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Analysis of the extreme heat events in Iran

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Abstract

Purpose – The purpose of this paper is to assess the spatial and temporal variations of extreme hot days (H*) and heat wave frequencies across Iran.

Design/methodology/approach – The authors used daily maximum temperature (T_{max}) data of 27 synoptic stations in Iran. These data were standardized using the mean and the standard deviation of each day of the year. An extreme hot day was defined when the Z score of daily maximum temperature of that day was equal or more than a given threshold fixed at 1.7, while a heat wave event was considered to occur when the Z score exceeds the threshold for at least three continuous days. According to these criteria, the annual frequency of extreme hot days and the number of heat waves were determined for all stations.

Findings – The trend analysis of H* shows a positive trend during the past two decades in Iran, with the maximum number of H* (110 cases) observed in 2010. A significant trend of the number of heat waves per year was also detected during 1991-2013 in all the stations. Overall, results indicate that Iran has experienced heat waves in recent years more often than its long-term average. There will be more frequent and intense hot days and heat waves across Iran until 2050, due to estimated increase of mean air temperature between 0.5-1.1 and 0.8-1.6 degree centigrade for Rcp2.6 and Rcp8.8 scenarios, respectively.

Originality/value – The trend analysis of hot days and heat wave frequencies is a particularly original aspect of this paper. It is very important for policy- and decision-makers especially in agriculture and health sectors of Iran to make some adaptation strategies for future frequent and intense hot days over Iran.

Keywords Iran, Climate, Heat wave, Hot days

Paper type Research paper

1. Introduction

The global temperatures during 1880 to 2012 show a warming trend of 0.85 ± 0.18° and in the Northern Hemisphere, 1983-2012 was likely the warmest 30-year period of the past 1400 years (IPCC, 2013).

One of the negative consequences of climate change is increasing the frequency, intensity, spatial extent, duration and timing of extreme weather and climate events, and can result in unprecedented extreme weather and climate events. Globally the length and

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frequency of warm spells has increased in large parts of Europe, Asia and Australia since the middle of the twentieth century (IPCC, 2012).

Because of global warming and increase of air temperature in future, confidence has increased that some extremes will become more frequent and intense as well as more widespread during the twenty-first century (IPCC, 2007, 2013).

Extreme heat events are among the most serious challenges for a society coping with a changing climate (CCSP, 2008) and can be very harmful for human health, ecosystems, agriculture and economic sectors such as energy and tourism (World Health Organization, 2004).

The health impacts of heat waves are an emerging environmental health concern (Wolf and McGregor, 2013). Recent heat wave events, in particular the 2003 European event (Beniston, 2004), the 2007 South Asian heat wave, the 2010 Russian event (Grumm, 2011) and the August 2015 heat wave in Europe and the Middle East (Climate.gov of NOAA, 2015), have highlighted the impacts of the phenomenon across the world.

In the Euro-Mediterranean region, extreme climatic events are characterized by significant changes in the trends of percentiles in the course of the twentieth century, and an increase in the temperature in the course of the twenty-first century is likely to produce an increase in the frequency of severe heat wave episodes (Baldi *et al.*, 2006).

Among others, Fujibe *et al.* (2007) and Baldi *et al.* (2006) support the hypothesis that heat wave episodes are a direct result of the warming of the lower troposphere, and according to this hypothesis, they analyzed the maximum air temperature in Japan and in the Mediterranean region, respectively, and found strong correlation between heat extremes and large-scale atmospheric patterns.

Hassan *et al.* (2004) investigated temperature data and synoptic maps over Kuwait and their results show that extremely high temperatures in the warm season are due to the changes in the regional circulation pattern.

Extremely high temperatures contribute to elevated values of the physiologically equivalent temperature (PET) across the world (Höppe, 1999; Matzarakis *et al.*, 1999). When PET exceeds given thresholds, it can produce a thermal stress impact and cause widespread mortality, especially among children and the elderly population, as evidenced by the 2003 heat wave in Europe that resulted in more than 15,000 fatalities in France alone (Justin, 2007). The extended heat wave in July and August 2003 resulted in above-average temperatures throughout Europe, Scandinavia and western Russia, and monthly mean temperatures during this event well exceeded the 90th percentile in several regions. Barriopedro *et al.* (2011) named 2003 and 2010 heat wave events over Europe and large parts of Russia events as "Mega-heatwaves" and found that these Mega-heatwaves likely broke the 500-year-long seasonal temperature records over approximately 50 per cent of Europe. The summer of 2003 was also unusually hot across much of Asia, and Shanghai recorded the hottest summer in over 50 years (Tan *et al.*, 2007). The intense and prolonged heat wave that occurred in 1998 in Shanghai resulted in numerous deaths: for several days, the daily number of fatalities in the city exceeded three times the daily summer average (Tan *et al.*, 2004). Frich *et al.* (2002) analyzed a new global climatic data set and found a significant change in climatic extremes during the second half of the twentieth century. However, the increase in hot days and hot spells is not homogeneous worldwide: Salinger and Griffiths (2001) analyzed extreme temperatures in New Zealand and found a trend toward lower temperature extremes over most of New Zealand.

In more recent years, it was noticed that a lower number of fatalities was associated to the occurrence of heat wave episodes most probably owing to some socioeconomic factors, like using the air-conditioning, and health risk warning systems. The other environmental factors such as air pollution combined with extreme weather conditions can have a negative impact on human comfort (Smoyer *et al.*, 2001; Sheridan and Dolney, 2003; Leiker, 2002).

Arid and semiarid climate conditions, with low annual precipitation and high potential evapotranspiration, are the dominant climate conditions of many places of Iran. According to the Köppen–Geiger classification (Markus, 2006), the most prevalent climates are arid and semi-arid with hot-summer Mediterranean climate (Csa), cold semi-arid climates (BSk) and cold desert climates (BWk). The annual precipitation varies from about 1,800 mm in the north parts of Iran and to less than 50 mm over central deserts of Iran (Amiri and Eslamian, 2010). Mildrexler *et al.* (2011) produced global maps of annual land surface maximum temperature based on high-resolution satellite data during 2003-2009 and found that the Lut Desert located in central parts of Iran had the highest surface temperature on Earth in 2004 (68.0°C), 2005 (70.7°C), 2006 (68.5°C), 2007 (69.0°C) and 2009 (68.6°C).

Although the analysis of annual and monthly rainfall time series in Iran revealed that there are no statistically significant trends in all seasons (Soltani *et al.*, 2011; Parak *et al.*, 2015), negative trends for surface and ground water reserves have been observed in several parts of Iran which suffer from frequent drought and hot weather phenomena (Saboohi *et al.*, 2012; Kousari *et al.*, 2013; Ghasemi, 2015; Parak *et al.*, 2015).

To get a better understanding of the effects of prolonged heat waves on human health, it is necessary to have a more detailed knowledge of the climatology of the phenomenon and of the mechanisms leading to those episodes (Zhang *et al.*, 2005), and the main objective of the present study is to analyze time series of extreme heat waves events and hot spells over Iran. Taking into account the fact that the time series of air temperature at the surface in Iran show a positive trend during the summer (Tabari and Talaee, 2011), we examine the time series of summer maximum temperatures for the period 1961-2013 in 27 meteorological stations over Iran to investigate if heat wave events show any significant long-term variation.

2. Data and methodology

2.1 Data and study area

Iran is located in the southwest of Asia, approximately between 25 and 40°N in latitude and between 40 and 64°E in longitude. Twenty-seven synoptic meteorological stations were selected over different climate regions of Iran (Figure 1). Daily maximum temperature data (T_{max}) of the selected stations were extracted from Iran Meteorological Organization data sets from 1961 to 2013.

2.2 Methods

An extreme event is as an event that is rare within its statistical reference distribution at a particular place (IPCC, 2013). An extreme weather event would normally be as rarer than 90th percentile based on departure from climatic mean. There are various indices of extreme temperature: percentile indices, absolute indices, threshold indices, duration indices and other indices which do not fall into any of the above categories but changes in them could have significant societal impacts (Alexander *et al.*, 2006).

Heat wave was defined as a unrelenting heat persisting for at least three consecutive days with temperature above the 90th percentile threshold (Karl and Knight, 1997), and for heat waves as a climatic extreme event, several factors such as duration and intensity need to be combined to produce an extreme event (Seneviratne *et al.*, 2012). In our study, a heat wave event is considered to occur when the standardized daily maximum temperatures (daily Z scores) keep exceeding the threshold value of 1.7 for at least four continuous days.

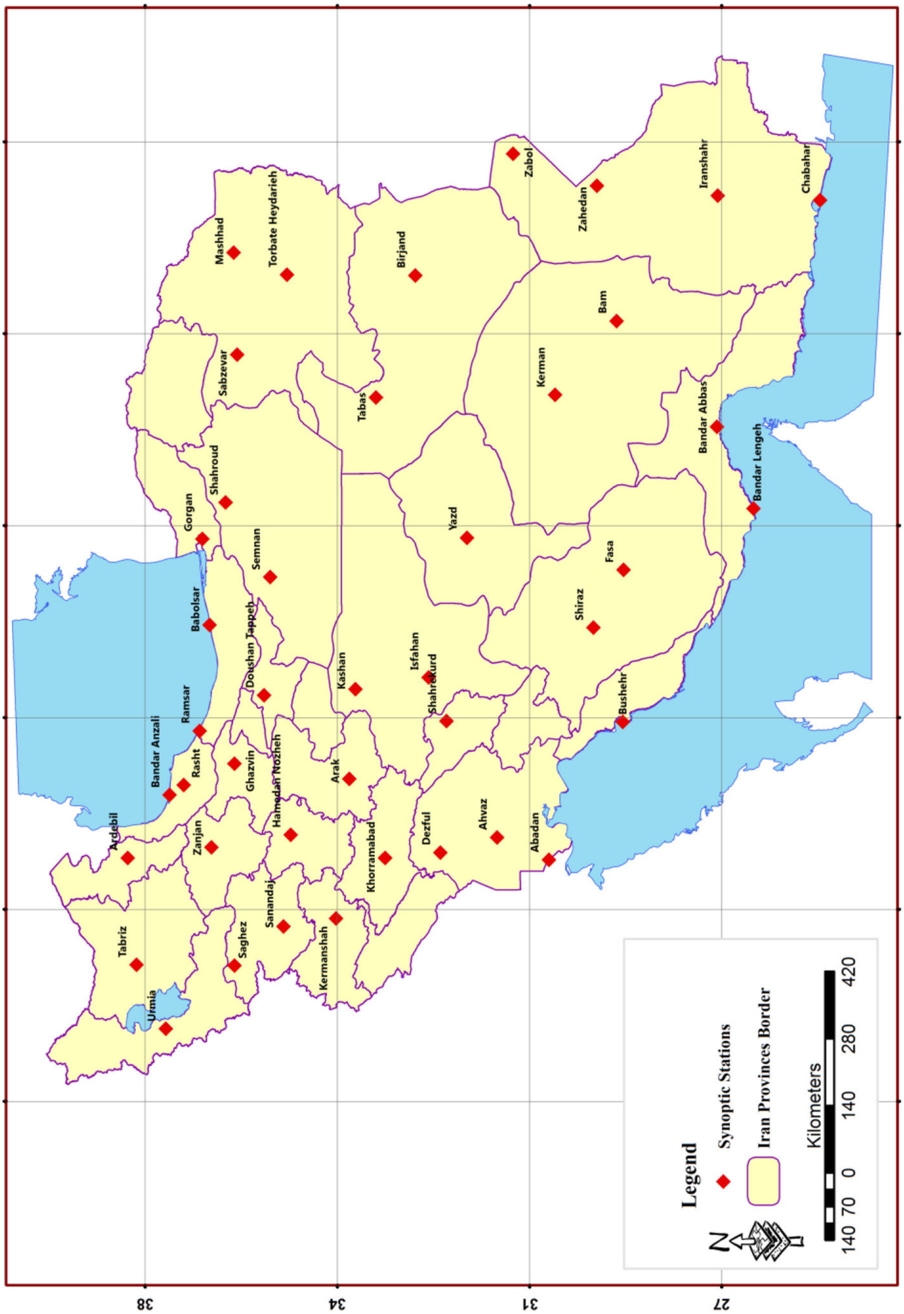


Figure 1.
Map of selected
synoptic stations

We defined extremely hot day as a day in which its standardized daily maximum temperature value exceeds 1.7 ($Z > 1.7$), where Z represents the Z score and is calculated as follows:

$$Z = \frac{(T_{max} - T_{mean})}{\sigma}$$

where T_{mean} and σ are the mean and standard deviation of daily maximum temperature and T_{max} is daily maximum temperature. Days showing a value of $Z \geq 1.7$ are then defined as hot days (H*).

For the analyses of heat waves, we followed the approach used by Fujibe *et al.* (2007), and to calculate the Z score, first we calculated the average of T_{max} for each calendar day (i) and for each station (j) ($\overline{T(i,j)}$):

$$\overline{T(i,j)} = \frac{\sum_{n=1}^{n=N} T(i,j,n)}{N} \tag{1}$$

where $T(i, j, n)$ is the value of daily maximum temperature at station i, on day j, in year n and N is the number of years.

Then, a nine-day running average was applied three times to filter out day-to-day irregularities. The departure from the climatic mean is given by:

$$\Delta T(i,j,n) = T(i,j,n) - \overline{T(i,j)} \tag{2}$$

The extremity of ΔT depends on the day-to-day temperature variability, which differs according to seasons and regions. As an index of day-to-day variability, the variance of ΔT in the 31 days centered on each calendar day was calculated as:

$$\overline{\sigma^2(i,j)} = \frac{1}{31N} \sum_{n=1961}^{2013} \sum_{j'=j-16}^{j'=j+16} \left[\Delta T(i,j',n) - \overline{\Delta T(i,j)}\right]^2 \tag{3}$$

where:

$$\overline{\Delta T(i,j)} = \frac{1}{31N} \sum_{n=1961}^{2013} \sum_{j'=j-16}^{j+16} [\Delta T(i,j',n)] \tag{4}$$

According to equations (1)-(4) and using daily T_{max} of each station, we calculated the daily value of Z and H* for each year and station. Then, we define a heat wave event when H* existed for at least four consecutive days. Frequency and duration characteristics of heat wave events were evaluated during 1961-2013. Heat wave frequency is the number of heat wave events that occur in each year for each station. Heat wave duration is the total number of consecutive days with $Z \geq 1.7$ and is averaged annually for each station (Habeeb *et al.*, 2015).

3. Results

3.1 Long-term changes of T_{max}

Figure 2 shows the monthly variation of T_{max} for each station. Between all the stations, Ahwaz, with a monthly maximum temperature above 45°C, is the warmest station. Considering all the 27 stations, the mean maximum temperature in July (warmest month of year) varies between 28 and 45°C.

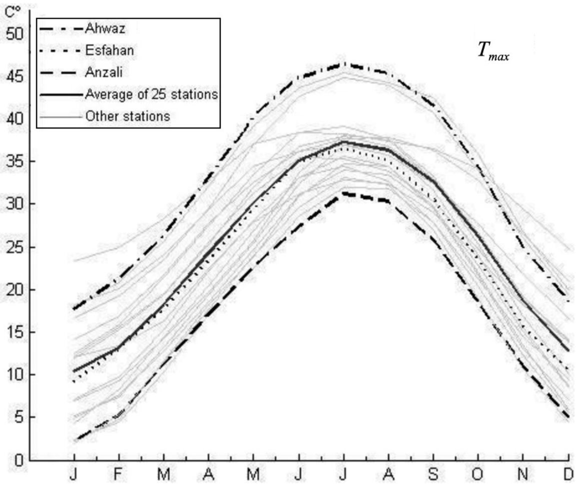


Figure 2. Annual variations of T_{max} for each station and the average of the 27 stations

A univariate, Mann–Kendall (MK) test was then applied to the time series of annual minimum and maximum temperature to detect monotonic trends. The results show a positive trend in annual minimum and maximum temperature over Iran, except for one station (Shahrekord) in the center of Iran (Figures 3 and 4). The negative trend is because of displacement of this station in 2001 from a warmer position to a colder one (near Shahrekord airport).

The annual maximum air temperatures were averaged across main synoptic stations (27 stations) in Iran (IMSS), so-called national maximum temperatures, and a trend analysis was also performed on this data set for the two study periods: 1961-2013 and 1991-2013.

The time series of T_{max} shows a positive trend (0.015°C/decade) during 1961-2013 [Figure 5(a)], but for the past three decades (1991-2013), the trend is higher (0.1°C/decade) [Figure 5(b)].

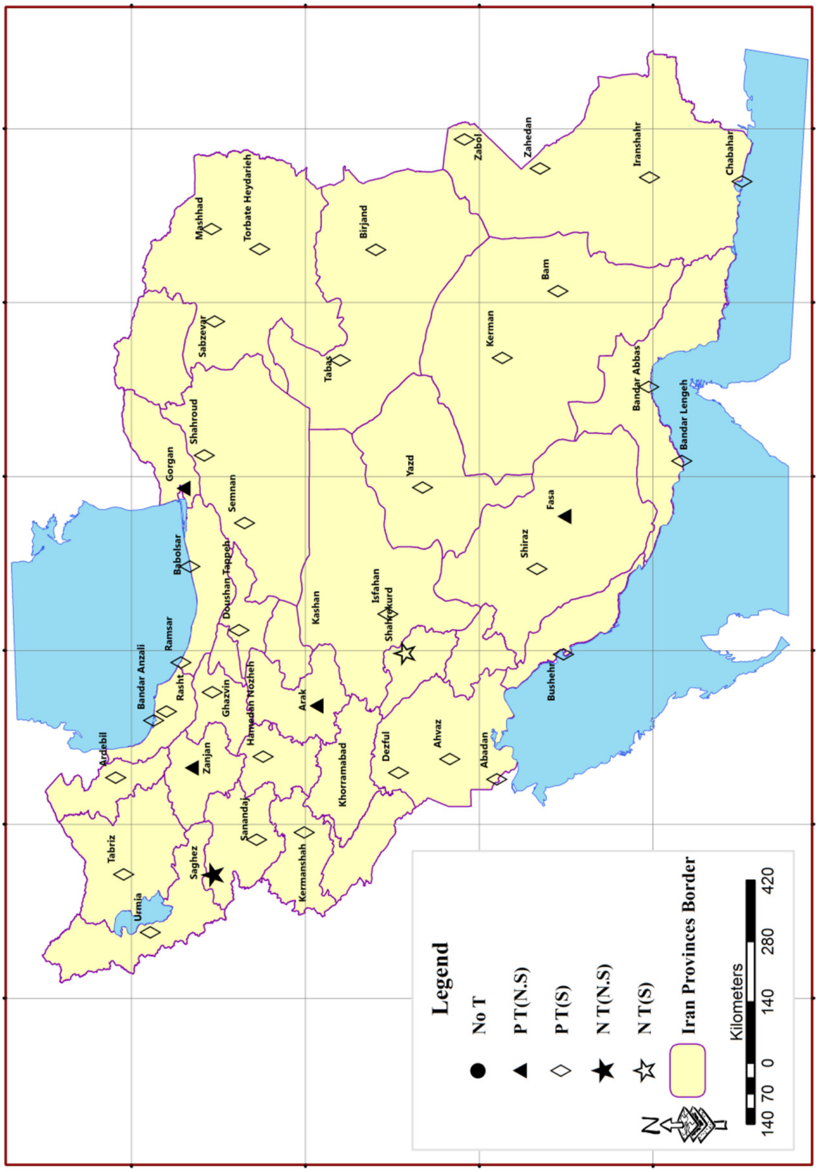
We analyzed the trends in heat wave frequencies for all the IMSS and at the national level. To obtain information at the national level, the heat wave characteristics were averaged across all IMSS.

The time series of the average number of heat waves in the 27 synoptic stations during the recent decades (1991-2013) shows a significant increase in heat wave occurrence (Figure 6).

The evaluation of trend coefficients of frequency of heat waves using the non-parametric MK test during 1961-1990 generally exhibits no statistically significant trends with respect to time, whereas assessment of the time series of frequency of heat waves during recent decades (1990-2013) indicates a significant positive trend ($p < 0.05$) at 55 per cent of studied stations (Table I). Overall, analyses of special distribution of heat wave time series show a positive trend in all parts of Iran, except some coastal stations located at the Caspian Sea. Using ANOVA test, we found significant differences between 1961-1990 period and recent decades (1991-2013) for heat wave frequencies in IMSS (Figure 8).

The analysis of the frequency of heat wave occurrence shows that the highest frequency of heat wave events was observed at southern parts of Iran, specially stations which were located across the coastal area of the Persian Gulf.

In average, the annual number of heat waves was found to increase by 0.2 heat waves per decade. Figure 7 shows the trend analysis of heat wave frequency during the two study periods over Iran (Figure 8).



Notes: T: Trend; P: Positive; N: Negative; S: significant ($p > 0.05$); N.S: Not significant

Figure 3.
Trend analysis of annual minimum temperature over Iran

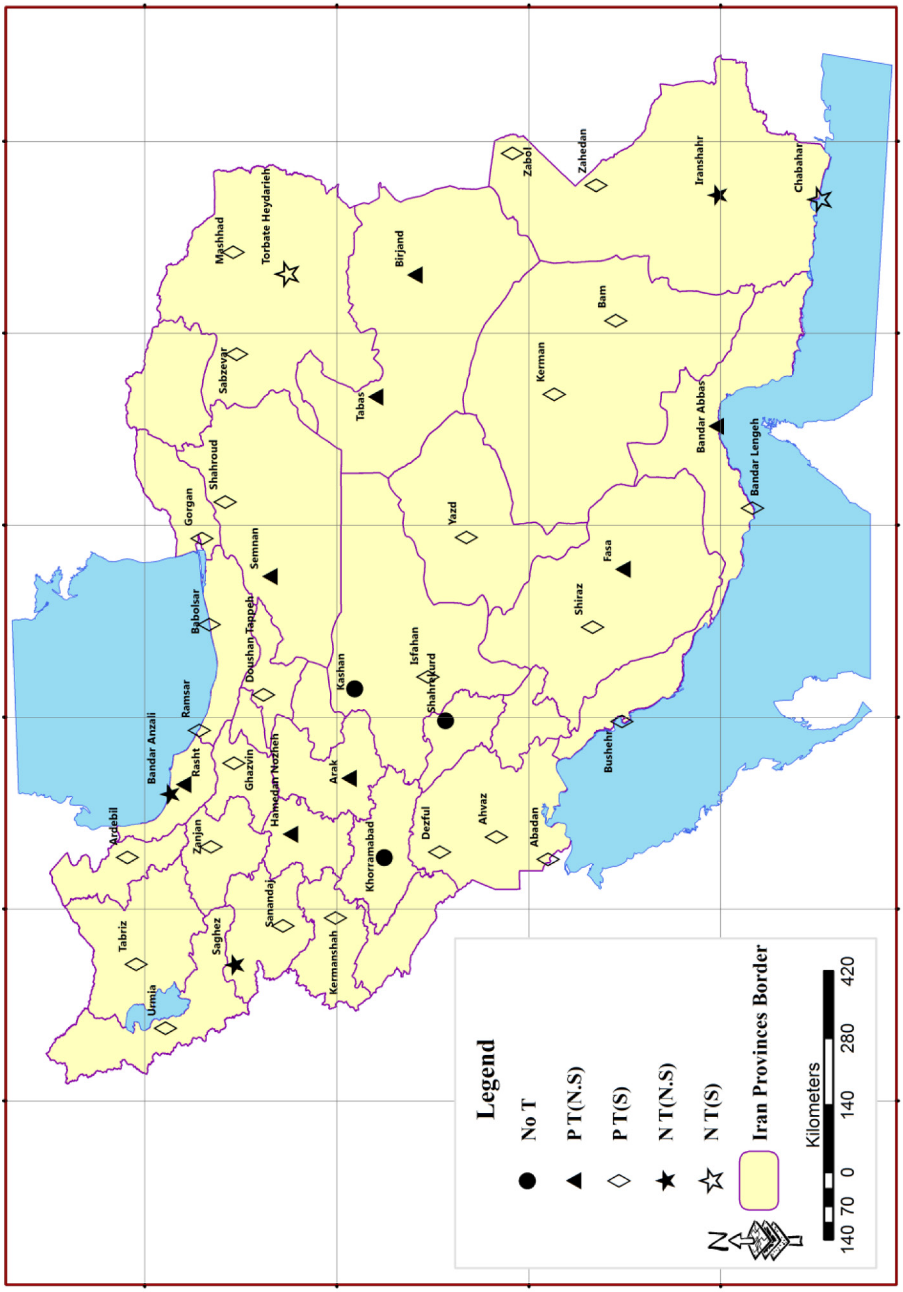


Figure 4.
Trend analysis of annual maximum temperature over Iran

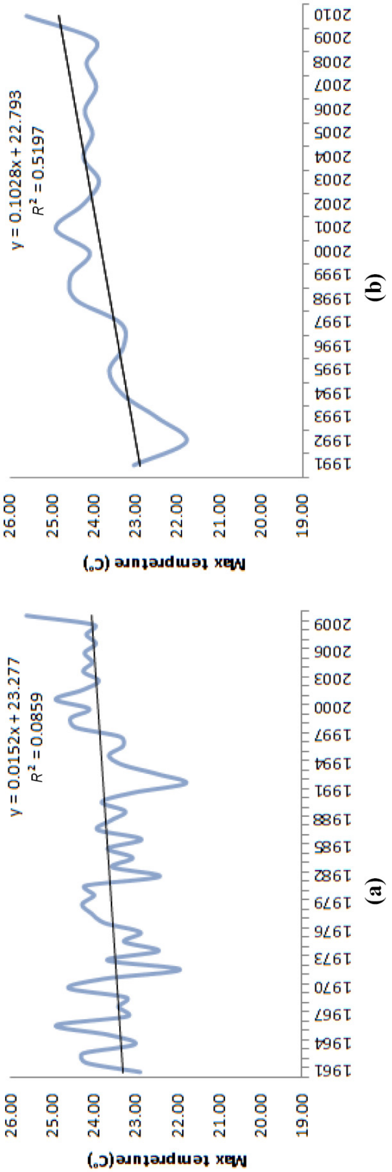


Figure 5.
Trend analysis of the national maximum temperatures during 1961-2013 (a) and 1991-2013 (b)

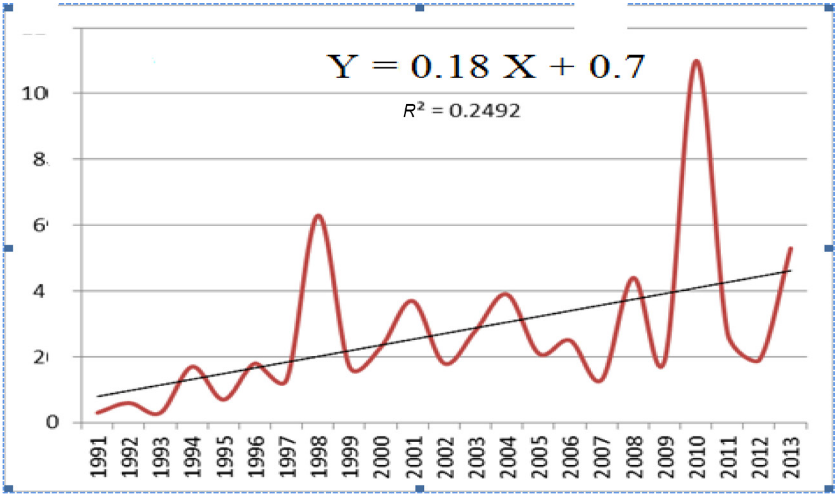


Figure 6. National trend of heat wave frequencies

No. of stations (1991-2013)	No. of stations (1961-1990)	Trend
10	8	Positive trend (not significant)
15	0	Positive trend (significant)
2	12	Negative trend (not significant)
0	7	Negative trend (significant)

Table I. Frequency analysis of heat wave frequency in two periods

4. Conclusion

One of the most important climate hazards is represented by heat waves, which is a usual and frequent phenomenon in Iran during summer. Occurrence of severe heat waves in the past few decades has increased more than 2 times compared to its long-term average, and it is continuously increasing in frequency and intensity.

In this study we investigated the spatial patterns of long-term trends in annual number of hot days and heat wave frequencies at 27 stations across Iran during 1961-2013. During this period, minimum and maximum number of heat waves were observed at Abadan (28 heat waves) and Bandar Abbas (88 heat waves), respectively. While the results do not show a positive significant trend ($p < 0.05$) in annual number of hot days and heat wave frequencies during the period 1961-1990 over Iran (except central and southern parts of the country), there was a positive trend for H* and heat waves during 1991-2013 over all 27 stations. Of the 27 stations over the observation period, only one station (Shahrekord) shows a statistically significant decrease in heat wave occurrence since 1961. It can be concluded that during recent decades, Iran has experienced heat waves more than before and it has been an inclusive event that is probably related to global warming.

Our findings are also consistent with what has been observed in Middle Eastern regions. Jeremy and Eltahir (2015) and Zhang *et al.* (2005) showed similar trends in central and southern Asia. Their results show significant, and spatially coherent, trends in temperature indices corresponding to a warming trend in the region. It was found that the frequency of warm days has significantly increased during 1961-2005 over the Persian Gulf region.

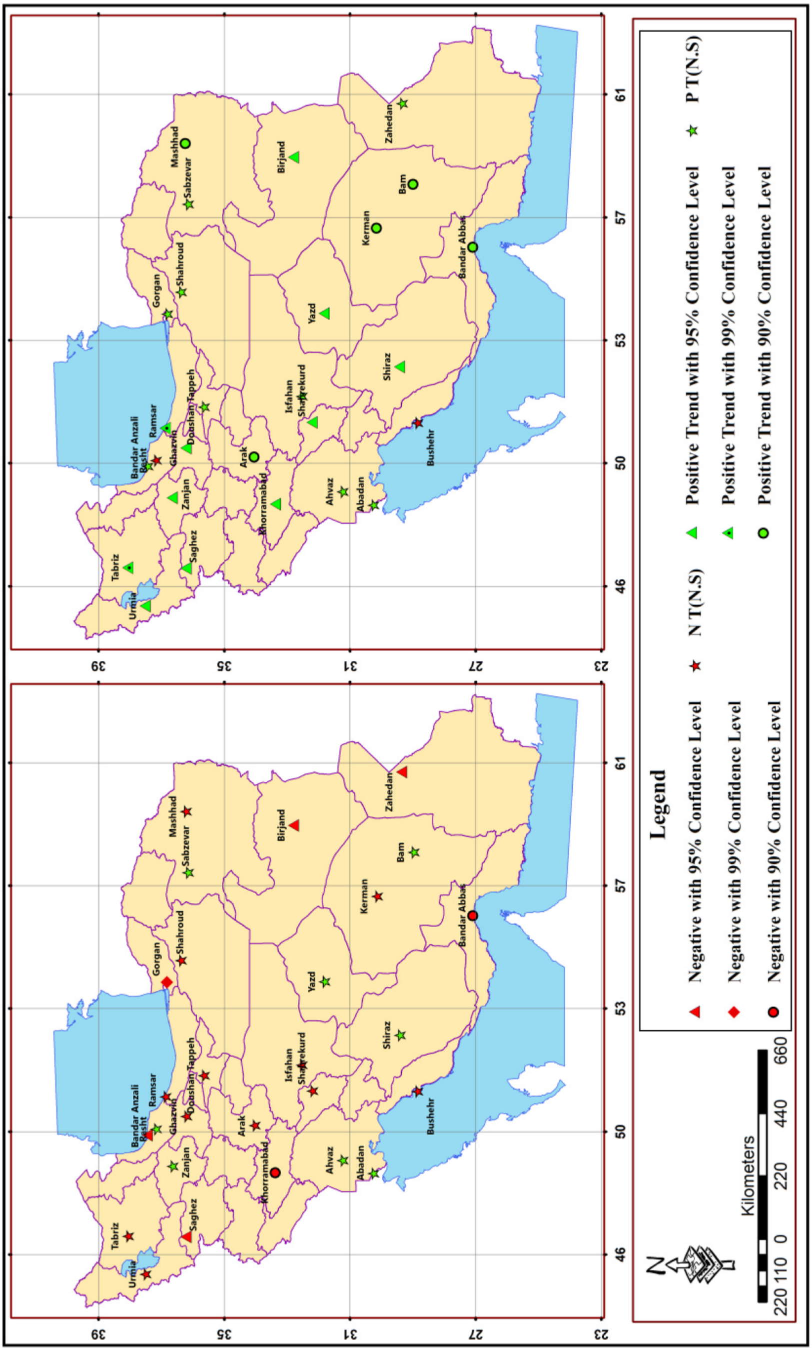


Figure 7.
Trend analysis of heat wave frequency during the two study periods: 1961-1990 (left) and 1991-2013 (right)

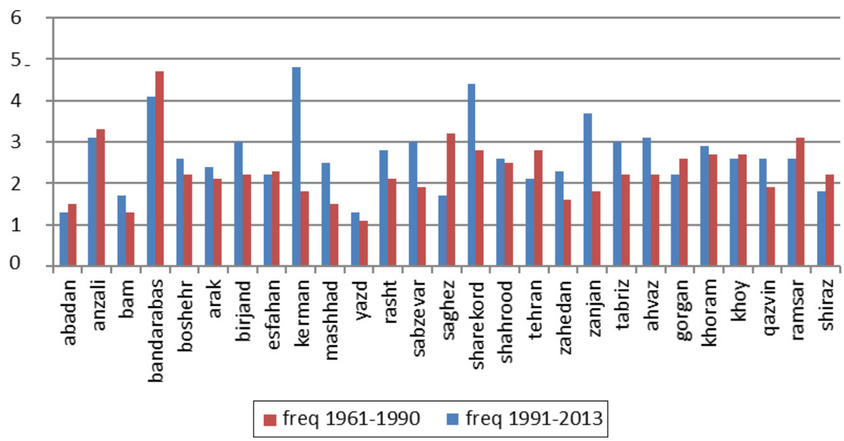


Figure 8.
Heat wave frequency at the 27 stations in the two study periods: 1961-1990 (red) and 1991-2013 (blue)

With regard to global warming, the Middle East and North Africa region is considered one of the most vulnerable regions facing climate change impacts, because of its dry and semi-dry climate (Elasha, 2010). As an example, on Friday, July 31, 2015, a combination of extreme heat and humidity yielded an extraordinary value of the heat index equal to 73°C at Mahshahr city located in the coastal area of the Persian Gulf in Iran. CNRM_CM5 climate model projection shows increase of Iran annual mean temperature between 0.5-1.1 and 0.8-1.6 degree centigrade for Rcp2.6 and Rcp8.8 until 2050, respectively. In both scenarios, the strongest rise in temperature over Iran is expected during summer, when it is already very hot. The maximum daytime temperature during the hottest days will increase by 3°C by the middle of this century in the RCP8.5 scenario (Lelieveld *et al.*, 2016).

If the same climate trends continue, extreme heat waves events will become more intense in the Persian Gulf countries and coastal cities in Iran until 2070 (Jeremy and Eltahir, 2015). The longer and more frequent intense heat waves in future will have negative impacts on Iran agriculture, energy and tourism sectors, in addition to Iranian people's health and life being impacted by the dry and hot climate and water shortage problem across the country. Considering the hot days and heat wave frequency trends discussed in this paper, and because of the negative impacts of these phenomena on human health and natural resources, it will be necessary to plan adaptation strategies to combat negative impacts of climate change in Iran. Reduction of exposure and vulnerability, enhancement of adaptive capacity and improvement of responses during and after a heat wave can be considered as adaptation strategies (Loughnan *et al.*, 2013), as well as cheapest and practical methods to combat negative impacts and the risk of extreme heat events in the future.

References

Alexander, L.V., Zhang, X., Peterson, T.C., Caesar, J., Gleason, B., Klein Tank, A.M.G., Haylock, M., Collins, D., Trewin, B., Rahimzadeh, F., Tagipour, A., Rupa Kumar, K., Revadekar, J., Griffiths, G., Vincent, L., Stephenson, D.B., Burn, J., Aguilar, E., Brunet, M., Taylor, M., New, M., Zhai, P., Rusticucci, M. and Vazquez-Aguirre, J.L. (2006), "Global observed changes in daily climate extremes of temperature and precipitation", *Journal of Geophysical Research*, Vol. 111, doi: 10.1029/2005JD006290.

Amiri, M.J. and Eslamian, S.S. (2010), "Investigation of climate change in Iran", *Journal of Environmental Science and Technology*, Vol. 3, pp. 208-216.

Baldi, M., Cesarone, F., Dalu, G.A., Maracchi, G. and Pasqui, M. (2006), "Heat-waves in the Mediterranean: a local feature or a larger scale effect?", *International Journal of Climatology*, Vol. 26, pp. 1477-1487, doi: 10.1002/joc.1389.

Barriopedro, D., Fischer, E.M., Luterbacher, J., Trigo, R.M. and García-Herrera, R. (2011), "The hot summer of 2010: redrawing the temperature record map of Europe", *Science*, Vol. 332, pp. 220-224.

Beniston, M. (2004), "The 2003 heat wave in Europe: a shape of things to come? An analysis based on Swiss climatological data and model simulations", *Geophysical Research Letter*, Vol. 31, doi: 10.1029/2003GL018857.

CCSP (2008), "Preliminary review of adaptation options for climate-sensitive ecosystems and resources", in Julius, S.H. and West, J.M. (Eds), *A Report by the US Climate Change Science Program and the Subcommittee on Global Change Research*, US Environmental Protection Agency, Washington, DC, p. 873.

Climate.gov of NOAA (2015), "Summer heat wave arrives in Europe", available at: www.climate.gov/news-features/event-tracker/summer-heat-wave-arrives-europe (accessed 15 March 2016).

Elasha , B.O. (2010), "Mapping of climate change threats and human development impacts in the Arab regions", *Arab Human Development Report*, UNDP Research Paper Series.

Frich, P., Alexander, L.V., Della-Marta, P., Gleason, B., Haylock, M., Klein Tank, A.M.G. and Peterson, T. (2002), "Observed coherent changes in climatic extremes during the second half of the twentieth century", *Climate Research*, Vol. 19, pp. 193-212.

Fujibe, F., Yamazaki, N., Kobayashi, K. and Nakamigawa, H. (2007), "Long-term changes of temperature extremes and day-to-day variability in Japan", *Papers in Meteorology and Geophysics*, Vol. 58, pp. 63-72.

Ghasemi, H.R. (2015), "Changes and trends in maximum, minimum and mean temperature series in Iran", *Atmosphere Science Letters*, doi: 10.1002/asl2.569.

Grumm, R.H. (2011), "The Central European and Russian heat event of July–August 2010", *Bulletin of the American Meteorological Society*, Vol. 92, pp. 1285-1296, doi: http://dx.doi.org/10.1175/2011BAMS3174.1.

Habeeb, D., Vargo, J. and Stone, B. (2015), *Natural Hazards*, Vol. 76, p. 1651, doi: 10.1007/s11069-014-1563-z.

Hassan, A.N., Nieplova, H.A. and Ramadan, E. (2004), "Warm season extreme temperature events in Kuwait", *Journal of Arid Environments*, Vol. 56 No. 2, pp. 357-371, doi: 10.1016/S0140-1963(03)00007-7.

Höppe, P. (1999), "The physiological equivalent temperature: a universal index for the biometeorological assessment of the thermal environment", *International Journal in Biometeorological*, Vol. 43 No. 2, pp. 71-75.

IPCC (2007), *Fourth Assessment Report: Climate Change*, IPCC Publication, available at: www.ipcc.ch/publications_and_data/publications_and_data_reports.htm#1 (accessed 12 June 2016).

IPCC (2012), *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, NY, p. 582.

IPCC (2013), *Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, NY.

Jeremy, S.P. and Eltahir, E. (2015), "Future temperature in Southwest Asia projected to exceed a threshold for human adaptability", *Nature Climate Change*, Vol. 6, pp. 197-200, doi: 10.1038/nclimate2833.

Justin, A. (2007), "The impacts of extreme events on biodiversity – lessons from die-offs in flying-foxes", *International Symposium on the Importance of Bats as Bioindicators*, Barcelona.

Karl, T.R. and Knight, R.W. (1997), "The 1995 Chicago heat wave: how likely is a recurrence?", *Bulletin of the American Meteorological Society*, Vol. 78 No. 6, pp. 1107-1119.

Kousari, M.R., Ahani, H. and Hendi-zadeh, R. (2013), "Temporal and spatial trend detection of maximum air temperature in Iran during 1960–2005", *Global and Planetary Change*, Vol. 111, pp. 97-110.

Leiker, K. (2002), "Heat waves and heat mortality in the United States during the twentieth century", *Proceedings of the 15th Conference on Biometeorology and Aerobiology*, *American Meteorological Society*, pp. 214-217, available at: https://ams.confex.com/ams/15BioAero/techprogram/paper_49534.htm

Lelieveld, J., Proestos, Y. and Hadjinicolaou, P. (2016), "Strongly increasing heat extremes in the Middle East and North Africa (MENA) in the 21st century", *Climatic Change*, Vol. 137, p. 245 doi: 10.1007/s10584-016-1665-6.

Loughnan, M.E., Tapper, N.J., Phan, T., Lynch, K. and McInnes, J.A. (2013), *A Spatial Vulnerability Analysis of Urban Populations During Extreme Heat Events in Australian Capital Cities*, National Climate Change Adaptation Research Facility, Gold Coast, p. 128.

Markus, K. (2006), "World map of the Köppen-Geiger climate classification updated", *Meteorologische Zeitschrift*, Vol. 15 No. 3, pp. 259-263.

Matzarakis, A., Mayer, H. and Iziomon, M.G. (1999), "Applications of a universal thermal index: physiological equivalent temperature", *International Journal in Biometeorological*, Vol. 43 No. 2, pp. 76-84.

Mildrexler, D.J., Maosheng, Z. and Running, S.W. (2011), "Satellite finds highest land skin temperatures on earth", *Bulletin of American Meteorology Society*, available at: http://dx.doi.org/10.1175/2011BAMS3067.1

Parak, F., Roshani, A. and Jamali, B. (2015), "Trends and anomalies in daily climate extremes over Iran during 1961–2010", *Journal of Environmental & Agricultural Sciences*, Vol. 2, p. 11.

Saboohi, R., Soltani, S. and Khodagholi, M. (2012), "Trend analysis of temperature parameters in Iran", *Theoretical and Applied Climatology*, doi: 10.1007/s00704-012-0590-5.

Salinger, J. and Griffiths, G. (2001), "Trends in New Zealand daily temperature and rainfall extremes", *International Journal of Climatology*, Vol. 21, pp. 1437-1452.

Seneviratne, S.I., Nicholls, N., Easterling, D., Goodess, C.M., Kanae, S., Kossin, J., Luo, Y., Marengo, J., McInnes, K., Rahimi, M., Reichstein, M., Sorteberg, A., Vera, C. and Zhang, X. (2012), "Changes in climate extremes and their impacts on the natural physical environment", in Field, C.B., Barros, V., Stocker, T.F., Qin, D., Dokken, D.J., Ebi, K.L., Mastrandrea, M.D., Mach, K.J., Plattner, G.K., Allen, S.K., Tignor, M. and Midgley, P.M. (Eds), *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC)*, Cambridge University Press, Cambridge, NY, pp. 109-230.

Sheridan, S.C. and Dolney, T. (2003), "Heat, mortality, and level of urbanization: measuring vulnerability across Ohio, USA", *Climate Research*, Vol. 24, pp. 255-265.

Smoyer, K.E., Rainham, D.G.C. and Hewko, J.N. (2000), "Heat-stress-related-mortality in five cities in Southern Ontario, 1980–1996", *International Journal of Biometeorology*, Vol. 44, pp. 190-197.

Soltani, S., Saboohi, R. and Yghmaei, L. (2011), "Rainfall and rainy days trend in Iran", *Climate Change*, doi: 10.1007/s10584-011-0146-1.

Tabari, H. and Talaee, P.H. (2011), "Recent trends of mean maximum and minimum air temperatures in the western half of Iran", *Meteorology and Atmospheric Physics*, Vol. 111 Nos 3/4, p. 121.

Tan, J., Zheng, Y., Song, G., Kalkstein, L.S., Kalkstein, A.J. and Tang, X. (2007), "Heat waves impacts on mortality in Shanghai, 1998 and 2003", *International Journal of Biometeorology*, Vol. 51, pp. 193-200.

Tan, J.G., Kalkstein, L.S., Huang, J.X., Lin, S., Yin, H. and Shao, D. (2004), "An operational heat/health warning system in Shanghai", *International Journal of Biometeorology*, Vol. 48, pp. 157-162.

Wolf, T. and McGregor, M. (2013), "The development of a heat wave vulnerability index for London, United Kingdom", *Weather and Climate Extremes*, Vol. 1, pp. 59-68.

World Health Organization. (2004), *Health and Global Environmental Change, Series No. 2*, World Health Organization, available at: www.euro.who.int/__data/assets/pdf_file/0008/96965/E82629.pdf

Zhang, X., Aguilar, E., Sensoy, S., Melkonyan, H., Tagiyeva, U., Ahmed, N., Kutaladze, N., Rahimzadeh, F., Taghipour, A., Hantosh, T.H., Albert, P., Semawi, M., Karam Ali, M., Al-Shabibi, M.H.S., Al-Oulan, Z., Zatari, T., Khelet, I.A.D., Hamoud, S., Sagir, R., Demircan, M., Eken, M., Adiguzel, M., Alexander, L., Peterson, T.C. and Wallis, T. (2005), "Trends in Middle East climate extreme indices from 1950 to 2003", *Journal of Geophysical Research*, Vol. 110 No. D22, doi: 10.1029/2005JD006181.

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