out focusing either on human-biometeorological or on air masses and synoptic type approaches methods. An analysis, however, should include mean extremes, frequencies and conditions for the quantification of the duration and the intensity. Besides, the analysis of consecutive days ≥3 that are used provides valuable details of cold and heat waves and interpretations regarding relevant events. Besides, the thermal adaptation of humans can be included in both approaches using appropriate statistical methods, i.e., moving average, Gaussian filters and human-biometeorological threshold values (Basarin et al., 2015). Iran, with regard to its geographical and climatic diversity, needs a definition for different thresholds of bioclimatic events including heat and cold waves for its different regions. In the study of Roshan et al. (2017), they identified different thresholds for reviewing the thermal comfort class of different cities of Iran using the component of temperature and Olgyay's Bioclimatic Chart. Besides, the outcome of their study has appropriate consistency with our results. Because their findings for cities of Southern coast of Iran suggest higher temperature threshold for the occurrence of thermal comfort compared to the stations located in the North West of the country. In the present study, our results suggest a variety of heat and cold wave thresholds for different climate zones of Iran. Thus, the maximum threshold of heat wave occurrence has been for Bandar Abbas in the regions of shores of the Persian Gulf and its minimum has been for Tabriz and Mashhad in regions of North West and North East of the country. However, findings of several research for Iran, confirm the link between cold and heat stress in people's health and mortality. In Farajzadeh and Darand’s (2008) study in Tehran, in the cold months of the year, the number of deaths due to respiratory diseases was maximum and as the average, minimum, and maximum temperature decreased, the more the number of respiratory deaths increased. In general, the number of deaths in the warm months was less than the cold months (Farajzadeh and Darand, 2008). Some studies in Iran have also mentioned that influenza causes increased mortality in the cold months and have reported some of these influenza epidemics (Haghshenas et al., 2015; Salimi et al., 2016).

Therefore, the results of this study show that PET's maximum extreme values in Iran have more potential than PET’s minimum extreme values, on the other hand, the frequency of occurrence of heat waves has been higher than the occurrence of cold waves. Therefore, it seems that Iranians have more compatibility with higher temperatures than lower temperatures, and this factor causes more deaths in lower temperatures or deaths are more in the occurrence of cold waves than the occurrence of heat waves. Of course, confirming this issue for different areas of Iran needs further studies. However, as the results of the present study show, the trend of the occurrence of heat wave for sample stations of Iran is increasing and the occurrence of cold wave is decreasing. Similar results can be seen in several studies that have been conducted around the world and Iran. Analyses of trends in extreme climate conditions found decreases in the diurnal temperature range, frost days, ice days, could days and could nights for the majority of stations across Iran (Rahimzadeh et al., 2009). For the arid to semi-arid regions of Iran, winter temperatures have been found to be increased (Tabari and Hosseinzadeh Talaee, 2011). The capital city of Tehran has additional heat stresses from the urban heat island, which has worsened over recent decades due to the urban sprawl (Roshan et al., 2009, 2010).

This result is appropriately consistent with the findings of this research. As the results showed, the trend of cold wave occurrence is also declining for cold stations of the country. Roshan et al. (2016b) in one study on PET changes for the period of 1960 to 2010 has used the Mann-Kendall non-parametric test and Pearson parametric method. The findings of long-term trend analysis have shown that 55% of the stations have significant increasing trends in terms of thermal comfort class based on the Pearson method, while it is 40% based on Mann-Kendall test. Spinoni et al. (2015) for one work on heat and cold waves trends in the Carpathian Region from 1961 to 2010 showed that the heat wave events have become more frequent, longer, more severe and intense in the entire Carpathian Region, in particular, in summer in the Hungarian Plain and in Southern Romania. Besides, a linear trend analysis showed that the cold waves frequency, average duration, severity and intensity have generally decreased in all seasons except autumn. Similar results, dealing with tendency towards a higher number of warm days and nights and a lower number of cold days and nights in the Carpathian Basin, have been discussed by Bartholy and Pongracz (2007) and by Bartholy et al. (2008). A study in the USA estimated that due to the climate change, winter mortality will decrease slightly but this lowered mortality will not offset the greater increase in summer mortality (Kalkstein and Greene, 1997). Based on the climate models, the analysis of climate change indicates that heat stress conditions will occur much more frequently in the future (IPCC, 2007; Matzarakis et al., 2007a).

Alexander and Arblaster (2009) used multiple simulations from nine globally coupled climate models to assess change of trends for indices representing temperature and precipitation extremes over Australia. Their results showed a shift towards warming of temperature extremes, particularly a significant increase in the number of warm nights and heat waves with much longer dry spells interspersed with periods of increased extreme precipitation, irrespective of the scenario used. Therefore, outcomes of the studies based on observational data and modeling of future climate change of Iran confirm temperature increase and heat stress events and reduction of cold stress and frost days. Simulation projects of future climate change for North West areas of Iran indicate the temperature increase of 1.35 °C until the late 2100's (Roshan and Orosa, 2015). Besides, Roshan and Grab (2012) showed that most zones of Iran, considering the global warming, will experience higher temperature thresholds for the coming decades. Thus, according to various studies for Iran and the world it is inferred that in the coming decades, the risk of heat stress events and more heat waves is more than the risk of cold wave occurrence. However, this should not make officials neglect the risk of management of cold waves.

5. Conclusion

Outputs and findings of the present study confirm the fact that the risk of occurrence of heat waves in Iran has more potential than the risk of cold wave occurrence. One of the main findings of this paper is the evaluation of thresholds of heat and cold wave occurrences based on the second method compared with the third method. In general, the results showed that based on the method of HW_{tr} (CW_{tr}), no significant differences that sometimes exist among some stations for determining thresholds of cold and heat waves and their monitoring can be applied. For example, it has been observed that although the threshold of HW_p for Bandar Abbas is 46.2°C and it is 42.8°C for Tehran; however, based on the method of HW_{tr}, for both of these stations, the threshold of heat wave occurrence has been selected to be 41°C. This method that is resulted from PET's conventional classes could not reveal the difference of these two stations regarding the threshold of heat wave occurrence. However, by applying the HW_{rcl}, it was found that the threshold of heat wave occurrence for Bandar Abbas has been PET = 46°C and it was 41 °C for Tehran. Therefore, the term "PET's extreme classes" has better shown the difference of various stations in the occurrence of thresholds of cold and heat wave. Finally, the results of this study indicate more potential of increasing trend of heat waves and decreasing of the frequency of cold wave occurrence for the sample stations of Iran. The results of this study are also consistent with the findings of other studies in different regions of the world.

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