Journal of Environmental Health and Sustainable Development

Trend Analysis and Temporal and Spatial Distribution of Wet Bulb Globe Temperature as a Heat Stress Index in Iran during the Summer Season over a 30-Year Period

Gholamabbas Fallah Ghalhari [1], Somayeh Farhang Dehghan [2], Elham Akhlaghi Pirposhteh [3], Mehdi Asghari [4*]

[1] Department of Climatology, Faculty of Geography and Environmental Sciences, Hakim Sabzevari University, Khorasan-Razavi, Iran.
[2] Environmental and Occupational Hazards Control Research Center, School of Public Health and Safety, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
[3] Department of Occupational Health Engineering, School of Medical Sciences, Tarbiat Modares University, Tehran, Iran.
[4] Department of Occupational Health and Safety Engineering, School of Public Health, Arak University of Medical Sciences, Arak, Iran.

ARTICLE INFO

ORIGINAL ARTICLE

Article History:
Received: 03 September 2021
Accepted: 20 November 2021

***Corresponding Author:**
Mehdi Asghari

Email:
m.asghari2011@gmail.com

Tel:
+988633662024

Keywords:
Heat Stress,
Wet Bulb Globe Temperature,
Trend Analysis,
Iran.

ABSTRACT

Introduction: Global warming is one of the most important environmental problems that have raised researchers' attention. The present study aimed to analyze heat stress trends using the Wet Bulb Globe Temperature (WBGT) index in the country of Iran during the summer over a 30-year period.

Materials and Methods: Daily summertime statistical data regarding mean temperature and mean relative humidity, taken from 40 synoptic meteorological stations across Iran during a 30-year period were obtained from the Iranian National Meteorological Department. The De Martonne climate classification system was used to categorize various climate regions of Iran. The WBGT index was calculated using the formula given by the Australian Bureau of Meteorology. The Mann-Kendall statistical test and the Sen's slope estimator were used to analyze the trends of the WBGT index.

Results: The WBGT index had an upward trend during the three months of June, July, and August in 71.42%, 57.14%, and 66.66% of all stations and this trend was statistically significant in 53.32%, 50%, and 42.85% of those stations, respectively. Moreover, throughout the summer, 45% of the WBGT index measurements were in the medium range (18-23°C), 37.5% were in the high range (23-28°C), and 17.5% were in the very high range (> 28°C).

Conclusion: The WBGT index followed an upward trend during the summer, especially in semi-arid regions of Iran. Considering the phenomenon of global warming, it is essential to monitor, plan ahead, and take necessary precaution measures for sensitive populations who are at high risk areas of the country.

Citation: Fallah Ghalhari Gh, Farhang Dehghan S, Akhlaghi Pirposhteh E, et al. ***Trend Analysis and Temporal and Spatial Distribution of Wet Bulb Globe Temperature as a Heat Stress Index in Iran during the Summer Season over a 30-Year Period.*** J Environ Health Sustain Dev. 2021; 6(4): 1476-93.

Introduction

The country of Iran is placed at mid-latitudes on earth and falls within the northern dry temperate zone inside the tropical and sub-tropical regions. The geographic location of Iran and especially airstreams has rendered its climate dry and arid. However, Iran has a diverse climate due to the existence of various natural features, including elevations in the north and west of the country, large basins, such as the central plains within the Iran plateau, and also proximity to the Caspian Sea, the Persian Gulf and the Indian Ocean which create separate climates themselves [1, 2].

Currently, research is mainly focused on various climatological phenomenon and especially heatwaves as it has a meaningful effect on natural ecosystems and human societies [3]. In certain parts of the world, the intensity, duration, and number of heatwave events has increased in recent years [4].

Nowadays, climate change and global warming are one of the most important environmental problems that raised researchers' attention on a regional and global scale [5]. Global warming has contributed to the reduction in solid precipitation and the accelerated melting of snow reservoirs in mountainous regions. This rising temperature trend seems to be accompanied by reduced water reservoirs as well. Considering the fact that rainfall in Iran is condensed and not dispersed throughout the year, the reduction of water reservoirs means the exacerbation of water shortages during warm and rainless months [6,7].

In a review article by Kovats et al., heat was reported as an important cause of death and it was suggested that further studies be conducted in order to better reduce the detrimental effects of heat and protect people against heatwaves [8]. A heatwave is defined as excessively hot weather or the dominance or incursion of extremely hot air in a vast area [9]. Heatwave can be a dangerous climatic phenomenon and research studies have shown that they are responsible for the highest annual rates of death compared to other climatic events [10]. Hübler et al. estimated that climate change in Germany increased the number of heat related fatalities by a factor of 3 and also increased heat related costs by a factor of 6 [11].

Heat absorbed from the environment combined with heat generated from metabolic and physical activity can build up inside the body [12]. Consequently, the internal body temperature will rise and this can have various physiological effects [13]. High internal body temperature due to short term chronic exposure to extreme heat can directly lead to heat related conditions, such as mild heat rash, muscle cramps, heat exhaustion, and even serious heat shock. Long term chronic exposure to heat can lead to cardiovascular disorders [14], psychological disorders [15], and chronic kidney disorders [16], and immunosuppression [17].

Although various indices have been used to evaluate heat stress, the Wet Bulb Globe Temperature (WBGT) index is one of the most reputable [18]. However, due to the limitations associated with using this index and the need to measure wet bulb temperature, it is not feasible to calculate this index using meteorological data. In order to overcome this limitation, the WBGT index devised by the Australian Bureau of Meteorology (ABM) was used as a thermal discomfort index in order to evaluate heatwave trends in Iran[19]. The facility and utility of this index has already been evaluated by Teimori et al. and is proven to be highly correlated with ISO WBGT and physiological parameters [19]. Due to its simplicity, low cost, and lack of a need for advanced measurement devices, the ABM model equation can be used to calculate the WBGT index as a screening tool for heat stress evaluation. This index is also suitable for using data obtained from meteorological stations to model the global warming phenomenon and climate change [19].

The present study aimed to analyze heat stress trends using the WBGT index in Iran during the summer. Meteorological data (air temperature, relative humidity) was used to calculate the WBGT index as a heat stress index. Given that there are a diverse climate, climate change, and global warming in Iran, the results of the present study can be used to prioritize risk and devise a strategic preventive approach for its risk mitigation. Limiting the consequences of future heatwaves lies in the identification and evaluation of these heatwaves beforehand and also finding methods to reduce the effects of heatwaves on public health and identifying areas that are most vulnerable.

Materials and Methods

Climatic Zoning

The De Martonne climate classification system was used to classify the diverse climate of Iran. Iran covers an area of 1,648,195 km^2, spanning from latitude of 25° to 40° north and a longitude of 44° to 62° east. The De Martonne system is based on the Aridity Index (AI) and determines the type of climate using temperature and rainfall [20]. The De Martonne climate classification system consists of six climate categories, including arid (AI < 10), semi-arid (10 < AI < 20), Mediterranean (20 < AI < 24), semi-humid (24 < AI < 28), humid (28 < AI < 35), and very humid (35 < AI).

Data collection

In order to analyze the trends of WBGT index according to ABM model, data regarding daily mean temperature (°C) and daily mean relative humidity (%), recorded during summertime from 40 synoptic meteorological stations for a 30-year statistical period (1985-2014), were obtained from the Iran Meteorological Organization [21]. These stations had the most complete period of statistical data among all meteorological stations in the country and it was ensured that only stations with 5% or less statistical errors during the intended period were used in the study. The specifications of the meteorological stations include latitude, longitude, and elevation.

The WBGT Index

In this study, the WBGT index was used according to the formula presented by the ABM [22]. Equation 1 was used to calculate the WBGT index by only using vapor pressure and air temperature. Equation 2 was used to calculate vapor pressure, where *Ta* is mean air temperature (°C), *RH* is relative humidity (%), and *p* is vapor pressure (hPa) [22].

$$WBGT(°C) = (0.567 \times Ta) + 3.94 + (0.393 \times e) \quad \text{(Eq.1)}$$

$$e = \frac{RH}{100} \times e_0 \times exp\left(17.27 \times \frac{Ta}{237.7 + Ta}\right) \quad \text{(Eq. 2)}$$

Where, *Ta* is dry air temperature (°C), *RH* is relative humidity (%), $e_0 = 6.112\ hPa$ and e is water vapor pressure (hPa).

Trend analysis

The Mann-Kendall statistical test was done using Minitab v17.1.0 software in order to analyze the trends of the WBGT index during the intended period. This method only measures the upward or downward trends of a variable within a time series and can be used to determine whether the central position or median of a time series has changed over time [23]. A positive *Z* value indicates an upward trend and a negative *Z* value indicates a downward trend within the data sets [24].

Sen's slope

In order to estimate the true slope of a trend within a time series, the Theil-Sen non-parametric estimator is used. This method, like many other non-parametric methods (Mann-Kendall), is based on the differential analysis of time series observations and is used when the time series has a linear trend [25, 26]

Ethical issue

The authors hereby certify that all data collected during the study are stated in the manuscript. This manuscript is the original work of the authors, and no data from the study has been or will be separately published elsewhere. Ethical approval for this study was obtained from Arak University of Medical Science (IR.ARAKMU.REC.1398.069).

Results

Figure 1 presents the De Martonne climate classification of Iran. Accordingly, of all the studied meteorological stations, 50% of them lie within an arid climate, 37.5% lie within semi-arid climate, 10% lie within humid or very-humid climates, and 2.5% lie within the Mediterranean climate.

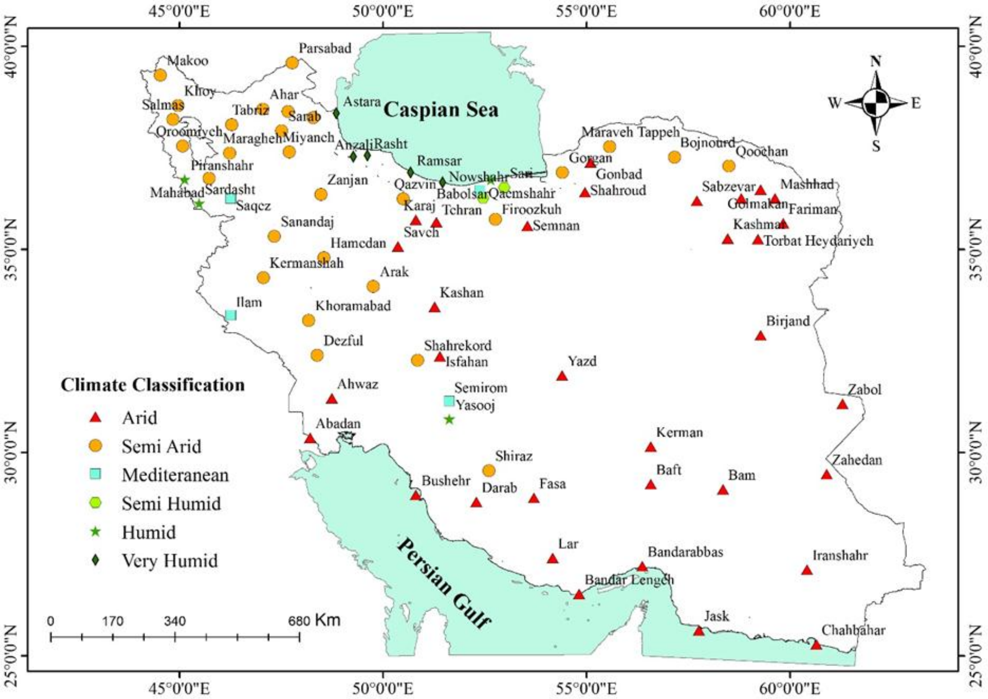

Figure 1: The De Martonne climate classification of Iran during the summer season over a 30-year period

Table 1 reveals the mean and standard deviation of the WBGT index from all the studied meteorological stations. The geographical location of each station can be seen in Figure 1. In June, Chahbahar station had the highest mean WBGT index (35.96°C ± 1.53); while the Ardebil station had the lowest one (18.46°C ± 2). In July, Bandarabbas and Ardebil stations had the highest (37.1°C ± 1.4) and (20.1°C ± 1.8) lowest mean WBGT index, respectively. In August, Bandarabbas and Ardebil stations had the highest (36.8°C ± 1.44) and (20.17°C ± 2) lowest mean WBGT index, respectively. Overall, throughout the summer, Bandarabbas station had the highest mean WBGT index (36.4°C ± 1.73) and Ardebil station had the lowest one (19.57°C ± 2.1). According to the climate classification, the lowest WBGT index of the semi-arid region was observed in June (18.46˚C ± 2), the arid region in June (20.17˚C ± 1.44), the humid region in June (20.8˚C ± 1.5), the very-humid region in June (26.13˚C ± 2.27), and the Mediterranean region in June (19.3˚C ± 1.6). Also, the highest WBGT index of the semi-arid region was obtained in August (29.6˚C ± 1.8), the arid region in July (37.1˚C ± 1.4), the humid region in August (30.11˚C ± 1.92), the very-humid region in August (29.36˚C ± 2.13), and the Mediterranean region in July (21.95˚C ± 1.6).

[DOR: 20.1001.1.24766267.2021.6.4.6.4]

[DOI: 10.18502/jehsd.v6i4.8153]

Table 1: Mean (± SD) summertime WBGT index (°C) for each station during the 30-year period

Stations	Climatic classification	June	July	August	Summer
Ahar	Semi-arid	19.6 ± 1.8	21.5 ± 1.65	21.5 ± 1.76	20.91 ± 1.96
Ahvaz	Arid	29.34 ± 1.75	31.38 ± 2	32 ± 2.6	30.92 ± 2.43
Anzali	Very humid	26.62 ± 2.26	29 ± 1.95	29.36 ± 2.13	28.35 ± 2.44
Arak	Semi-arid	22.46 ± 1.78	22.9 ± 1.47	20.3 ± 2.2	21.88 ± 2.16
Ardebil	Semi-arid	18.46 ± 2	20.1 ± 1.8	20.17 ± 2	19.57 ± 2.1
Babolsar	Humid	27.17 ± 2	29.57 ± 1.76	30.11 ± 1.92	29 ± 2.2
Bam	Arid	26.33 ± 1.85	26.97 ± 1.88	25.71 ± 1.9	26.34 ± 1.96
Bandarabbas	Arid	35.07 ± 165	37.1 ± 1.4	36.8 ± 1.44	36.4 ± 1.73
Birjand	Arid	22 ± 1.77	22.91 ± 1.66	21.5 ± 1.73	22.15 ± 1.82
Bushehr	Arid	32.16 ± 1.67	34.8 ± 1.8	36.17 ± 1.98	34.4 ± 2.46
Chahbahar	Arid	35.96 ± 1.53	34.69 ± 1.6	32.98 ± 1.6	34.53 ± 2
Darab	Arid	20.17 ± 1.44	22 ± 1.49	20.7 ± 1.47	21 ± 1.65
Fasa	Arid	25.68 ± 1.7	25.11 ± 1.6	22.1 ± 1.75	24.27 ± 2.31
Gorgan	Semi-arid	26.7 ± 2	29.15 ± 1.67	29.6 ± 1.8	28.5 ± 2.23
Hamedan	Semi-arid	19.9 ± 1.5	22.32 ± 1.4	21.5 ± 1.45	21.25 ± 1.77
Karaj	Arid	22.93 ± 1.7	25 ± 1.46	24.47 ± 1.46	24.15 ± 1.76
Kashan	Arid	25.32 ± 1.6	27.23 ± 1.46	26.2 ± 1.47	26.27 ± 1.7
Kermanshah	Semi-arid	21.26 ± 1.48	23.64 ± 1.39	23 ± 1.4	22.65 ± 1.74
Mahabad	Semi-arid	20.63 ± 1.56	23.19 ± 1.39	22.67 ± 1.39	22.18 ± 1.81
Maku	Semi-arid	19.35 ± 1.88	22.18 ± 1.63	22.1 ± 1.57	21.23 ± 2.14
Maragheh	Semi-arid	20.43 ± 1.74	23.15 ± 1.5	22.75 ± 15	22.1 ± 1.98
Mashhad	Arid	22.86 ± 1.8	24.17 ± 1.8	22.77 ± 2	23.27 ± 1.98
Qazvin	Semi-arid	21.8 ± 1.58	24.1 ± 1.33	23.4 ± 1.27	23.1 ± 1.69
Qom	Arid	24.7 ± 1.58	26.65 ± 1.37	25.58 ± 1.55	25.65 ± 1.7
Rasht	Very humid	26.13 ± 2.27	28.23 ± 1.9	28.5 ± 2.14	27.63 ± 2.33
Sabzevar	Arid	24.16 ± 1.8	25.38 ± 1.7	24.1 ± 1.8	24.55 ± 1.87
Sanandaj	Semi-arid	20.9 ± 1.58	23.65 ± 1.47	22.94 ± 1.53	22.51 ± 1.92
Saqez	Mediterranean	19.3 ± 1.6	21.95 ± 1.6	21.18 ± 154	21.02 ± 2.1
Semnan	Arid	24.4 ± 1.86	26.6 ± 1.57	25.66 ± 1.76	25.57 ± 1.95
Shahrekord	Semi-arid	18.92 ± 1.38	21.2 ± 1.34	20.22 ± 135	20.12 ± 1.64
Shahroud	Arid	22 ± 1.78	23.94 ± 1.7	23.26 ± 1.75	23.1 ± 1.9
Shiraz	Semi-arid	25.48 ± 1.43	24.78 ± 1.45	21.75 ± 1.55	24 ± 2.2
Tehran	Arid	24 ± 1.7	26.24 ± 1.5	25.68 ± 1.64	25.32 ± 1.87
Torbat Heydariyeh	Arid	21.72 ± 1.73	22.65 ± 1.55	21.42 ± 1.76	21.95 ± 1.76
Urmia	Semi-arid	20.27 ± 1.68	22.97 ± 1.5	22.37 ± 1.4	21.88 ± 1.92
Yasuj	Humid	20.8 ± 1.5	22.87 ± 1.6	22.23 ± 1.46	22 ± 1.75
Yazd	Arid	24.25 ± 1.46	25.64 ± 1.54	24.17 ± 1.65	24.7 ± 1.7
Zabol	Arid	27.77 ± 2.15	28.6 ± 1.85	27.1 ± 1.96	27.8 ± 2.1
Zahedan	Arid	23 ± 1.6	23.7 ± 1.6	22.25 ± 1.58	23 ± 1.7
Zanjan	Semi-arid	19.35 ± 1.78	21.9 ± 1.6	21.46 ± 1.5	20.93 ± 1.97

The frequency distribution of measurement station according to health risk of exposure during summertime is presented in Table 2. The WBGT index was classified into four categories based on the health risk of exposure (low, medium, high, very high) [27]. In total over summertime and during the 30-year period, 42.5% and 40% of measurement station experienced the medium and high risk conditions, respectively.

Table 2: Frequency distribution of measurement stations according to health risk of exposure during summertime

Heat stress index	Health risk of exposure	Range	Frequency (n = 40)				Percentage (%)			
			June	July	August	Summer	June	July	August	Summer
WBGT (˚C)	Low	< 18	0	0	0	0	0	0	0	0
	Medium	18 -23	21	13	20	17	52.5	32.5	50	42.5
	High	23 - 28	15	18	12	16	37.5	45	30	40
	Very High	> 28	4	9	8	7	10	22.5	20	17.5

Figure 2 reveals the summertime climate classification of Iran according to the WBGT index. As can be seen from Figure 2, the entire southern belt of Iran and some parts of the northern belt lie within the 29˚C to 34˚C range (very high-risk exposure) of the WBGT index.

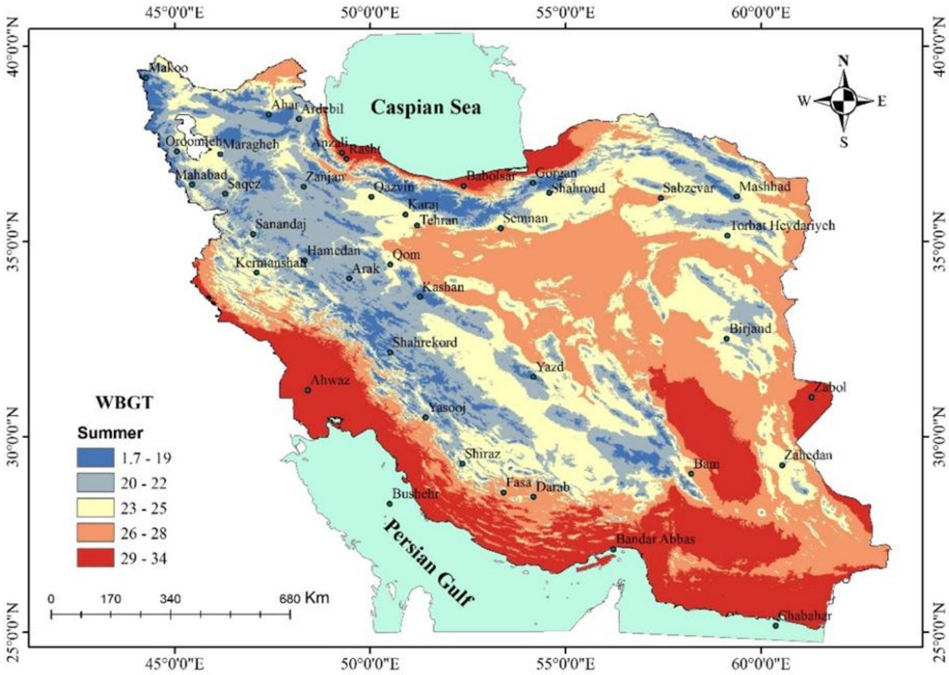

Figure 2: Climate classification of Iran based on the WBGT index during the summer season over a 30-year period

The results of WBGT trend analysis based on the Mann-Kendall test, during the months of June, July, and August and the summertime are presented in Tables 3 to 6. According to Table 3, the WBGT index had an upward trend during June in 71.42% of stations and this upward trend was statistically significant in 53.33% of them. Based on the Sen’s slope estimator, the highest significant reduction of the WBGT index was observed at Zabol station (-0.535°C/decade) and the highest significant increase of the WBGT index was obtained at Arak station (+ 1.100°C/decade).

[DOR: 20.1001.1.24766267.2021.6.4.6.4]
[DOI: 10.18502/jehsd.v6i4.8153]

Table 3: The results of the WBGT trend analysis in June

Stations	Z	P-value	Trend	Sen's slope
Ahar	0.821	0.206	Upward	0.200
Ahvaz	2.997	0.001	Upward	0.490
Anzali	0.428	0.334	Upward	0.138
Arak	3.782	0.000	Upward	1.100
Ardebil	2.319	0.010	Upward	0.537
Babolsar	0.963	0.168	Upward	0.225
Bam	0.107	0.457	Upward	0.028
Bandarabbas	0.678	0.249	Upward	0.116
Birjand	1.855	0.032	Upward	0.305
Bushehr	3.104	0.001	Upward	0.703
Chahbahar	-0.785	0.216	Downward	-0.115
Darab	0.500	0.309	Upward	0.110
Fasa	2.605	0.005	Upward	0.620
Gorgan	1.249	0.106	Upward	0.299
Hamedan	1.213	0.113	Upward	0.152
Isfahan	-0.785	0.216	Downward	-0.115
Karaj	-0.071	0.472	Downward	-0.017
Kashan	0.000	0.500	-	0.000
Kermanshah	2.319	0.010	Upward	0.375
Mahabad	2.748	0.003	Upward	0.348
Maku	1.713	0.043	Upward	0.293
Maragheh	3.176	0.001	Upward	0.527
Mashhad	-0.500	0.309	Downward	-0.095
Qazvin	2.462	0.007	Upward	0.321
Qom	2.498	0.006	Upward	0.355
Rasht	0.464	0.321	Upward	0.161
Sabzevar	-0.678	0.249	Downward	-0.092
Sanandaj	2.819	0.002	Upward	0.439
Saqez	-0.036	0.486	Downward	-0.016
Semnan	0.963	0.168	Upward	0.183
Shahrekord	0.607	0.272	Upward	0.057
Shahroud	1.320	0.093	Upward	0.229
Shiraz	-0.178	0.429	Downward	-0.037
Tabriz	2.462	0.007	Upward	0.400
Tehran	-0.285	0.388	Downward	-0.039
Torbat Heydariyeh	0.428	0.334	Upward	0.055
Urmia	2.676	0.004	Upward	0.429
Yasuj	-0.771	0.221	Downward	-0.296
Yazd	-0.250	0.401	Downward	-0.051
Zabol	-2.569	0.005	Downward	-0.535
Zahedan	0.143	0.443	Upward	0.026
Zanjan	3.247	0.001	Upward	0.555

Table 4 shows that 57.14% of stations had a WBGT upward trend during July and this upward trend was statistically significant in 50% of them. Based on the Sen's slope estimator, the highest meaningful reduction of the WBGT index was observed at Zabol station (-0.616°C/decade) and the highest significant increase of the WBGT index was observed at Ardebil station (+ 0.581°C/ decade).

[DOR: 20.1001.1.24766267.2021.6.4.6.4]
[DOI: 10.18502/jehsd.v6i4.8153]

Table 4: The results of the WBGT trend analysis in July

Stations	Z	P-value	Trend	Sen's Slope
Ahar	-0.428	0.334	Downward	-0.070
Ahvaz	1.998	0.023	Upward	0.444
Anzali	0.749	0.227	Upward	0.204
Arak	-2.605	0.005	Downward	-0.543
Ardebil	2.997	0.001	Upward	0.581
Babolsar	0.963	0.168	Upward	0.181
Bam	-0.321	0.374	Downward	-0.122
Bandarabbas	1.534	0.062	Upward	0.243
Birjand	0.821	0.206	Upward	0.214
Bushehr	0.856	0.196	Upward	0.166
Chahbahar	-1.463	0.072	Downward	-0.263
Darab	-0.642	0.260	Downward	-0.103
Fasa	1.691	0.048	Upward	0.240
Gorgan	1.927	0.027	Upward	0.375
Hamedan	0.000	0.500	-	0.000
Isfahan	-1.748	0.040	Downward	-0.325
Karaj	-0.214	0.415	Upward	-0.064
Kashan	0.642	0.260	Upward	0.116
Kermanshah	-0.464	0.321	Downward	-0.059
Mahabad	0.892	0.186	Upward	0.118
Maku	0.607	0.272	Upward	0.089
Maragheh	2.426	0.008	Upward	0.434
Mashhad	-1.534	0.062	Downward	-0.274
Qazvin	2.498	0.006	Upward	0.300
Qom	1.963	0.025	Upward	0.296
Rasht	0.714	0.238	Upward	0.139
Sabzevar	-1.820	0.034	Downward	-0.348
Sanandaj	-0.642	0.260	Downward	-0.076
Saqez	-2.391	0.008	Downward	-0.496
Semnan	0.642	0.260	Upward	0.094
Shahrekord	-0.535	0.296	Downward	-0.063
Shahroud	1.657	0.048	Upward	0.378
Shiraz	0.321	0.374	Upward	0.059
Tabriz	2.070	0.019	Upward	0.314
Tehran	-1.070	0.142	Downward	-0.182
Torbat Heydariyeh	0.749	0.227	Upward	0.154
Urmia	1.106	0.134	Upward	0.166
Yasuj	-0.099	0.461	Downward	-0.013
Yazd	-0.250	0.401	Downward	-0.066
Zabol	-2.712	0.003	Downward	-0.616
Zahedan	-0.642	0.260	Downward	-0.109
Zanjan	2.926	0.002	Upward	0.414

Based on Table 5, the WBGT index had an upward trend during August in 66.66% of stations and this upward trend was statistically significant in 42.85% of those stations. Based on the Sen's slope estimator, the highest meaningful reduction of the WBGT index was observed at Arak station (-1.050°C/decade) and the highest significant increase of the WBGT index was obtained at Ardebil station (+ 0.896°C/ decade).

Table 5: The results of the WBGT trend analysis in August

Stations	Z	P-value	Trend	Sen's slope
Ahar	-0.393	0.347	Downward	-0.070
Ahvaz	1.534	0.062	Upward	0.451
Anzali	1.666	0.047	Upward	0.495
Arak	-3.640	0.000	Downward	-1.050
Ardebil	3.390	0.000	Upward	0.896
Babolsar	2.070	0.019	Upward	0.424
Bam	0.607	0.272	Upward	0.179
Bandarabbas	0.428	0.334	Upward	0.090
Birjand	1.570	0.058	Upward	0.286
Bushehr	2.212	0.013	Upward	0.568
Chahbahar	0.714	0.238	Upward	0.165
Darab	-0.428	0.334	Downward	-0.092
Fasa	-0.285	0.388	Downward	-0.029
Gorgan	1.927	0.027	Upward	0.406
Hamedan	0.393	0.347	Upward	0.078
Isfahan	-1.784	0.037	Downward	-0.349
Karaj	0.321	0.374	Upward	0.068
Kashan	0.250	0.401	Upward	0.068
Kermanshah	0.678	0.249	Upward	0.171
Mahabad	2.391	0.008	Upward	0.330
Maku	1.356	0.088	Upward	0.248
Maragheh	3.568	0.000	Upward	0.481
Mashhad	0.143	0.443	Upward	0.022
Qazvin	2.141	0.016	Upward	0.279
Qom	0.285	0.388	Upward	0.065
Rasht	1.748	0.040	Upward	0.404
Sabzevar	-1.035	0.150	Downward	-0.241
Sanandaj	1.106	0.134	Upward	0.200
Saqez	0.000	0.500	-	0.000
Semnan	-0.250	0.401	Downward	-0.055
Shahrekord	-2.248	0.012	Downward	-0.320
Shahroud	1.820	0.034	Upward	0.246
Shiraz	-0.749	0.227	Downward	-0.085
Tabriz	1.784	0.037	Upward	0.300
Tehran	-0.642	0.260	Downward	-0.142
Torbat Heydariyeh	2.462	0.007	Upward	0.559
Urmia	1.320	0.093	Upward	0.186
Yasuj	-0.691	0.245	Downward	-0.079
Yazd	-0.357	0.361	Downward	-0.088
Zabol	-1.142	0.127	Downward	-0.294
Zahedan	0.607	0.272	Upward	0.067
Zanjan	4.032	0.000	Upward	0.698

As Table 6 indicates, 66.66% of stations had an upward WBGT trend throughout the summer and this upward trend was statistically meaningful in 50% of them. Based on the Sen’s slope estimator, the highest meaningful reduction of the WBGT index was observed at Zabol station (-0.562°C/decade) and the highest significant increase of the WBGT index was observed at Zanjan station (+ 0.664°C/decade).

Table 6: The results of the WBGT trend analysis during the summer season

Stations	Z	P-value	Trend	Sen's slope
Ahar	0.285	0.388	Upward	0.030
Ahvaz	2.676	0.004	Upward	0.507
Anzali	1.427	0.077	Upward	0.233
Arak	-1.677	0.047	Downward	-0.328
Ardebil	3.675	0.000	Upward	0.602
Babolsar	1.499	0.067	Upward	0 .267
Bam	0.571	0.284	Upward	0.133
Bandarabbas	1.142	0.127	Upward	0.138
Birjand	2.391	0.008	Upward	0.326
Bushehr	2.391	0.008	Upward	0.520
Chahbahar	-0.250	0.401	Downward	-0.054
Darab	-0.428	0.334	Upward	-0.047
Fasa	1.891	0.029	Upward	0.200
Gorgan	2.426	0.008	Upward	0.363
Hamedan	0.678	0.249	Upward	0.094
Isfahan	-1.499	0.067	Downward	-0.233
Karaj	-0.107	0.457	Downward	-0.051
Kashan	0.285	0.388	Upward	0.025
Kermanshah	1.178	0.119	Upward	0.185
Mahabad	2.498	0.006	Upward	0.266
Maku	1.249	0.106	Upward	0.198
Maragheh	3.640	0.000	Upward	0.440
Mashhad	-0.749	0.227	Downward	-0.107
Qazvin	3.604	0.000	Upward	0.358
Qom	2.391	0.008	Upward	0.297
Rasht	1.320	0.093	Upward	0.195
Sabzevar	-1.570	0.058	Downward	-0.184
Sanandaj	1.142	0.127	Upward	0.116
Saqez	-0.928	0.177	Downward	-0.170
Semnan	0.963	0.168	Upward	0.080
Shahrekord	-1.213	0.113	Downward	-0.103
Shahroud	3.318	0.000	Upward	0.370
Shiraz	-0.178	0.429	Downward	-0.013
Tabriz	2.997	0.001	Upward	0.361
Tehran	-0.428	0.334	Downward	-0.070
Torbat Heydariyeh	1.142	0.127	Upward	0.134
Urmia	2.319	0.010	Upward	0.256
Yasuj	-0.415	0.339	Downward	-0.059
Yazd	-1.070	0.142	Downward	-0.140
Zabol	-2.355	0.009	Downward	-0.562
Zahedan	-0.357	0.361	Downward	-0.052
Zanjan	4.175	0.000	Upward	0.664

Figure 3 presents the mean values of WBGT index for the month of June according to different climate zones of Iran during the intended 30-year period. Based on this chart, overall, the WBGT index followed a somewhat upward trend in arid and semi-arid regions and a slight downward trend in Mediterranean and humid regions. As shown in Figure 3, the WBGT index is the highest in the arid, humid, and very humid regions and has the lowest mean value in the semi-arid and Mediterranean regions. Given that this index is calculated in terms of temperature and relative humidity, in dry areas of temperature, and in humid and very humid areas, relative humidity increases the values of the index. However, in the Mediterranean and semi-arid regions, these two parameters neutralize each other and the index values are lower. Therefore, according to Table 2,

[DOR: 20.1001.1.24766267.2021.6.4.6.4]
[DOI: 10.18502/jehsd.v6i4.8153]

the risk of heat stress is higher in dry, humid, and very humid environments. These results are repeated in Figure 4. According to these two figures, there is no significant increase or decrease in the index values in June and July in these two figures.

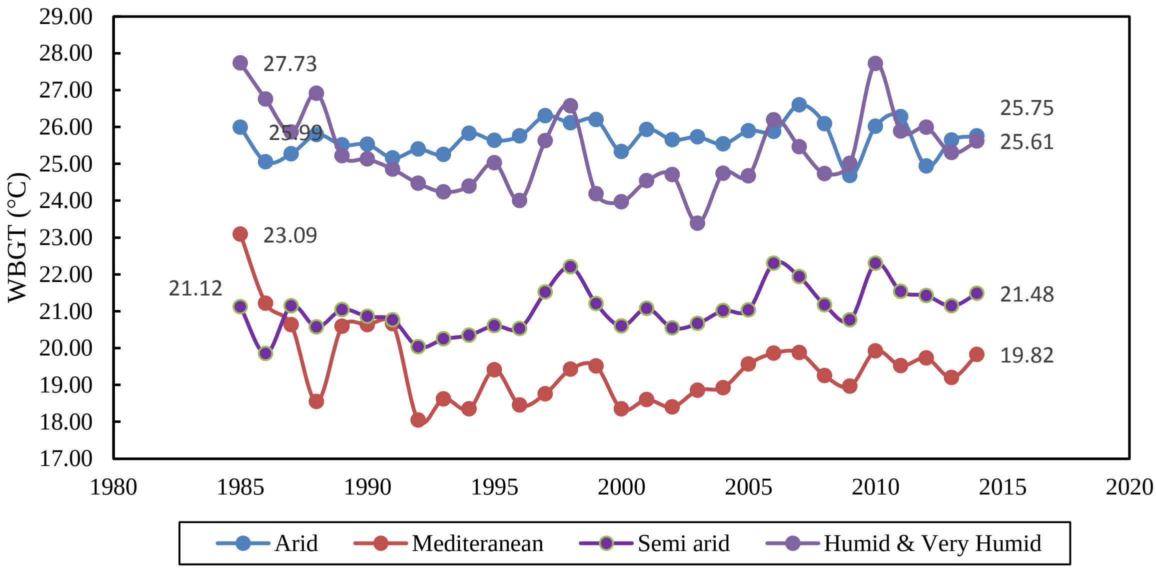

Figure 3: The mean values of WBGT index in June during the 30-year period across Iran (in the selected stations)

Figure 4 presents the mean values of WBGT index in July according to the different climate zones of Iran during the 30-year period. The WBGT index followed a somewhat upward trend in arid and semi-arid regions and a slight downward trend in Mediterranean and humid regions.

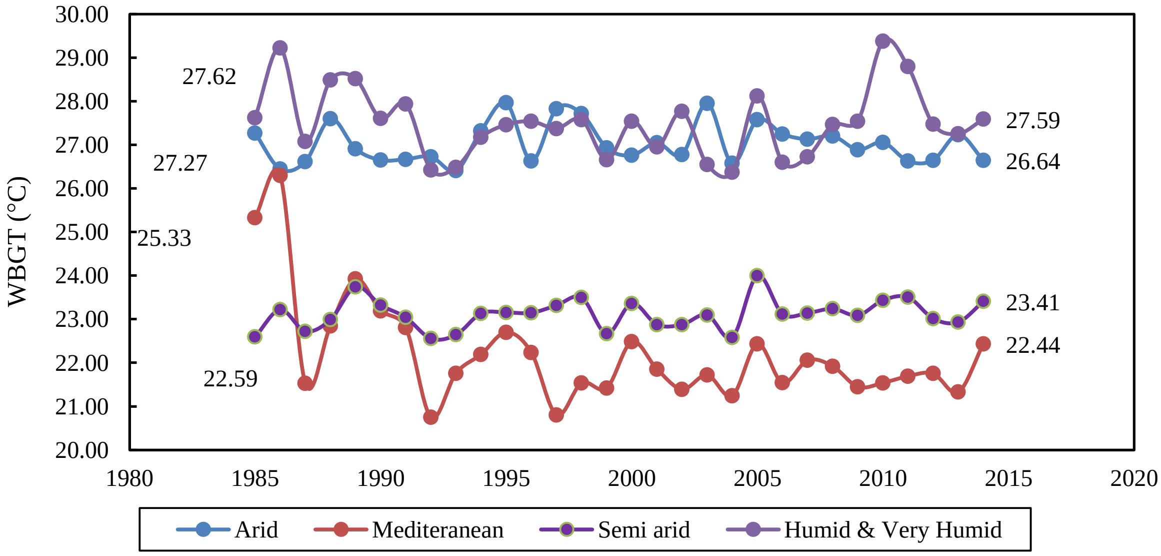

Figure 4: The mean values of WBGT index for the July during the 30-year period across Iran (in the selected stations).

The mean values of WBGT index in August according to the different climate zones of Iran are presented in Figure 5. Overall, the WBGT index followed a somewhat upward trend in arid, semi-arid, and humid regions and a slight downward trend in Mediterranean regions.

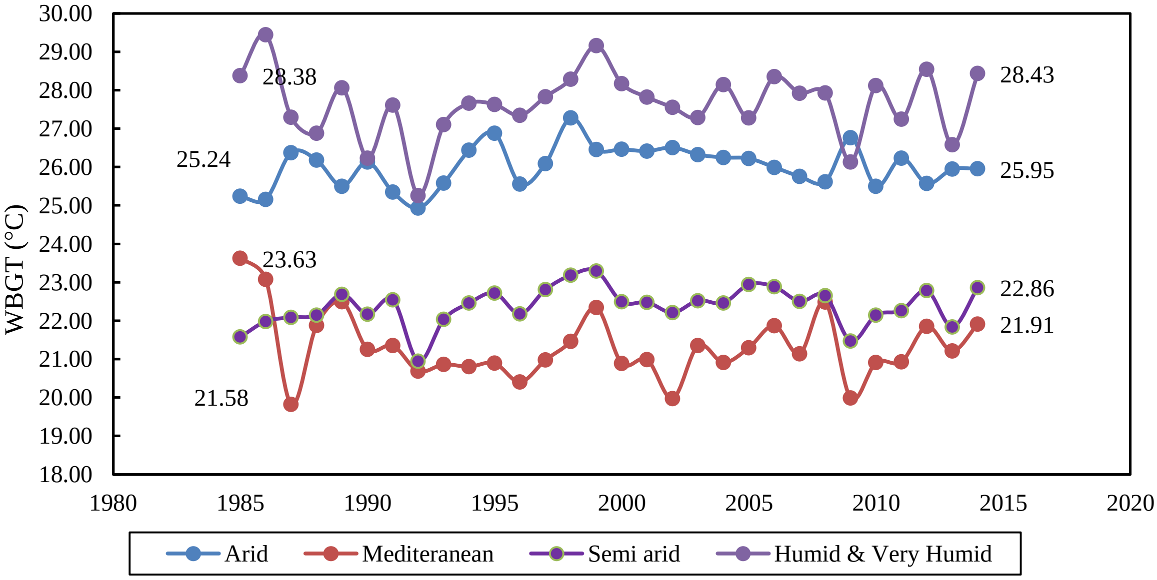

Figure 5: The mean values of WBGT index in August during the 30-year period across Iran (in the selected stations)

Figure 6 depicts the mean values of WBGT index throughout the summer according to the different climate zones. The summertime WBGT fluctuated in various climates of Iran during this 30-year period. Overall, the WBGT index followed a somewhat upward trend in semi-arid regions and a slight downward trend in arid, Mediterranean and humid regions.

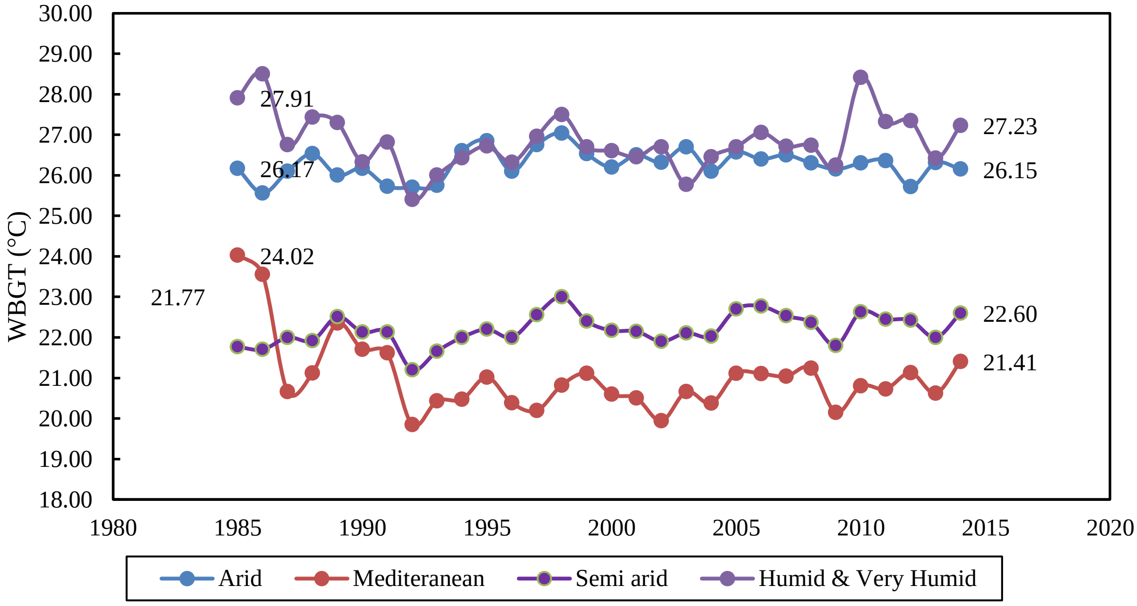

Figure 6: The mean values of WBGT index over the summer season during the 30-year period across Iran (in the selected stations)

Discussion

The results showed that the lowest mean WBGT index was observed in Ardebil station (18.46°C ± 2) in June, while the highest mean WBGT was observed in Bandarabbas station (37.1°C ± 1.4) in July. Based on the results, the highest mean WBGT index for the months of July and August was observed at Bandarabbas station, while the lowest WBGT index was observed at Ardebil. In June, the highest mean WBGT index was obtained at Chabahar station. Maeda et al. assessed risk factors for heatstroke among Japanese forestry workers and found that heat-related deaths in July and August were higher than in any other time of the year, indicating a higher heat stress level in these months [28].

Fallah Ghalhari et al. assessed the monthly changes in heat stress indices in outdoor environments over a 15-year period (2014-2014) in hot and dry climates in Iran [27]. The results of this study showed that the highest mean WBGT index was during July (37.22 ± 0.43 ° C) and the lowest in January (18.73 ± 0.37 ° C), which is consistent with the results of the present study. It has been stated that considering the phenomenon of global warming in the coming decades, it is better to predict climate change by considering different scenarios of climate change and using heat stress indicators, such as the WBGT index in order to take the necessary measures in the future [27].

The increase in temperature in Iran is from north to south and west to east, the highest temperature is observed at the southern end of Iran and the lowest temperature is observed at the northern half of Iran. This is mainly due to elevations in the north and in the west of Iran, and the gradual decrease in angle of sunlight towards the north [29]. A similar study by Leconte et al. confirmed it [30].

The results of Mann-Kendall test showed that the WBGT index had an upward trend during the three months of June, July, and August in 71.42%, 57.14%, and 66.66% of all stations and this trend was statistically meaningful in 53.32%, 50%, and 42.85% of those stations, respectively. The WBGT index had an upward trend in 66.66% of all stations throughout the summer and this trend was statistically meaningful in 50% of those stations. Some studies have indicated the effects of high pressure sub-tropical systems on the climate of Iran, suggesting that they cause increased temperatures, aridity, and prolonged droughts (such as systems inbound from Saudi Arabia) [31]. In some studies in the country through the climate change activities project under the United Nations Framework Convention on Climate Change (UNFCCC) and using the scenarios provided by the Intergovernmental Panel on Climate Change (IPCC), it is estimated that if CO_2 concentration doubles by 2100, the mean temperature in Iran will increase by 1.5 to 4.5 °C [32]. Modarres et al. studied the future heat stress effects of climate change on the health of the Iranian population based on various climate change scenarios. Their results suggest that the heat index in Iran will rise beyond the risk threshold of human acclimatization in the future [1]. The effect of climate change on the future heat index risk in Iran is considerable. In order to combat this, it is essential to institute early warning systems, healthcare strategies for population growth and socio-economic countermeasures for the future. According to the findings of the present study, throughout the summer, 45% of the measured WBGT index were in the medium range (18-23°C) from the point of view health risk of exposure, 37.5% were in the high range (23-28°C), and 17.5% were in the very high range (> 28°C). In other words, of all the measured WBGT that fell in the high and very high category, 47.5% were in June, 67.5% were in July, and 50% were in August. This must be taken into account from a health preservation perspective.

Heidari et al. investigated the heat stress of outdoor work environments in Iran. The results of this study showed that heat stress, especially in the central and southern regions of Iran, can increase and intensify in the coming decades. Therefore, it is necessary to apply the necessary policies and programs[33]. The study by Roshan et al. also confirmed this issue of climate change in Iran and rising temperature using the Markov chain model [34].

Awareness of climatic conditions is a good guide for many human activities. Mohammadi et al. prepared a bioclimatic map of Iran using the predicted mean vote (PMV) index using data from 193 synoptic stations [35]. The results showed that the bioclimatic conditions in time and space in Iran are very diverse. So that a place in Iran can have both very cold and hot conditions during a year. Of course, such a contradiction can also be seen in Iran at a certain time. However, in each month of the year, one of the climatic conditions in Iran has become more prevalent. In November and April, for example, a wide range of Iranians experienced climatic comfortable conditions[35].

Climate change is a global challenge and its effects are different at a local level and are dependent on the specific characteristics of each region [36]. In many parts of the world, higher mean temperatures have become a norm in recent decades. The rate of temperature increase was greater for inland surfaces compared to oceans surfaces in both hemispheres [37]. The maximum of earth's surface temperature from 1850 has been seen in the past three decades. In the northern hemisphere, the 30-year period from 1983 to 2012 has been the warmest three decades in the past 1400 years. The linear trend of mean data from earth's surface and the surface of oceans show an increase in temperature between 0.85°C to 2°C from 1880 to 2012 [38]. Climate change has also increased the size and intensity of climatological events, such as drought, heat waves, monsoons, floods, and wildfires in various parts of the world [36].

Although Iran has a varied climate, the positive slope of temperature, the rise in mean temperature seen in most meteoroidal stations, along with considerable changes in maximum temperature in all areas of Iran indicate that Iran is now witnessing the effects of climate change and global warming [39]. Reducing the negative consequences of future heatwaves relies on our understanding of the mechanisms involved, the weather systems that cause them, finding ways to reduce their destructive effects on public health, and identifying at risk areas [8]. A clear example is the 2003 heatwave in France which occurred in one of the warmest summers of the past 250 years [40].

The secretion and evaporation of sweat during prolonged physical activity in warm environments lead to dehydration. Dehydration and heat exhaustion increase the concentration of hemoglobin and raise hematocrit percentage which can in turn increase cardiovascular risk and even lead to sudden death [41]. Patz et al. conducted a study in 2016 regarding the effects of climate change on human health and concluded that climate change is one of the biggest environmental and economic challenges related to health equality in the present age. More importantly, wealthy nations are the biggest consumers of energy obtained from fossil fuels and are most responsible for global warming, while poor and undeveloped nations face the biggest threat of global warming [42]. Hayes et al. also noted the psychological effects of climate change on human health [43].

The climatic conditions prevailing in Iran during different months of the year indicate its great diversity. Although recognizing the causes of diversity of climatic conditions is not in line with the objectives of this study, the vastness of Iran can be one of the reasons for the diversity of climatic conditions. In addition, the shape of the roughness, their distribution, and the location of Iran in the path of different air masses during the year, has helped to intensify the diversity of Iran's climatic conditions.

The highest WBGT index according to the climate classification was observed in the semi-arid region in August (29.6˚C ± 1.8), the arid region in July (37.1˚C ± 1.4), the humid region in August (30.11˚C ± 1.92), the very-humid region in August (29.36˚C ± 2.13), and the Mediterranean region in July (21.95˚C ± 1.6). Based on the charts presented, overall, the WBGT index had an upward trend throughout the summer in the semi-arid regions of Iran (40% of the country) and was somewhat unchanged or had a downward trend in other regions. Given the specific geographic location of Iran, large parts of the country lie within the fluctuating high pressure sub-tropical belt (23° to 40° north).

Rahimi et al. investigated climate change in Iran using De Martonne climate classification by examining the monthly average minimum and maximum temperature and rainfall from 181 synoptic meteorological stations (in the years 1970-2005) [44]. The climate change scenarios were simulated through the relevant software. The results of this study showed that global climate change will have a profound impact on the climate and severe land distribution in Iran in the future. It was stated that hot and dry areas will be highly susceptible to change [44], which is in line with the results of the current study.

The high pressure sub-tropical system of Saudi Arabia follows the apparent movement of the sun towards northern and southern latitudes into the Persian Gulf and sometimes into the south west of Iran during the warm periods of the year. This system is dominant in Iran at this time of the year and its persistence contributes to warm, dry summers and removes unstable processes in the region [45].

The mountainous elevations in Iran are so high that they prevent the humid winds of the Caspian Sea, the Mediterranean Sea, and the Persian Gulf from reaching the central regions of Iran. As a result, the outer sides of these mountains have a humid climate, while the inner sides have an arid climate. The southern coast of the Caspian has a temperate climate and the amount of rainfall is higher in the western coasts of the province of Gilan compared to other areas. The mean annual temperature in these areas is around 18˚C. The climate of the west of the country is Mediterranean and the warm and semi-arid climate of the south of the country affects this region. During the summer, the valleys within these areas are very warm, while the higher elevations enjoy a more temperate summer. In winter, the valleys are temperate, while the higher elevations are very cold. Although the southern regions of Iran are humid, the temperature can be high, sometimes reaching 54˚C in Khouzestan. These regions have warm summers and temperate winters without excessive daytime and nighttime temperature differences throughout the seasons. The Alborz Mountains in the north of the country and the Zagros Mountains in the west isolate the central basin of Iran, creating a dry and arid climate. Based on the above, three types of climates can generally be seen in Iran which includes arid or semi-arid climates, temperate mountainous climates, and temperate Caspian climates [8].

The World Health Organization (WHO) has stated that although the warming of the planet is gradual, the frequency and intensity of climatological events, such as extreme storms, heatwaves, droughts, and floods can be sudden and can have dire effects on human health. The population of the South East Asia (SEA) region is disproportionately susceptible to the effects of climate change. The 61st session of the World Health Assembly has requested that the WHO and member states enact immediate measures in this regard and as a result, the SEA countries have devised a regional action plan for the protection of human health from the effects of climate change with the aim of increasing the capacity and strength of their health infrastructure [46]. In 2017, the American Public Health Association (APHA) stated that climate change is one of the most important threats to human kind and it is time to take actions regarding climate change and human health. The APHA has devised a strategic preventive approach to overcome the effects of climate change and prioritize the risks involved [47]. Increasing awareness regarding the effects of climate change, planning for social risk management, localization of infrastructures and systems, using compatible strategies of mitigation, and reducing negative effects of climate change have become necessary and unavoidable topics.

Conclusion

The present study analyzed the trend and zoning of the WBGT index applied as a heat stress index in the diverse climate of Iran using meteoroidal data obtained during a 30-year period for the summer season. Due to its specific geographic location of Iran, it is extremely susceptible to climate change and a large portion of the country is already inside the desertification belt. Based on the

[DOR: 20.1001.1.24766267.2021.6.4.6.4]

[DOI: 10.18502/jehsd.v6i4.8153]

results obtained, the WBGT trend, as a heat stress assessment index, during the summer had an upward trend, especially in semi-arid regions. The positive significant slope of rising temperatures in most meteorological stations along with the fact that half of all measured stations had a high or very high health risk of exposure during the summer can be an alarming issue.

Acknowledgement

The authors gratefully acknowledge the assistance provided by the Iran Meteorological Organization.

Funding

There is no funding source to report.

Conflict of interest

The authors declare that there is no conflict of interest.

References

1. Modarres R, Ghadami M, Naderi S, et al. Future heat stress arising from climate change on Iran's population health. Int J Biometeorol. 2018;62(7):1275-81.
2. Nassiri P, Monazzam MR, Golbabaei F, et al. Applicability of modified discomfort index (MDI) in Outdoor occupational environments: a case study of an open pit mines in Tehran Province. Iran Occupational Health. 2018;15(1):136-45. [In Persian]
3. Beniston M, Diaz HF. The 2003 heat wave as an example of summers in a greenhouse climate? Observations and climate model simulations for Basel, Switzerland. Glob Planet Change. 2004;44(1-4):73-81.
4. Ding T, Qian W, Yan Z. Changes in hot days and heat waves in China during 1961–2007. Int J Climatol. 2010;30(10):1452-62.
5. Guzmán A, Pinto-Gutiérrez C, Trujillo MA. Attention to global warming and the success of environmental initial coin offerings: Empirical Evidence. Sustainability. 2020;12(23):9885.
6. Esmaeili HR, Parak. F. The variability of climate compound extreme indices and thermal waves in the watershed area of the country. J Atmos Sci. 2018;1(2):97-113.
7. Nassiri P, Reza Monazzam M, Golbabaei F, et al. Exposure to heat stress in the workplace: A systematic review. Iran Occupational Health. 2018;15(2):118-28. [In Persian]
8. Kovats RS, Hajat S. Heat stress and public health: a critical review. Annu Rev Public Health. 2008;29:41-55.
9. Konkel L. Feeling the Heat: The health effects of hot days vary across the globe. Environ Health Perspect. 2017;125(10):104003.
10. Cheng J, Xu Z, Bambrick H, et al. Heatwave and elderly mortality: an evaluation of death burden and health costs considering short-term mortality displacement. Environment International. 2018;115: 334-42.
11. Hübler M, Klepper G, Peterson S. Costs of climate change: the effects of rising temperatures on health and productivity in Germany. Ecol Econ. 2008;68(1-2):381-93.
12. Epstein Y, Moran DS. Thermal comfort and the heat stress indices. Industrial Health. 2006;44(3):388-98.
13. Nassiri P, Monazzam MR, Golbabaei F, et al. Application of universal thermal climate index (UTCI) for assessment of occupational heat stress in open-pit mines. Industrial Health. 2017;55(5):437-43.
14. Vangelova K, Deyanov C, Ivanova MJ. Dyslipidemia in industrial workers in hot environments. Cent Eur J Public Health. 2006;14(1):15.
15. Tawatsupa B, Lim LY, Kjellstrom T, et al. The association between overall health, psychological distress, and occupational heat stress among a large national cohort of 40,913 Thai workers. Glob Health Action. 2010;3(1):5034.
16. Luo H, Turner LR, Hurst C, et al. Exposure to ambient heat and urolithiasis among outdoor workers in Guangzhou, China. Sci Total Environ. 2014;472:1130-6.

17. Jafari MJ, Pirposhteh EA, Dehghan SF, et al. Relationship between heat stress exposure and some immunological parameters among foundry workers. Int J Biometeorol. 2010;3(1):1-9.
18. Hajizadeh R, Farhang DS, Mehri A, et al. Heat stress assessment in outdoor workplaces of a hot arid climate based on meteorological data: A case study in Qom, Iran. Journal Mil Med. 2015;17(2):89-95.
19. Teimori G, Monazzam MR, Nassiri P, et al. Applicability of the model presented by Australian Bureau of Meteorology to determine WBGT in outdoor workplaces: A case study. Urban Clim. 2020;32:100609.
20. De Martonne E. Une nouvelle fonction climatologique: L'indice d'aridité. Impr. Gauthier-Villars, 1926:449-58.
21. Organization IM. Iran Weather. Available from: https://irimo.ir/eng/index.php. [Cited 13 September 2015].
22. Australian Bureau of Meteorology About the WBGT and Apparent Temperature Indices. Bureau of Meteorology, Commonwealth of Australia, Melbourne. Available from: http://wwwbomgovau/info/thermal_stress/.[Cited 16 September 2018].
23. Ghalhari G, Dastjerdi J, Nokhandan M. Using mann kendal and t-test methods in identifying trends of climatic elements: A case study of northern parts of Iran. Environ Res Lett. 2012;2(3):911-20.
24. Fathian F, Dehghan Z, Bazrkar MH, et al. Trends in hydrological and climatic variables affected by four variations of the Mann-Kendall approach in Urmia Lake basin, Iran. Hydrol Sci J. 2016;61(5):892-904.
25. Sen PK. Estimates of the regression coefficient based on Kendall's tau. Journal of the American Statistical Association. 1968;63(324):1379-89.
26. Theil H. A rank-invariant method of linear and polynomial regression analysis. Henri Theil's contributions to economics and econometrics: Springer; 1992pp. 345-81.
27. Ghalhari GF, Dehghan SF, Shakeri F, et al. Assessing the monthly changes of heat stress indices in outdoor environment during a 15-year period: Case of study in a dry and warm climate. Urban Clim. 2020;31:100538.
28. Maeda T, Kaneko Sy, Ohta M, et al. Risk factors for heatstroke among Japanese forestry workers. Iran Occupational Health. 2006;48(4):223-9. [In Persian]
29. Masoudian A. Study of Iranian temperatures in the recent half-century. Geographical Study. 2005;54:29-45. [In Persian]
30. Leconte F, Bouyer J, Claverie R, et al. Using local climate zone scheme for UHI assessment: Evaluation of the method using mobile measurements. Build Environ. 2015;83:39-49.
31. Babaee o, Alijani B. Spatial analysis of long duration droughts in Iran. Phys Geog Res. 2013;45(3):1-12.
32. Amiri M, Eslamian S. Investigation of climate change in Iran. J Environ Sci Technol. 2010;3(4):208-16.
33. Heidari H, Golbabaei F, Shamsipour A, et al. Outdoor occupational environments and heat stress in Iran. J Environ Health Sci Eng. 2015;13(1):1-8.
34. Roshan G, Nastos PT. Assessment of extreme heat stress probabilities in Iran's urban settlements, using first order Markov chain model. Sustain Cities Soc. 2018;36:302-10.
35. Mohammadi B, Mohammadkhani P, Gholizadeh MH. Preparing Iran's bioclimatic map by using the predicted mean vote index. Geographical Researches. 2017;32(2):21-39.
36. Leonard M, Westra S, Phatak A, et al. A compound event framework for understanding extreme impacts. Wiley Interdiscip Rev Clim Change. 2014;5(1):113-28.
37. Solomon S, Manning M, Marquis M, et al. Climate change 2007-the physical science basis: Working group I contribution to the fourth assessment report of the IPCC: Cambridge university press; 2007.
38. Stocker TF, Qin D, Plattner GK, et al. Climate change 2013: The physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. 2013;1535.
39. Kotlyakov VMK, A Elsevier's Dictionary of

Geography. Elsevier. 2007.
40. Schär C, Vidale PL, Lüthi D, et al. The role of increasing temperature variability in European summer heatwaves. Nature. 2004;427(6972): 332-6.
41. Akhlaghi Pirposhte E, Jafari MJ, Farhang Dehghan S, et al. Investigating the relationship between heat stress and workers' blood parameters in a foundry. Journal of Military Medicine. 2019;21(6):618-27.
42. Frumkin H. Environmental health: from global to local: John Wiley & Sons; 2016.
43. Hayes K, Blashki G, Wiseman J, et al. Climate change and mental health: Risks, impacts and priority actions. Int J Ment Health Syst. 2018;12(1):28.
44. Rahimi J, Ebrahimpour M, Khalili A. Spatial changes of extended De Martonne climatic zones affected by climate change in Iran. Theor Appl Climatol. 2013;112(3):409-18.
45. Lashkari H, Mohamadi Z. The role of saudi arabian sub-tropical high pressure on the rainfall systems on South and Southwest Iran. Physical Geography Research. 2015;47(1):73-90. [In Persian]
46. World Health Organization. Climate change and health. New Delhi : WHO Regional Office for South-East Asia. 2008.
47. DeJarnett N, Robb K, Castellanos I, et al. The American Public Health Association's 2017 Year of Climate Change and Health: Time for Action. American Public Health Association; 2018.