Environmental Health Engineering and Management Journal 2022, 9(2), 165-176
http://ehemj.com
doi 10.34172/EHEM.2022.18
Environmental Health Engineering and Management Journal
Original Article
Open Access Publish Free

Trend analysis of Humidex as a heat discomfort index using Mann-Kendall and Sen's slope estimator statistical tests

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Abstract
Background: The aim of this research was to assess the Humidex (HD) trends as a thermal discomfort index by analyzing meteorological data during a 30-year period of summertime in Iran.
Methods: For this purpose, data regarding average temperature and relative humidity were collected daily from 40 different synoptic meteorological stations during a 30-year statistical period (1985-2014). The HD index was calculated based on temperature and relative humidity according to an equation introduced by Masterton and Richardson. The Mann-Kendall and Sen's slope tests were performed to analyze the changing trend of the HD.
Results: Based on the findings, in 72% of the meteorological stations, the HD followed an upward trend, so that 40% of them was statistically significant. The changing trends in temperature during summertime throughout the studied years fluctuated greatly but generally, in many regions such as the arid, semi-arid, and humid regions, this trend was mostly incremental. Also, the changing trends in relative humidity in all regions was decremental throughout the years under study.
Conclusion: The changing trend of the HD, which is based on temperature and humidity, was incremental in arid and semi-arid regions and decremental in the Mediterranean and humid regions.
Keywords: Humidity, Temperature, Meteorology, Data analysis, Iran
Citation: Fallah Ghalhari G, Farhang Dehghan S, Asghari M. Trend analysis of humidex as a heat discomfort index using mann-kendall and sen's slope estimator statistical tests. Environmental Health Engineering and Management Journal 2022; 9(2): 165-176. doi: 10.34172/EHEM.2022.18.

Article History:
Received: 18 September 2021
Accepted: 17 November 2021
ePublished: 7 May 2022

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Introduction

The diverse climate found in Iran include hyper-arid (35.5%), arid (29.2%), semi-arid (20.1%), Mediterranean (5%), and humid (10%) regions. Almost 82% of Iran's territory is located in arid and semi-arid zones. These regions, which are mostly located near the center and southern parts of the country, experience very hot summers (1, 2).

The diversity of climate in Iran has created various heating and cooling patterns that have a significant relationship with the physical and mental health and wellbeing of the people living there. Climate analysis is important for many reasons. Therefore, climate analysis can be a significant issue from a medical point of view as a cause of diseases, from an economic point of view as a pattern of energy consumption, and from an urban point of view for development planning and tourism (3, 4).

Urban development and expansion have caused changes in both climatic and atmospheric conditions in recent years (5). These changes have affected the stability of the natural environment and the health of people especially those who live in urban areas (6). The importance of the effects of climate on human health has caused the World Health Organization (WHO) to place the protection of human health against climate change at the top of its priorities (7, 8).

Heatwaves have had adverse health effects throughout the world in recent decades (9). The Athens heatwave in 1987 had 2000 fatalities, the Chicago heatwave had 700 fatalities, the European heatwave in 2003 had at least 7000 deaths, and Russia in 2010 had 55 000 deaths due to heatwaves. On average, 400 deaths are reported annually in the United States as being directly caused by heat, especially among people over the age of 65 (10).

Extreme heat exposure may lead to heat rash, heat syncope, muscle cramps, heat exhaustion, and heat shock (11,12). It may also cause shortness of breath and tachycardia. Heat exposure contributes to anger and aggressive behavior which increase heart rate and, in conjunction with tightness of the coronary artery, can increase the risk of heart attacks (13,14). The rise in deaths during heatwaves is mostly attributed to cardiovascular

(13%-90%) and cerebrovascular disorders (6%-52%) especially among older individuals (15, 16).

Temperature, humidity, wind, and sunlight are the four main factors that play a role in human climate comfort. Of these four factors, temperature and humidity have a greater effect on human health and comfort, therefore, these two factors are the basis for most human comfort evaluation models (17). Researchers have used various indices and models to evaluate human comfort (18, 19). Most evaluations have tried to use meteorological statistics such as temperature, humidity, wind, sunlight or a combination of them to determine levels of comfort (20, 21). Thermal comfort indices present meteorological data in a manner that reflects people's reaction to weather conditions while scaling them from very comfortable to very uncomfortable (22). These indices simplify the interpretation of the complicated effects of atmospheric elements on human comfort and enable the comparison of different regions in terms of climate comfort (23).

The temperature-humidity index or Humidex (HD), is a heat stress index introduced by Masterton and Richardson in 1979 that reflects the relationship between thermal comfort conditions and two important meteorological parameters namely air temperature and relative humidity (24). HD was first used for meteorological predictions but because of its simplicity, ease of use, and the fact that no complicated measurement devices are needed, its application in the evaluation of heat stress in indoor and outdoor thermal environments was considered (25). In fact, this index expresses the collective perception of people regarding the combined effects of warm and humid climates (26). The formula presented for HD is based on two principles regarding the thermoregulation of the human body. The first principle, based on the equilibrium equation of the human body, states that the thermal equilibrium of the human body when exposed to heat is in the range of 27 to 30°C (if naked and presiding in static air). The second principle states that at humidity higher than 75%, the human body is incapable of enduring temperatures exceeding 32°C (27). Based on the above-mentioned issue, it can be stated that HD, a commonly used experimental index based on temperature and relative humidity, does not take into consideration many other factors influencing heat stress such as clothing resistance, rate of metabolism, and air velocity (28).

The validity of HD was assessed by Heidari et al (25). They found a strong correlation between the HD and Wet-Bulb Globe Temperature (WBGT) indices in both arid and semi-arid regions and a moderate correlation between HD and tympanic temperature. Based on the obtained Kappa coefficient, the HD and WBGT indices had an agreement level of 0.878 while the HD and tympanic temperature indices had a coefficient of 0.226. Heidari et al reported that HD can be a suitable alternative to WBGT, provided that low or extremely high temperatures are being evaluated, in which HD will suffice and can provide a realistic evaluation of heat strain on the human body (25).

Santee and Wallace attempted to validate HD by comparing rectal temperatures predicted by the thermal equilibrium equation and HD and reported a strong relationship between rectal temperatures and HD (29). By assessing heat-related deaths in Italy in 2004, Conti et al concluded that there was a correlation between high HD values and heat-related deaths (30).

The present study aimed to assess changing HD trends as a thermal discomfort index by analyzing 30-years meteorological data during summertime in Iran. Climate zoning analysis has also been conducted regarding this index.

Materials and Methods

In order to analyze the changes in HD in Iran, data regarding average temperature and relative humidity collected daily from 40 different synoptic meteorological stations during a 30-year statistical period (1985-2014) were obtained from Iran Meteorological Organization. These stations had the most complementary statistical period among all other stations and the goal was to use stations which had statistical gap equal to or less than 5% during the designated period. The geographic features of these stations include latitude, longitude, and sea elevation. As can be seen, the study data do not cover recent years, since according to Iran Meteorological Organization, they were not processed for most stations and contained the statistical gaps in 40 different synoptic meteorological stations.

Climate classification

The De Martonne climate classification system was used in this study to classify the climate regions of Iran. This classification is based on the aridity index and uses temperature and precipitation to determine the type of climate. In order to determine the type of climate in a particular region, the following equation is used:

$$I = \frac{P}{T + 10} \qquad \text{(Eq. 1)}$$

Where, I is the aridity index, P is the average precipitation in millimeters (mm), and T is the average annual temperature in Celsius (°C).

De Martonne defines six types of climate in his classification which include arid (aridity index below 10), semi-arid (aridity index of 10 to 19.9), Mediterranean (aridity index of 20 to 23.9), semi-humid (aridity index of 24 to 27.9), humid (aridity index of 28 to 34.9), and very humid (aridity index of 35 or higher) (31). Figure 1 presents the climate classification of Iran according to the classification of De Martonne. Based on this classification, the distribution of the meteorological stations are as follows: 50% in arid regions, 37.5% in semi-arid regions, 10% in humid/very humid regions, and 2.5% in Mediterranean regions.

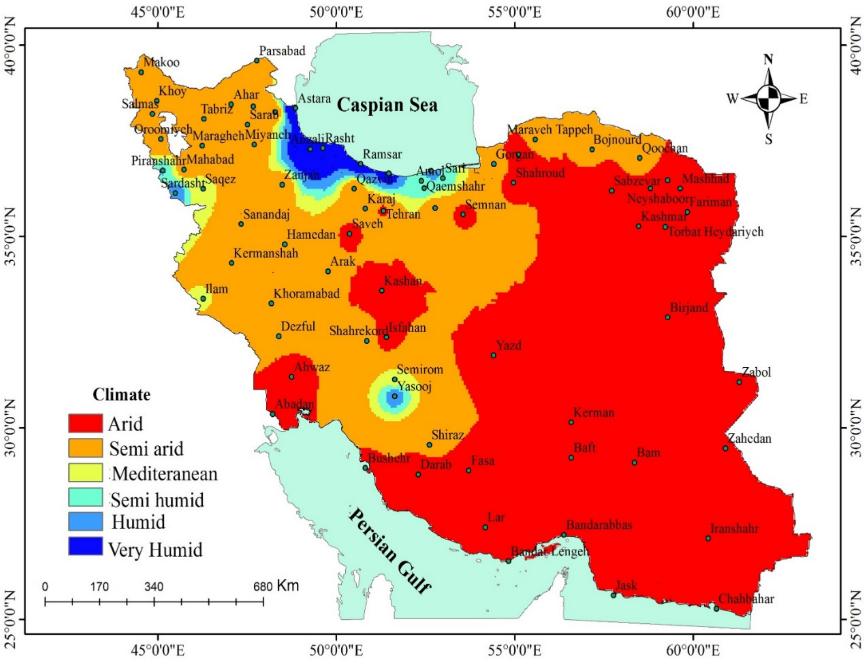

Figure 1. Classification of Iran climate based on the De Martonne index.

Humidex

The HD index was first expanded in Europe and the United States where it was used by meteorological organizations to determine the likelihood of heat stress and thermal comfort conditions in a particular area and was reported to the public (27). The interpretation of the range of this index from a value of 20 to above 54 is expressed in Table 1. HD was calculated using Eqs. 2 and 3 (27):

$$HD = T_a + \left[\frac{5}{9} \times (e - 10) \right] \tag{2}$$

$$e = e_0 \times \left[10^{\frac{7.5 \times T_a}{237.7 + T_a}} \right] \times \frac{RH}{100} \tag{3}$$

Where T_a is the air temperature in °C, e is the water vapor pressure in hpa, RH is the percentage of relative humidity, and e_0=6.112 hpa.

The climate zone maps of the HD index for the summer months of June, July, and August were prepared based on regression relations and the Digital Elevation Model (DEM). Regression analysis enables the prediction of variance in the dependent variable based on independent variables and estimates the causal role of each independent variable in determining the target variable. Different regression equations are available for interpolation which are selected based on the degree of correlation between the target and secondary variables. For this purpose, using linear regressions, HD data and elevation of the meteorological stations were first recalled using Curve Expert version 4.1 and the data were then processed using the best theoretical regression functions.

The Mann-Kendall test

The Mann-Kendall statistical test was performed using the Minitab version 17.10 software to analyze the changing trends of HD, temperature and relative humidity during the period under study. Climatological parameters change for many reasons during timescales and in different regions, and the way in which they change must be determined based on observations and with the use of statistical methods. The Mann-Kendall test is one of the most common and widely used non-parametric statistics overview for time series analysis, which enables the detection of trends in data along with the time and type of changes in data (32). This test only measures the upward or downward trend of a variable of interest in a particular time series and can be used to determine whether the central or median value of a time series has changed over time. The Mann-Kendall test does not require the measurements to be normally distributed. This test has been widely suggested for general purpose applications by meteorological organizations throughout the world (33).

The Mann-Kendall method was first introduced by Mann in 1945, and then, developed further and expanded by Kendall in 1970. The null hypothesis in this method is the random nature of the data series and the lack of any trends while the rejection of the null hypothesis (alternative hypothesis) implicates the existence of a trend in the data series. In this method, the difference between

Table 1. Interpretation of Humidex (HD) in terms of thermal comfort (27)

Humidex range	Thermal discomfort level
29≥ HD ≥20	Comfort
39≥ HD ≥30	Some discomfort
45≥ HD ≥40	Great discomfort, avoid exertion
54> HD ≥46	Dangerous
>54	Heat stroke imminent

each measurement and all subsequent measurements are calculated and the parameter S is obtained from Eq. (4):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(\chi_j - \chi_k) \tag{4}$$

Where n is the number of observations in the series while x_j and x_k represent the j_{th} and k_{th} measurements in the series. The *sgn* function can be calculated based on the following equations:

$$\begin{aligned} &for\ (x_j\text{-}x_k)>0 && \mathrm{sgn}(x_j - x_k) = +1 \\ &for\ (x_j\text{-}x_k)=0 && \mathrm{sgn}(x_j - x_k) = 0 \\ &for\ (x_j\text{-}x_k)<0 && \mathrm{sgn}(x_j - x_k) = -1 \end{aligned} \tag{5}$$

The variance of the S parameter was then calculated based on the following equations:

$$for\ n>10 \quad Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t(t-1)(2t+5)}{18} \tag{6}$$

$$for\ n<10 \quad Var(S) = \frac{n(n-1)(2n+5)}{18} \tag{7}$$

Where n and m represent those sequences with at least one duplicate measurement and t represents the frequency of measurements with the same value in a sequence (number of knots). Finally, the Z statistic can be extracted using one of the following equations:

$$\begin{aligned} &for\ S>0 && z = \frac{S-1}{\sqrt{Var(S)}} \\ &for\ S<0 && z = \frac{S+1}{\sqrt{Var(S)}} \\ &for\ S=0 && z = 0 \end{aligned} \quad \text{(Eq. 8)}$$

For a two-tailed hypothesis test, the null hypothesis is accepted if the following condition is met:

$$|Z| < Z_{\alpha/2} \tag{9}$$

where α is the significance level attributed to the test, Z_α is the statistics of standard normal distribution for the significance level of α that, considering the two-tailed nature of the test, was $\alpha/2$. Confidence levels of 95% and 99% were considered for this study. A positive value obtained for Z was considered as an upward trend while a negative value was considered as a downward trend in the data series (34).

Sen's slope

In order to determine the actual slope of a trend over time, the use of the nonparametric method can be an appropriate choice. Like the Mann-Kendall test, this method is based on analysis of the difference between the observations of a series. If the trend is observed in the data series, the actual slope can be calculated based on the Sense method. For this purpose, the slope of each pair of successive data in the time series is obtained according to Eq. (10).

$$\text{For i=1, 2,….., n} \quad Q_t = \frac{(x_t - x_k)}{t-k}, \quad t>k \tag{10}$$

Where, x_t and x_k are data values in time t and k, respectively, which have a difference in one unit time. The estimated median n is the slope of the Sense curve. If n is odd and/or even, the slope of the Sense curve will be calculated according to Eqs. 11 and 12, respectively.

$$Q_{med} = Q_{(n+2)/2} \tag{11}$$

$$Q_{med} = (Q_{(n)/2} + Q_{(n+2)/2})/2 \tag{12}$$

If Q_{med} is assessed in the two-tailed test with the confidence level of 100 (1-á)%, the trend curve will be obtained. If the respective interval contains the zero value, the null hypothesis of non-trend is accepted, otherwise, the null hypothesis is rejected and the trend is statistically significant with a decreasing/increasing trend (35).

All data analyses were conducted using SPSS version 21 and graphs were made using Microsoft Excel 2013.

Results

Mean and standard deviation for air temperature, relative humidity and the HD index during a 30-year period are presented in Table 2. The geographical location of each meteorological station can be found in Figure 1. During the summertime, 62.5% of stations was in "comfort", 30% in "some discomfort", 5% in "great discomfort", and 2.5% were in the "dangerous" range. The highest average HD value in summertime during this period was obtained in the Bandar Abbas station (47.25 ± 2.6) and the lowest one was obtained in the Ardebil station (20.15 ± 3.48). The highest average temperature was recorded by the Zabol station (33.90 ± 2.47°C) and the lowest one was recorded by the Ardebil station (17.75 ± 2.70°C). The Chabahar station had the highest relative humidity (82.10 ± 5.86%) while the Yazd station had the lowest one (15.20 ± 5.95%). During the summer, the Bandar Abbas station was in the "dangerous" HD range while the Bushehr and Chabahar stations were in the "great discomfort" range. All these three stations are located at the southern band of Iran in the shores of the Persian Gulf and the Oman Sea.

Equation 13 shows the regression relationship between the HD and the stations' latitude and elevation (r=0.933; P=0.001). Using DEM, the climate zone map of summertime HD during the 30-year period was obtained. In fact, using this relationship, it is possible to estimate the changes in HD based on latitude and elevation. Based on the results obtained, with a rise in latitude and elevation, the HD value is reduced.

Humidex=60.345-(0.659 Latitude (km))-(0.008* Elevation (minutes, seconds and degrees))* (13)

Figure 2 shows the climate zoning of Iran based on the HD thermal discomfort index during summertime. On average, during the 30-year period under study, some

Table 2. Mean (± standard deviation) of Humidex during summer in the studied years

Weather station	Climatic classification	Air temperature (°C)	Relative humidity (%)	Humidex	Thermal discomfort level
Ahar	Semi-Arid	21.22±3.00	51.30±12.20	22.73±3.30	Comfort
Ahvaz	Arid	37.40±1.84	23.27±7.80	40.14±3.72	Some discomfort
Anzali	Very Humid	25.46±2.32	78.90±7.30	34.20±3.91	Some discomfort
Arak	Semi-Arid	25.74±3.12	26.40±8.80	25.00±3.64	Comfort
Ardebil	Semi-Arid	17.75±2.70	70.80±12.40	20.15±3.48	Comfort
Babolsar	Humid	26.20±2.10	77.00±5.40	35.23±3.67	Some discomfort
Bam	Arid	33.83±2.39	15.80±5.65	32.92±3.20	Some discomfort
Bandarabbas	Arid	33.75±1.32	66.13±9.80	47.25±2.60	Dangerous
Birjand	Arid	27.00±2.59	20.74±6.20	25.65±30	Comfort
Bushehr	Arid	33.00±1.58	60.2±8.53	44.34±3.77	Great discomfort
Chahbahar	Arid	30.10±1.43	82.10±5.86	43.93±3.10	Great discomfort
Darab	Arid	25.58±2.37	20.00±6.20	23.66±2.78	Comfort
Fasa	Arid	29.20±2.96	24.10±7.30	29.10±3.82	Comfort
Gorgan	Semi-Arid	26.95±2.27	67.50±8.30	34.70±3.59	Some discomfort
Hamedan	Semi-Arid	23.75±2.66	34.24±9.60	23.70±3.00	Comfort
Karaj	Arid	27.36±3.10	34.22±10.7	28.54±3.00	Comfort
Kashan	Arid	32.20±2.50	22.20±6.90	32.50±2.83	Some discomfort
Kermanshah	Semi-Arid	27.65±2.67	21.41±6.43	26.45±2.96	Comfort
Mahabad	Semi-Arid	24.65±2.72	36.00±10.50	25.20±3.00	Comfort
Maku	Semi-Arid	22.40±3.30	44.40±12.00	23.40±3.65	Comfort
Maragheh	Semi-Arid	25.00±3.00	32.60±9.20	25.20±3.36	Comfort
Mashhad	Arid	26.82±2.59	30.60±11.00	27.20±3.23	Comfort
Qazvin	Semi-Arid	25.26±2.66	39.36±9.76	26.60±2.85	Comfort
Qom	Arid	31.28±2.43	22.60±7.00	31.43±2.82	Some discomfort
Rasht	Very Humid	24.87±2.35	78.60±7.37	33.04±3.77	Some discomfort
Sabzevar	Arid	29.80±2.56	23.20±8.00	29.60±3.10	Comfort
Sanandaj	Semi-Arid	26.56±2.90	26.30±6.30	26.05±3.28	Comfort
Saqez	Mediterranean	23.36±3.20	35.2±11.00	23.30±3.55	Comfort
Semnan	Arid	30.7±2.79	25.00±7.80	31.20±3.24	Some discomfort
Shahrekord	Semi-Arid	22.95±2.30	29.20±6.40	21.95±2.77	Comfort
Shahroud	Arid	26.00±2.87	34.23±9.18	26.76±3.23	Comfort
Shiraz	Semi-Arid	28.74±2.87	24.55±6.20	28.579±3.65	Comfort
Tehran	Arid	30.1±2.75	26.53±8.90	30.72±3.11	Some discomfort
Torbat Heydariyeh	Arid	25.74±2.46	26.8±8.70	25.07±2.92	Comfort
Urmia	Semi-Arid	22.7±2.52	47.64±90	24.41±3.19	Comfort
Yasuj	Humid	25.9±2.00	26.1±9.45	25.15±2.81	Comfort
Yazd	Arid	31.80±2.60	15.20±5.95	30.15±2.86	Some discomfort
Zabol	Arid	33.90±2.47	22.90±7.70	35.05±3.34	Some discomfort
Zahedan	Arid	29.00±2.20	16.73±6.10	27.18±2.80	Comfort
Zanjan	Semi-Arid	22.35±2.90	41.70±10.80	22.97±3.32	Comfort

parts of southern Iran fall under the "great discomfort" or "dangerous" range while the rest of the regions are in the "comfort" or "some discomfort" range.

The results of the trend analysis of temperature, relative humidity and HD during the statistical years are presented in Tables 3 to 5, respectively.

Table 3 shows the temperature trend during summertime for the years under study. Based on the results of the analysis, in 95% of the stations, mean temperature followed an upward trend and this trend was statistically significant in 79% of them. Considering Sen's slope, the highest significant increase in temperature was observed in the Zabol station (+0.86°C/decade) while the highest significant decrease in temperature was observed in the

Shahre Kord station (-0.156°C/decade).

Table 4 shows the relative humidity trend during summertime over a 30-year period. In 87.5% of the stations, mean relative humidity followed a downward trend with the trend being statistically significant in 63% of them. According to Sen's slope, the highest significant decrease in mean relative humidity was observed in the Hamedan station (-3.73% per decade) while the highest significant increase was observed in the Bushehr station (+2.11% per decade).

According to Table 5, in 72% of the stations, HD followed an upward trend but this trend was statistically significant in only 40% of these stations. Regarding Sen's slope, the highest significant increase in HD was observed in the Ardebil station (+1.030 per decade) while the highest significant decrease was observed in the Arak station (-0.368 per decade).

Figure 3 shows the temperature trend during the 30-year period under study in the different climate zones of Iran at summertime. As can be seen, there are temperature fluctuations in different climate zones during the summer in the years under study and overall, in arid, semi-arid and humid regions, this trend is somewhat incremental while in the Mediterranean regions, this trend is decremental.

The relative humidity trend during the 30-year period under study in the different climate zones of Iran at summertime is presented in Figure 4. There are fluctuations in relative humidity in different climate zones during the summer in the years under study and overall, in all regions, this trend is decremental.

Figure 5 shows the HD trend during the 30-year period in the different climate zones of Iran at summertime. There are fluctuations in HD in different climate zones during the summer in the years under study and overall, in arid, semi-arid, and humid regions, this trend is somewhat incremental while in humid and Mediterranean regions, this trend is decremental.

Discussion

The present study analyzed the trends and climate zoning of HD as a thermal discomfort index using summertime meteorological data (temperature and relative humidity)

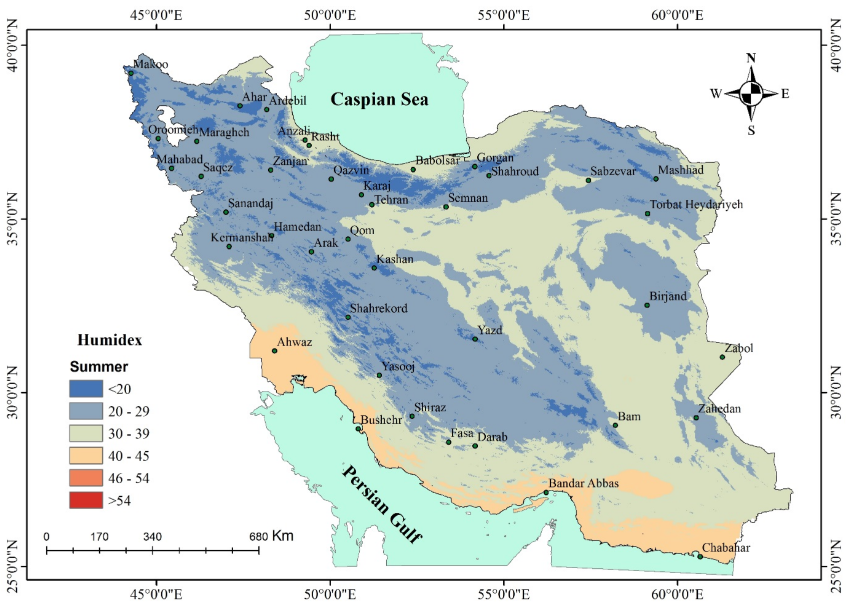

Figure 2. Climate zoning of Iran based on the Humidex during summertime.

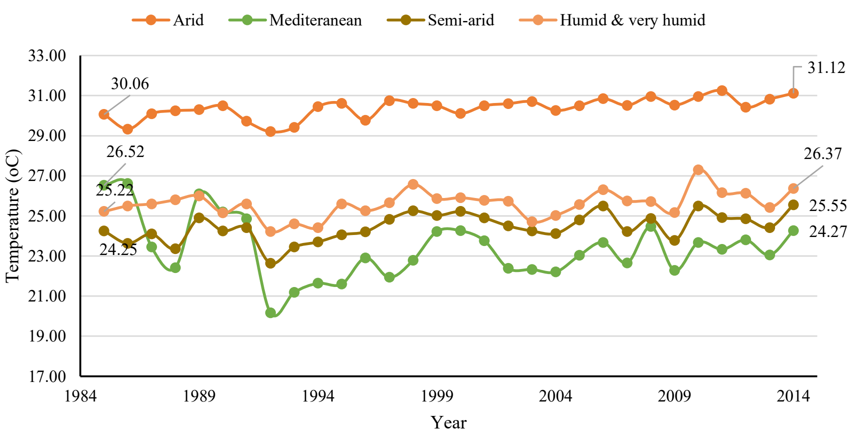

Figure 3. Trend graph of the mean air temperature for different climate zones during summer in the studied years.

Table 3. The trend analysis results for air temperature (°C) during summer in the studied years

Weather station	Z*	*P* value	Trend**	Sen's slope***
Ahar	0.963	0.167	Upward	0.252
Ahvaz	3.514	0.001	Upward	0.675
Anzali	3.140	0.001	Upward	0.495
Arak	0.249	0.401	Upward	0.052
Ardebil	3.675	0.001	Upward	0.737
Babolsar	2.622	0.001	Upward	0.368
Bam	2.961	0.001	Upward	0.487
Bandarabbas	2.462	0.001	Upward	0.3
Birjand	2.783	0.001	Upward	0.443
Bushehr	1.355	0.0871	Upward	0.144
Chahbahar	1.034	0.1501	Upward	0.144
Darab	0.981	0.1631	Upward	0.177
Fasa	2.961	0.001	Upward	0.348
Gorgan	3.389	0.001	Upward	0.5
Hamedan	3.853	0.001	Upward	0.577
Karaj	0.392	0.347	Upward	0.14
Kashan	1.106	0.134	Upward	0.151
Kermanshah	3.461	0.001	Upward	0.716
Mahabad	3.282	0.001	Upward	0.65
Maku	1.498	0.066	Upward	0.306
Maragheh	3.996	0.001	Upward	0.813
Mashhad	3.996	0.001	Upward	0.733
Qazvin	2.176	0.014	Upward	0.322
Qom	3.015	0.001	Upward	0.52
Rasht	1.784	0.037	Upward	0.305
Sabzevar	2.105	0.0171	Upward	0.33
Sanandaj	1.445	0.074	Upward	0.23
Saqez	-0.160	0.436	Downward	-0.083
Semnan	3.140	0.001	Upward	0.48
Shahrekord	-1.177	0.119	Downward	-0.156
Shahroud	2.265	0.011	Upward	0.329
Shiraz	1.784	0.037	Upward	0.237
Tehran	2.319	0.010	Upward	0.348
Torbat Heydariyeh	2.979	0.001	Upward	0.366
Urmia	2.644	0.001	Upward	0.523
Yasuj	1.264	0.102	Upward	1.05
Yazd	3.568	0.001	Upward	0.6
Zabol	3.318	0.001	Upward	0.86
Zahedan	3.068	0.001	Upward	0.49
Zanjan	2.533	0.001	Upward	0.43

*Zα is the statistics of standard normal distribution for the significance level of α. If the *P* value is less than 0.01 or 0.05, the trend is significant at the 1% and 5% levels, respectively.
**A positive and negative value of Z was considered as an upward and downward trend, respectively.
***The values in this column show the slope of the trend line in degrees Celsius per decade. If the trend is significant at the desired confidence level, the slope of the trend line will also be significant at the desired confidence level.

Table 4. The trend analysis results for relative humidity (%) during summer in the studied years

Weather Station	Z*	*P* value	Trend**	Sen's slope***
Ahar	-1.712	0.043	Downward	-2.00
Ahvaz	-0.820	0.205	Downward	-0.58
Anzali	-3.496	0.001	Downward	-2.65
Arak	-2.497	0.001	Downward	-2.37
Ardebil	-0.963	0.167	Downward	-1.32
Babolsar	-3.568	0.001	Downward	-1.38
Bam	-3.247	0.001	Downward	-1.4
Bandarabbas	-0.999	0.158	Downward	-.773
Birjand	-0.178	0.429	Downward	-0.2
Bushehr	2.711	0.003	Upward	2.11
Chahbahar	-1.427	0.076	Downward	-1.00
Darab	-2.551	0.001	Downward	-1.16
Fasa	-0.142	0.443	Downward	-0.094
Gorgan	-2.462	0.001	Downward	-1.65
Hamedan	-2.818	0.001	Downward	-3.73
Karaj	-0.892	0.186	Downward	-0.753
Kashan	-0.285	0.387	Downward	-0.144
Kermanshah	-3.425	0.001	Downward	-2.22
Mahabad	-2.604	0.001	Downward	-3.05
Maku	-0.820	0.205	Downward	-1.35
Maragheh	-1.926	0.027	Downward	-1.74
Mashhad	-3.603	0.001	Downward	-5.2
Qazvin	0.7136	0.237	Upward	0.57
Qom	-1.855	0.0317	Downward	-1.00
Rasht	-1.677	0.046	Downward	-1.00
Sabzevar	-3.032	0.001	Downward	-2.60
Sanandaj	-1.748	0.0401	Downward	-1.00
Saqez	-0.820	0.205	Downward	-1.23
Semnan	-2.569	0.001	Downward	-1.52
Shahrekord	-0.802	0.211	Downward	-0.63
Shahroud	0.178	0.4292	Upward	0.17
Shiraz	-2.140	.0161	Downward	-1.42
Tehran	-1.712	0.0433	Downward	-1.67
Torbat Heydariyeh	-1.195	0.115	Downward	-1.40
Urmia	-1.891	0.0293	Downward	-1.40
Yasuj	1.264	0.102	Upward	1.05
Yazd	-5.780	0.001	Downward	-2.70
Zabol	-3.782	0.001	Downward	-5.70
Zahedan	-3.710	0.001	Downward	-2.33
Zanjan	1.570	0.0582063	Upward	1.35

*Zα is the statistics of standard normal distribution for the significance level of α. If the *P* value is less than 0.01 or 0.05, the trend is significant at the 1% and 5% levels, respectively.
**A positive and negative value of Z was considered as an upward and downward trend, respectively.
***The values in this column show the slope of the trend line in degrees Celsius per decade. If the trend is significant at the desired confidence level, the slope of the trend line will also be significant at the desired confidence level.

Table 5. The Mann-Kendall trend analysis results for the Humidex during the period under study

Weather station	Z*	P value	Trend**	Sen's slope***
Ahar	0.321	0.374	Upward	0.102
Ahvaz	2.819	0.001	Upward	0.848
Anzali	1.499	0.067	Upward	0.415
Arak	-1.427	0.077	Downward	-0.368
Ardebil	3.711	0.001	Upward	1.030
Babolsar	1.677	0.047	Upward	0.482
Bam	0.892	0.186	Upward	0.278
Bandarabbas	1.178	0.119	Upward	0.237
Birjand	2.569	0.001	Upward	0.560
Bushehr	2.034	0.021	Upward	0.621
Chahbahar	-0.214	0.415	Downward	-0.052
Darab	-0.375	0.354	Downward	-0.082
Fasa	2.212	0.013	Upward	0.353
Gorgan	2.569	0.001	Upward	0.630
Hamedan	1.106	0.134	Upward	0.224
Karaj	-0.250	0.401	Downward	-0.091
Kashan	0.250	0.401	Upward	0.080
Kermanshah	1.671	0.047	Upward	0.355
Mahabad	2.712	0.001	Upward	0.476
Maku	1.392	0.082	Upward	0.379
Maragheh	4.103	0.001	Upward	0.820
Mashhad	-0.107	0.457	Downward	-0.043
Qazvin	3.533	0.001	Upward	0.608
Qom	2.676	0.001	Upward	0.530
Rasht	1.392	0.082	Upward	0.303
Sabzevar	-1.213	0.113	Downward	-0.241
Sanandaj	1.320	0.093	Upward	0.266
Saqez	-0.714	0.238	Downward	-0.207
Semnan	1.249	0.106	Upward	0.197
Shahrekord	-1.178	0.119	Downward	-0.185
Shahroud	3.283	0.001	Upward	0.603
Shiraz	0.036	0.486	Upward	0.009
Tehran	-0.178	0.429	Downward	-0.053
Torbat Heydariyeh	1.231	0.109	Upward	0.240
Urmia	2.355	0.001	Upward	0.472
Yasuj	0.198	0.422	Upward	0.020
Yazd	-0.285	0.388	Downward	-0.100
Zabol	-1.963	0.025	Downward	-0.625
Zahedan	0.143	0.443	Upward	0.026
Zanjan	4.103	0.001	Upward	0.888

*Zα is the statistics of standard normal distribution for the significance level of α. If the P-value is less than 0.01 or 0.05, the trend is significant at the 1% and 5% levels, respectively.

**A positive and negative value of Z was considered as an upward and downward trend, respectively.

***The values in this column show the slope of the trend line in degrees Celsius per decade. If the trend is significant at the desired confidence level, the slope of the trend line will also be significant at the desired confidence level.

during a 30-year period in Iran with a highly diverse climate.

Based on the findings (Table 2), parts of the southern band of Iran (Persian Gulf coast and the Oman Sea) fall within the "great Discomfort" and the "dangerous" category of HD. The southern regions of Iran, due to their low latitude and proximity to the southern coast, experience high temperature and humidity in warm months of the year, and thus, have a higher HD score compared to higher latitude regions and the ones further away from the coast. These conditions, combined with the dominance of sub-tropical high pressure (STHP), which begin earlier in these regions and subside later than other regions of the country, prevent the rise of heat and humidity that is overtly saturated in warmer months of the year, causing severe heat stress. These regions are also less effected by western winds and the respective systems that arise from them (36).

The north wind is caused by the establishment of a low-pressure center (which has a Counterclockwise rotation in the Northern Hemisphere) on the Persian Gulf. The north wind blows from the Zagros Heights towards the plain of Khuzestan and brings cool air with it. The wind from Saudi Arabia brings dry air to Iran. After crossing the Persian Gulf, the wind becomes warm and humid and creates a sultry state which is hard to bear (37).

In summer, the STHP belt at 30° latitude surrounds the entire world. Within this system, dynamic air subsidence from higher atmospheric altitudes in subtropical high pressures create clear skies while the sunlight enhances surface heat. As a result, the air near the surface is rapidly warmed, slightly elevated, and flows several hundred meters above the ground. The decrease in surface pressure growth creates a shallow thermal low. For example, thermal low over India, also called the Monsoon thermal low, develops along with the warming of Asia. By strengthening this thermal low, warm and humid air is drawn from the ocean, resulting in a humid summer that is the characteristic of India and Southeast Asia. This strengthens the Monson's thermal low position on the ground-level pressure map in July (38, 39).

The temperature trends in Iran from 1960 to 2010 were studied by Rahimzadeh and Nassaji Zavareh and it was found that temperature has followed a predominantly incremental trend in the coastal stations of the Persian Gulf (40).

In the North of Iran, the Caspian Sea also acts as a high-pressure center (which has a clockwise rotation in the Northern Hemisphere) in the summer, distributing humid air to the prevailing winds, and thus, results in the formation of Northeast winds at Bandar Anzali, North winds in Ramsar, Northwest winds in Babolsar, and Western winds in Gorgan and Bojnourd (41).

The results of the HD regression analysis in the meteorological stations under study (Table 3) indicate that during the summer, the highest HD values are observed

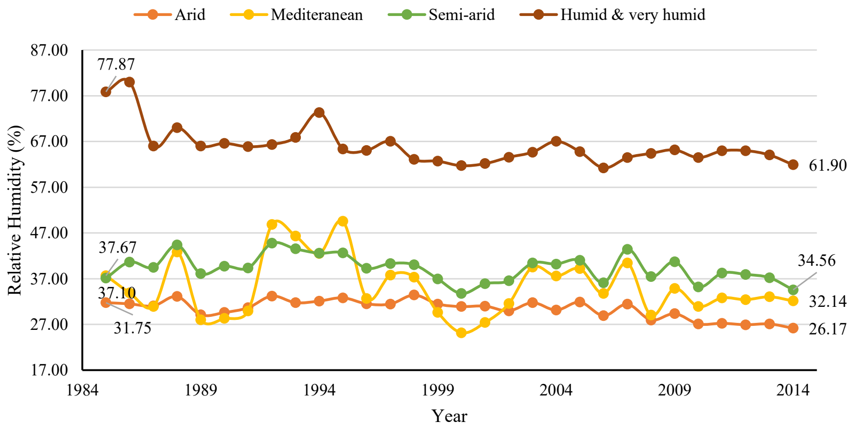

Figure 4. Trend graph of the mean relative humidity for different climate zones during summer in the studied years.

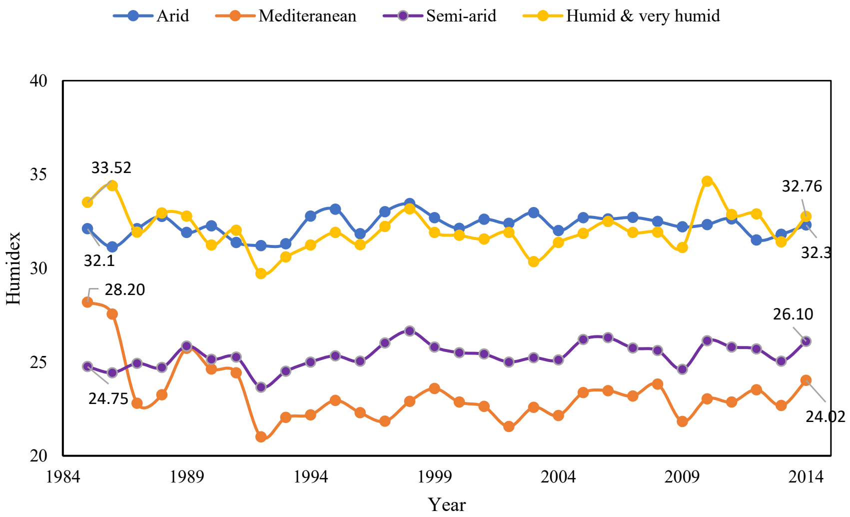

Figure 5. Trend graph of the mean Humidex for different climate zones during summer in the studied years.

in the stations that had the lowest latitude which may be due to the higher angle of sunlight causing higher temperatures (36). Revadekar et al studied the effects of latitude and elevation on temperature extremes in South Asia from 1971 to 2000. Their results indicate that the trends of extreme indices are congruent with general warming at lower latitude and elevation. The trends observed in the areas of low elevation in the South Asia suggest that these areas should expect an increase in extreme temperatures (42).

According to the results of the Mann-Kendall test (Tables 4-5), in 72% of the meteorological stations, HD followed an upward trend during summertime for the years under study, so that 40% of them was statistically significant. Also, air temperature followed an upward trend in 95% of the meteorological stations and relative humidity followed a downward trend in 87.5% of the stations during summertime for the years under study.

Tabari et al studied variations in the De Martonne and Pinna aridity indices during 40 consecutive years from 41 different meteorological stations (43). Their results showed that around 63% of the two indices series had a downward trend, meaning an increasing rate of arid regions. The relative changes in these aridity indices for stations with significant downward trends ranged from 18% to 54%. Tabari and Talaee also studied the changing trends in temperature time series from 20 meteorological stations in the western half of Iran from 1966 to 2005 using Mann-Kendall, Sen's slope estimator, and linear regression (44). They found that annual temperature changes followed an upward trend in 85% of the stations under study with the highest rate of increase being observed in the summer during the month of August.

Based on the results obtained, the changing trends in temperature during summertime throughout the years under study fluctuated greatly but generally, in many regions such as the arid, semi-arid and humid regions, this trend was mostly incremental. Also, the changing trends in relative humidity in all regions was decremental throughout the years under study. Despite showing fluctuations throughout the years under study, the changing trends of HD which is based on temperature and humidity, was incremental in arid and semi-arid regions and decremental in the Mediterranean and humid regions. On average, during the course of a decade, a +0.418 increase in HD was observed in arid and semi-arid regions.

According to the forecasted increase in aridity in Iran stated by Tabari and Talaee (44) and Tabari et al (43), and also, in the present study, adopting the following preventive measures can be helpful:

- Use of green roof technology and reflective pavements to reduce air temperature
- The use of climate-friendly architecture to prevent direct sunlight in hot seasons
- Increasing urban green spaces to change the microclimate of the city and reduce air temperature
- Use of high albedo materials in buildings to reduce the heat island of the city (45, 46).

Alizadeh and Najafi studied trends and changes in temperature and precipitation in Iran from 1951 to 2013 using meteorological data obtained from 15 different regions. Their results showed rising daily temperatures and declining precipitation in most regions of Iran during the years under study. They concluded that the reduction in precipitation and rising temperatures indicate that Iran has become more arid in recent decades. The warm climate of the arid and semi-arid subtropical regions which affects most parts of Iran causes an increase in the time it takes for the atmosphere to be saturated by water vapor and rain to start falling. This means that a greater amount of water vapor is transferred to higher latitudes by the general atmospheric circulation before rainfall has commenced (47).

Heat waves have a considerable effect on the health and safety of the general public (48). Extreme temperature rise accompanied by high humidity leads to many problems for the general public and if precautionary awareness is issued, many of the negative ramifications and fatalities resulting from it can be reduced (49). Meteorological departments can consider precautionary measures before the onset of heat waves and provide necessary advice. If the heatwaves persist for a number of consecutive days, warnings suitable with tolerance thresholds against heat are issued in large cities and coastal areas as these areas are especially vulnerable (50).

In many countries, meteorological organizations use HD in their forecasting services to issue timely warnings to the general public, they also give advice based on age and environmental conditions (29). Since adverse conditions such as heatwaves amplify the effects of heat and humidity, exposure to sunlight or being in an area with inadequate ventilation can increase perceived temperature. On the other hand, a 3 m/s wind, wearing light and bright clothing, adequate hydration, eating light food, staying in the shade, and reducing physical activity can decrease perceived temperature and reduce the health risks of heat. It is noteworthy that the effects of heat during these waves gradually becomes incremental and the harm from them reach its peak after the maximum heat index is observed. Thus, by using forecast maps, meteorological organizations can issue precautionary measures and raise awareness while at the same time coordinating with medical agencies to reduce the vulnerability of the general public to heatwaves.

It is worth noting that in the present study, for the first time, the changing trends of a thermal discomfort index derived from two meteorological parameters (temperature and humidity) were analyzed at a large scale. The results of the present study can be used as the basis for administrative planning regarding human comfort especially in the fields of health and tourism. Also, the analysis of the changing trends in temperature and thermal indices during different years can be used as a management guide, since many studies have shown that extreme changes in temperature throughout the year lead to various disorders and even loss of life.

Conclusion

The present study aimed to assess the trends of HD as a thermal discomfort index by analyzing meteorological data (air temperature, water vapor pressure, and the percentage of relative humidity) during a 30-year period of summertime in Iran. According to the results, in most of the studied meteorological stations, the HD followed an upward trend, and also, the changing trends in temperature during summertime in many regions such as arid, semi-arid, and humid regions were mostly incremental. The changing trends in relative humidity in all regions was decremental throughout the studied years. In general, the changing trends of the HD, was incremental in arid and semi-arid regions and decremental in the Mediterranean and humid regions. It seems necessary to implement precise and innovative policies and programs in accordance with climate change and global warming and the ability to prevent and reduce the risks it poses.

Acknowledgements

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

Ethics approval

Ethical approval for this study was obtained from Ethics Committee of Arak University of Medical Sciences (Ethical code: IR.ARAKMU.REC.1398.069).

Competing interests

The authors declare that they have no conflict of interests.

Authors' contribution

All authors have equally contributed to the conception, design of the work, interpretation of data for the work, and final approval of the manuscript.

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