Advanced Journal of Environmental Sciences (AJES)
Volume.1, Number 1; February-2023;
Published By: Zendo Academic Publishing
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TREND ANALYSIS OF THERMAL COMFORT INDICES IN THREE DIFFERENT CLIMATES OF IRAN OVER 15 YEARS

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Abstract: this study aimed to assess the trend of thermal comfort indices in the outdoor environment of three different climates in Iran over a 15-year period. The meteorological data required to estimate the thermal comfort indices were obtained from the Iran Meteorological Organization for the period between 2000 and 2014. Three thermal comfort indices, including the humidex, temperature-humidity, and effective temperature, were utilized for estimation. The results revealed that Arak, representing the cold and semi-arid climate, experienced warm conditions in June, July, and August. Sari, representing the humid subtropical climate, had warm conditions in June, July, and September, while August was very hot. Bandar Abbas, representing the hot and arid climate, had sultry conditions in May, June, and September, while July and August had extremely hot conditions. These findings suggest the need for precise and innovative policies and programs to prevent and reduce the risks associated with climate change and global warming. The trend analysis of air temperature and thermal indices over the years can serve as a guide for future planning and adopting preventive or control measures to protect people from thermal stress hazards in outdoor environments.

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INTRODUCTION:

Climate change and its impacts on human health and the environment have been a growing concern worldwide since the 21st century. The increase in greenhouse gas emissions caused by human activities has resulted in rising global temperatures, sea level rise, changes in precipitation patterns, and more frequent extreme weather events such as heatwaves, droughts, and floods. These changes in climate have significant implications for human health, including increased morbidity and mortality from heat stress, air pollution, vector-borne diseases, and food insecurity.

The World Health Organization (WHO) has identified climate change as one of the most significant global health threats of the 21st century, calling for urgent action to reduce greenhouse gas emissions and to adapt to the changing climate. The Paris Agreement of 2015, which aimed to limit global warming to well below 2 degrees Celsius above pre-industrial levels, has set the stage for global efforts to mitigate and adapt to climate change.

In recent years, researchers have conducted numerous studies on the impacts of climate change on human health, with a particular focus on the effects of extreme weather events such as heatwaves. Heatwaves, which are becoming more frequent and intense due to climate change, can cause a range of health problems, including heat exhaustion, heatstroke, and cardiovascular and respiratory diseases. Vulnerable populations, such as the elderly, children, and those with pre-existing health conditions, are at higher risk of heat-related illnesses.

In response to these challenges, governments, public health agencies, and other organizations are implementing various measures to reduce the risks posed by climate change and to enhance resilience to its impacts. These include reducing greenhouse gas emissions, improving infrastructure and urban planning, enhancing public health surveillance and response systems, and promoting public awareness and education on climate change and its health impacts.

This paper aims to contribute to the understanding of the impacts of climate change on human health by examining the trend of thermal comfort indices in the outdoor environment of three different climates in Iran over a 15-year period. The study utilized meteorological data to calculate and assess thermal comfort indices, including the humidex, temperature-humidity, and effective temperature, and analyzed their trends over time. The results of this study can provide insights into the effects of climate change on human thermal comfort in Iran and contribute to the development of policies and programs to mitigate and adapt to its impacts

MATERIALS AND METHODS

Study area: This study has been done during 2020-2021 on the meteorological data that have been obtained from the Iran Meteorological Organization to calculate and assess the trend of the thermal comfort indices for the outdoor environment. The meteorological data consisted of three different climates of Iran for 15 years (2000-2014). The studied data do not cover recent years, since they were not processed for most stations and contained the statistical gaps in 40 different synoptic meteorological stations according to Iran Meteorological Organization.

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Based on the Köppen climate classification system, there are ten different climates in Iran, 80% of which is classified as arid, 16.7% is classified as temperate and 2.3% is classified as cold[11]. In the present study, three cities have been selected from three different climates: Arak from the central part of Iran as a representative of the cold semi-arid climate, Bandar Abbas from the south of Iran as a representative of the hot desert climate and Sari from the southern coast of the Caspian Sea as a representative of the humid subtropical climate[11]. The geographical characteristics of these cities are presented in Table 1.

Data collection: The necessary data required to estimate the thermal comfort indices include the average air temperature in centigrade and the percentage of relative humidity per day have been acquired from the Iran Meteorological Organization for the period between the year 2000 and 2014 (fifteen years). 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.

Thermal comfort indices: Each thermal comfort index has its particular benefits and weaknesses and it is not possible to obtain acceptable results using only one index, which means that a more accurate and concise estimate for a single area can be obtained by analyzing and comparing multiple indices[12]. For this reason, in the present study, three comfort indices have been utilized for an estimation which includes the humidex, the temperature-humidity and the effective temperature indices.

Humidex index: The humidex index was introduced in 1979 by Richardson and Masterton as a thermal stress index that represents the relationship between thermal comfort conditions and environmental parameters including air temperature and relative humidity. The formula for this index is based on two hypotheses regarding the body's thermal regulatory system[12]. The first is that the thermal equilibrium of a naked body in quiet air is 27-30EC, based on the thermal equilibrium equation. The second is that the human body cannot withstand temperatures above 32EC if the humidity is

Table 1: Location and characteristics of the station's understudy

Cities	Location in Iran	Latitude (deg N)	Longitude (deg E)	Height above sea level (m)
Arak	Center	34.06	49.42	1700
Bandar Abbas	South	27.13	56.18	16
Sari	North	34.36	53.37	20

Table 2: Ranges of the humidex corresponding to the level of thermal discomfort conditions

HumidexEC	Descriptions
20≤humidex≤29	Comfort
30≤humidex≤39	Some discomfort
40≤humidex≤45	Great discomfort, avoid exertion
46<humidex≤54	Dangerous

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Table 3: Ranges of the temperature-humidity (THI) index corresponding to a level of thermal discomfort conditions

THIEC	Descriptions	Type of bioclimatic comfort/discomfort
-20<THI≤–10	Excessive cold	Bioclimatic discomfort due to overcooling
-10<THI≤-1.8	Very cold	
-1.8<THI≤+13	Cold	
+13<THI≤+15	Cool	
+15<THI≤+20	Comfortable	Bioclimatic comfort
+20<THI≤26.5	Hot	Bioclimatic discomfort by heating
+26.5<THI≤+30	Very hot	
THI>+30	Sultry	

higher than 75%[12]. Considering the above, it can be said that this experimental index is more suited to particular climates (such as the temperate areas in Canada) and as such does not consider many factors that affect thermal stress such as clothing resistance, metabolic rate, air velocity and different levels of humidity. Although this index was first used for weather prediction, its ease of use and the lack of a need for complex measurement tools have drawn attention to it for thermal comfort assessment in outdoor environments[13,14].

The index can be calculated using Eq. 1 and 2:

$$HD = ta + \frac{5}{9}(pas - 10) \quad (1)$$

$$Pas = 6{,}112 \times 237{,}7 \times ta \quad (2)$$

where ta is the air temperature in EC, pas is the vapour pressure in mbar and RH is the relative humidity in percent[13].

The index value is in the range from 20-54EC (Table 2).

Temperature-humidity index: The temperature-humidity index (THI) index is being ranked as one of the best indicators of effective temperature, which expresses the combined effect of air temperature and relative humidity on human health but also of the air movements in the region. There is the classification of the weather conditions, both for the hot and cold (Table 3)[15].

THI indicates the conditions under which certain values of atmosphere moisture affects human thermoregulatory mechanisms, thus intensifying the state of bioclimatic discomfort due to either overheating or over-cooling conditions. It expresses the real ambient temperature that is effectively being perceived by the human organism, under specified conditions of humidity and air temperature, calculated through Eq. 3[16]:

$$THI\ (EC) = ta - 0.55\ (1 - 0.01 \times RH) \times (ta - 14.5) \quad (3)$$

where ta is the air temperature in EC and RH is the relative humidity in percent.

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Effective temperature Index: Effective temperature (ET) refers to the temperature of still and saturated air which would produce the same effect without radiation. To estimate this index, two variables, namely air temperature and relative humidity are used (Eq. 4)[14]:

$$ET\ (°C) = T - 0.4\,(T-10) \times \left(\frac{1-RH}{100}\right) \quad (4)$$

Ranges of the effective temperature (ET) index corresponding to the level of thermal discomfort conditions has been shown in Table 4.

Data were analyzed using SPSS 18 and Microsoft Excel. Descriptive statistics, Spearman's correlation coefficient and linear regression were used.

Table 4: Ranges of the effective temperature (ET) index corresponding to the level of thermal discomfort conditions

ETEC	Descriptions
Extremely hot	30<
Sultry	27.5-30
Very hot	25.6-27.5
Hot	22.2-25.6
Comfortable	17.8-22.2
Cool	15.5-17.8
Very cool	1.67-15.5
Cold	-10 to 1.67
Very cold	-20 to -10
Excessive cold	<-20

RESULTS

Table 5 shows the mean and standard deviation for temperature (centigrade) and relative humidity (percentage) obtained for each month of the year during 15 years at the three different climates under study.

As can be seen from Table 5, for the city of Arak, the highest mean temperature throughout the years was recorded in July (28.1±0.65EC) while the lowest temperature was in January, (-1.14±1.94EC). Also, the highest humidity was observed in January (70.6±3.87%) and the lowest humidity was in July (22.96±1.25%). For the city of Bandar Abbas, the highest mean temperature was in July (34.27±0.26EC) while the lowest one was in January (6.44±0.17EC). Also, the highest humidity was in August (68.39±2.41%) and the lowest humidity was in December (57%±4). As for the city of Sari, the highest mean temperature was in August
(27.55±0.57EC) and the lowest mean temperature was in January (7.90±0.68EC). Also, the highest humidity was in December (81.2±2.6%) and the lowest humidity was in August (73.7±1.94%).

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The calculation results of the thermal comfort indices during the 15 years has been presented for each month in Table 6. Also, the trend graph of the mean humidex, THI and ET over the different months during 15 years has been shown in Fig. 1a-c, respectively.

In Table 6 the Arak, which represents the cold and semi-arid climate, the highest and lowest humidex value (27.41±0.7 vs. -4.48±2.1EC) were in July and January, respectively. The Arak has thermal comfort conditions throughout the year in all months. In the Sari, which represents the humid subtropical climate, the highest and lowest humidex value (37.012±0.77 vs. 7.00±0.84EC) were in August and January, respectively. The Sari has mild thermal discomfort in June, July, August and September but the rest of the months are within thermal comfort thresholds. In the Bandar Abbas, which represents the hot and arid climate, the highest Humidex value was in July (48.26±0.64EC) while the lowest was in January (18.88±1.16EC). Table 6 shows that based on this index, the city if Bandar Abbas has thermal comfort conditions in January, February, March, November and December. This city has mild thermal discomfort in April and October, while May, was uncomfortable for all people. Conditions are dangerous for the occupants in June, July, August and September.

In the Arak, the highest value of the temperaturehumidity index was observed in July (22.35±0.32EC) and the lowest one in January (1.36±1.8EC). The months of January, February, March, November and December, were in cold condition while April, was cool and the months of May, September and October are within ranges of thermal comfort. In June, July and August, warm conditions were present. In the Sari, the highest mean of temperature-humidity index was determined in August (25.65±0.37EC) and the lowest one in January (8.63±0.65EC). The months of January, February, March and December, were cold, while November, was cool and the months of April and October, were within the ranges of thermal comfort. In the five months of May, June, July, August and September, hot conditions were present. In the Bandar Abbas, the highest and lowest mean of THI was in July (30.63±0.23EC) and January (16.85±0.52EC), respectively. The months of January, February and December, conditions were in a comfortable range and in March, April, October and November, conditions were hot. In May, June and September, conditions were very hot and in July and August conditions were sultry.

In the Arak, the highest and lowest mean of effective temperature index was recorded in July (22.54±0.4EC) and January (0.15±1.80EC), respectively. Results indicate that January was in cold condition and the months of February, March, April, October, November and December, were in very cool. Conditions were cold in May but in June, August and September conditions were comfortable. In July, conditions were warm. In the Sari, the highest and lowest mean of ET index were in August (25.7±0.4EC) and January (8.06±0.64EC), respectively. Conditions were very cool in January, February, March, April, November and December and in May and October, conditions were comfortable. The months of June, July and September are warm and the month of August was very hot. In the Bandar Abbas, the highest and lowest mean of ET index were in July (31.02±0.22EC) and January (16.35±0.59EC), respectively. Conditions were cool in January and December and were comfortable in February,

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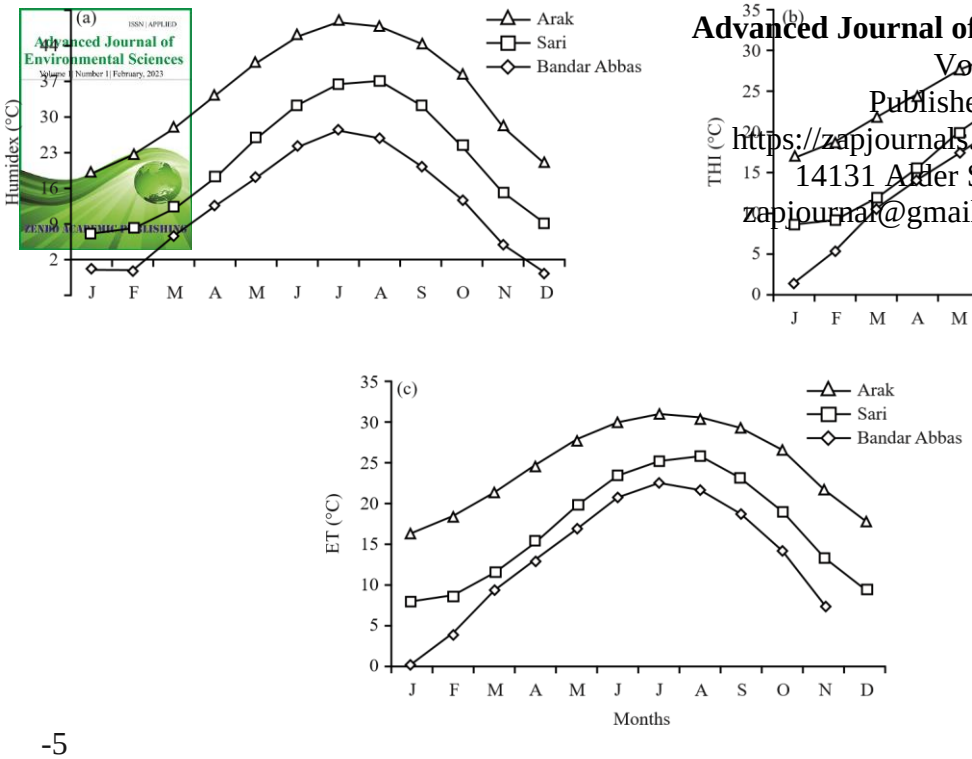

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Months

Fig. 1(a-c): Trend graph of the mean thermal comfort indices over the different months during 15 years, (a) Humidex, (b) Temperature-humidity index (THI) and (c) Effective temperature (ET)

Table 5: Mean±SD of environmental parameters during 15 years in the three different climates

Months	Parameters	Arak	Sari	Bandar Abbas
January	Ta (EC)	-1.14±1.94	7.90±0.68	6.44±0.17
	RH (%)	70.67±3.87	79.53±2.20	63.10±4.40
February	Ta (EC)	2.84±2.48	8.52±0.90	22.75±1.19
	RH (%)	60.54±6.70	80.38±2.10	65.10±4.20
March	Ta (EC)	9.13±1.16	11.55±1.00	23.19±1.00
	RH (%)	46.10±2.73	78.94±2.90	64.40±2.71
April	Ta (EC)	13.90±1.53	15.74±1.50	27.50±1.18
	RH (%)	46.50±3.40	78.34±2.60	59.68±2.20
May	Ta (EC)	19.10±2.00	20.86±1.80	31.60±0.09
	RH (%)	36.93±5.41	76.00±2.60	57.40±2.33
June	Ta (EC)	25.20±1.37	24.87±0.79	33.73±0.50
	RH (%)	24.70±1.55	73.80±1.90	60.30±3.37
July	Ta (EC)	28.10±0.65	27.00±0.75	34.27±0.26
	RH (%)	22.96±1.25	73.74±1.75	66.51±2.46
August	Ta (EC)	26.80±1.11	27.55±0.57	33.58±0.56
	RH (%)	23.10±2.44	73.70±1.94	68.39±2.41
September	Ta (EC)	22.20±1.84	24.46±1.36	32.12±0.61
	RH (%)	25.25±2.80	77.60±1.30	67.22±2.27
October	Ta (EC)	15.60±2.38	19.60±1.60	29.23±1.20
	RH (%)	39.22±8.00	79.00±1.80	64.97±2.66

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November	Ta (EC)	7.04±2.10	13.51±1.80	8.83±1.23
	RH (%)	62.30±3.53	80.73±1.67	58.96±2.80
December	Ta (EC)	2.26±1.21	9.33±0.86	19.35±1.16
	RH (%)	68.66±2.21	81.20±2.60	57.00±4.00

Ta: Air temperature and RH: Relative humidity

Table 6: Mean±SD of studied indices during 15 years in the three different climates

Months	Index	Arak	Sari	Bandar Abbas
January	HD (EC)	-4.48±2.1	7.00±0.84	18.88±1.16
	THI (EC)	1.36±1.80	8.63±0.65	16.85±0.52
	ET (EC)	0.15±1.80	8.06±0.64	16.35±0.59
February	HD (EC)	-0.2±2.67	7.93±1.16	22.56±2.30
	THI (EC)	5.28±2.38	9.16±0.84	18.76±1.00
	ET (EC)	3.90±2.00	8.63±0.84	18.40±1.18
March	HD (EC)	6.54±1.35	11.96±1.35	27.80±1.64
	THI (EC)	10.71±.86	11.88±0.98	21.48±0.83
	ET (EC)	9.31±0.93	11.41±0.97	21.31±0.89
April	HD (EC)	12.5±1.73	17.98±2.00	34.10±1.78
	THI (EC)	14.00±1.00	15.58±1.29	24.60±.083
	ET (EC)	13.10±1.16	15.24±1.31	24.67±0.90
May	HD (EC)	18.00±1.96	25.72±2.70	40.84±1.78
	THI (EC)	17.46±1.20	20.01±1.50	27.6±0.73
	ET (EC)	16.77±1.30	19.8±1.55	27.92±0.78
June	HD (EC)	24.00±1.60	32.18±1.37	45.69±1.28
	THI (EC)	20.74±0.76	23.37±0.68	29.53±0.48
	ET (EC)	20.60±0.91	23.3±0.69	29.96±0.48
July	HD (EC)	27.41±0.70	36.1±1.10	48.62±0.64
	THI (EC)	22.35±0.32	25.2±0.56	30.63±0.23
	ET (EC)	22.54±0.40	25.23±0.59	31.02±0.22
August	HD (EC)	25.80±1.10	37.02±0.77	47.71±0.71
	THI (EC)	21.61±0.54	25.65±0.37	30.26±0.29
	ET (EC)	21.65±0.66	25.70±0.40	30.6±0.32
September	HD (EC)	20.33±1.90	32.13±2.40	44.42±1.61
	THI (EC)	18.98±0.98	23.23±1.18	28.95±0.64
	ET (EC)	18.5±1.17	23.16±1.22	29.22±0.65
October	HD (EC)	13.83±2.10	24.10±2.44	38.32±2.30

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	THI (EC)	15.12±1.60	19.00±1.39	26.39±1.00
	ET (EC)	14.16±1.60	18.80±1.40	26.54±1.07
November	HD (EC)	4.97±2.50	14.94±2.62	28.02±3.20
	THI (EC)	8.55±1.80	13.62±1.61	21.74±1.50
	ET (EC)	7.46±1.87	13.24±1.66	21.58±1.63
December	HD (EC)	-0.55±1.43	9.10±1.23	20.92±1.84
	THI (EC)	4.36±1.00	9.87±0.75	18.20±0.90
	ET (EC)	3.22±1.00	9.38±0.74	17.74±1.00

HD: Humidex, ET: Effective temperature and THI: Temperature-humidity index

March and November. In April, conditions were hot while in October they are very hot. In May, June and September, conditions were sultry while in July and August, conditions were extremely hot.

Descriptive characteristics of the thermal comfort indices are presented in Table 7. As can be seen from Table 7, the results from the humidex index indicate that in the city of Arak, comfortable conditions are prevalent throughout the year. The results also show that in the city of Sari, 68% of the year and in the city of Bandar Abbas, 46% of the year, conditions meet thermal comfort thresholds. In terms of the temperature-humidity index, in the city of Arak, cold stress exists for almost 51% of the year while heat stress exists for 25% of the year. The results of the index show that in the city of Sari, heat stress exists for 40% of the year while cold stress exists for 42% of the year. As for the city of Bandar Abbas, the index shows that heat stress exists for 75% of the year while 25% of the year meets comfort conditions and there is no cold stress. The results of the effective temperature index show that in the city of Arak, 9% of the year is in cold rang, 49% of the year is very cool, 9% of the year is in cool and 23% of the year is in a comfortable condition. In the city of Sari, 45% of the year is very cool, 25% is hot and almost 14% is in the comfortable range. As for the city of Bandar Abbas, results of the index shows 23% of the year is comfortable while 60% of the year conditions are to various levels of heat stress.

Scatterplot showing the correlation between the studied indices in Arak, Sari and Bandar Abbas has been presented in Fig. 2 a-c, Fig. 3 a-c and Fig. 4 a-c, respectively (A: Humidex vs. ET, B: Humidex vs. THI and C: THI vs ET) As can be seen, a high correlation is observed between the indices used among the three climates under study.

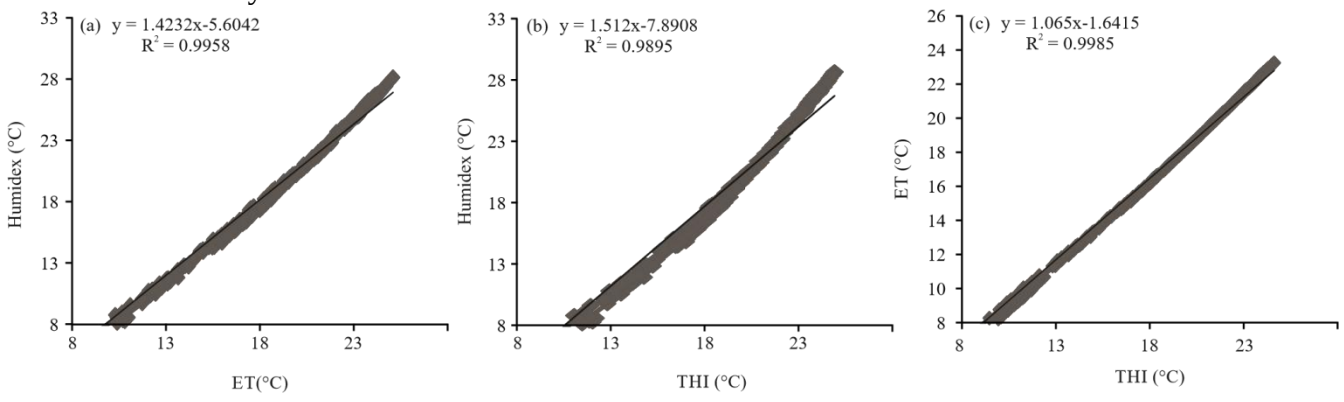

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Fig. 2(a-c): Scatterplot showing the correlation between the indices for the cold and semi-arid climate (Arak), (a) Humidex vs. effective temperature (ET), (b) Humidex vs. temperature-humidity index (THI) and (c) THI vs. ET

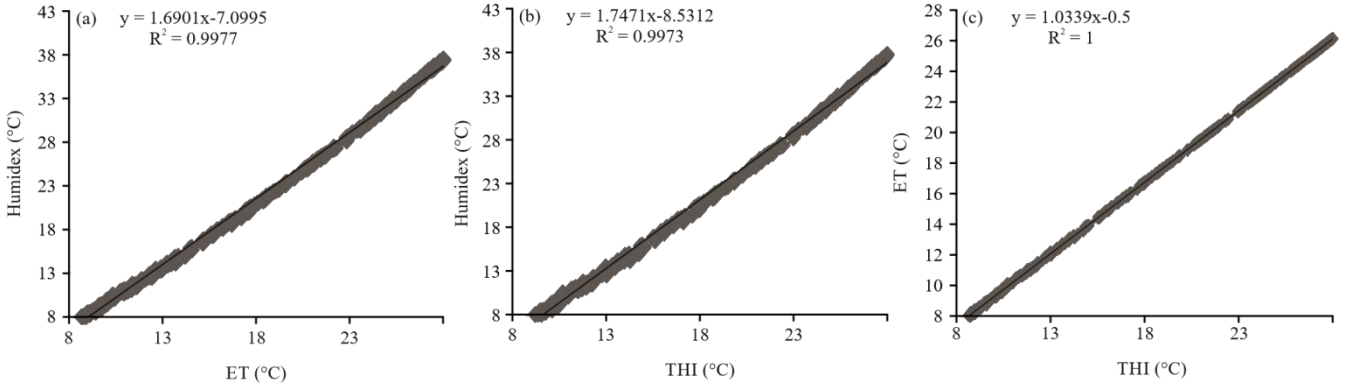

Fig. 3(a-c): Scatterplot showing the correlation between the indices for the humid subtropical climate (Sari), (a) Humidex vs. effective temperature (ET), (b) Humidex vs. temperature-humidity index (THI) and (c) THI vs. ET

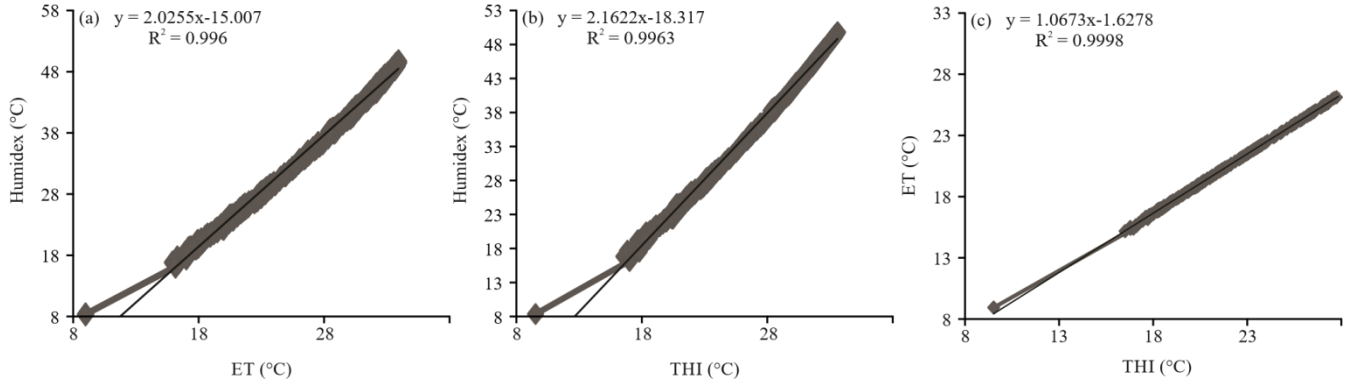

Fig. 4(a-c): Scatterplot showing the correlation between the indices for the hot and arid climate (Bandar Abbas), a) Humidex vs. effective temperature (ET), (b) Humidex vs. temperature-humidity index (THI) and (c) THI vs. ET

Table 7: Descriptive characteristics of heat strain during the studied years

Thermal index	Cities	Descriptions	Percentage
Humidex (EC)	Arak	Comfort	100
	Sari	Comfort	67.8
		Some discomfort	32.2
	Bandar Abbas	Comfort	46.3
		Some discomfort	18
		Great discomfort, avoid exertion	14.5
		Dangerous	21.2
THI (EC)	Arak	Hot	25.2
		Comfortable	23.6

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		Cool	7.5
		Cold	43.7
	Sari	Hot	40.2
		Comfortable	17.8
		Cool	6
		Cold	36.1
	Bandar Abbas	Comfortable	24.9
		Hot	29.9
		Very hot	28.2
		Sultry	17
ET(EC)	Arak	Cold	9.3
		Very Cool	48.8
		Cool	9
		Comfortable	23.3
		Hot	9.6
	Sari	Very Cool	45.1
		Cool	8.5
		Comfortable	14.2
		Hot	25.1
		Very hot	7.1
	Bandar Abbas	Cool	15
		Comfortable	23.2
		Hot	12.3
		Very hot	8.3
		Sultry	20.6
		Extremely hot	20.6

ET: Effective temperature and THI: Temperature-humidity index

DISCUSSION

It is of the utmost importance to be aware of the effects of weather and climate on the various aspects of human life with the aim of accurate planning at different times and places. One of these -aspects is climate comfort. Currently, bioclimate studies from the perspective of human comfort, is the basis for administrative planning, particularly in the field of health and medicine[17]. Various studies have shown that extreme temperature variation throughout the year can lead to some disorders and even death. Nastos and Matzarakis[18] conducted a study examining the role of climate on the rate of death in the city of Athens, Greece, using the thermal comfort indices for 10 years. They and found a significant correlation between air temperature, selected indices and the rate of death for each day[18].

Advanced Journal of Environmental Sciences (AJES)
Volume.1, Number 1; February-2023;
Published By: Zendo Academic Publishing
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The results of the present study show that the highest temperature during the period under consideration in the three cities under study belongs to July and August while the lowest temperature belongs to January. Based on the study of Basu[19] the rise in temperature increases the number of deaths and the susceptibility of those suffering from cardiovascular and respiratory illnesses. Maeda et al.[20] show that the number of heat exhaustion fatalities due to higher temperatures is predominant in July and August. These results indicate that people are more at risk of heat stress and underlying diseases in the aforementioned months of the year. Therefore, during these months, preventive measures should be seriously considered, especially for workers in outdoor environments to prevent heat stress.

The results of the thermal comfort assessment using the humidex index indicate that the city of Arak (as a representative of semi-arid and cold climate) had the highest levels of this index in July and the lowest in January. This city enjoys thermal comfort conditions throughout the year and all the days are within thermal comfort range. The results of the study by Javan[21] on the tourism climate of the city of Urmia using the humidex index, along with other indices, showed that neither month of the year had discomfort conditions and that conditions were suitable for tourism throughout the year. Their study states that this index is highest in July (25.9) and lowest in January (-5.4), which is also consistent with the present[21].

In the city of Sari (as a representative of humid subtropical climate), the highest mean for the Humidex index during the years under consideration was for August while the lowest was for January. Minor discomfort is present in June, July, August and September, though other months of the year are in thermal comfort. Overall, 68% of the days throughout the year are in the thermal comfort range. In the city of Bandar Abbas (as a representative of hot and arid climate), the highest and lowest mean for the Humidex index were for July and January, respectively. The months of January, February, March, November and December, were in thermal comfort range, the months of April and October, were in minor discomfort, the month of May is uncomfortable for all and in June, July, August and September, conditions were dangerous. The city of Bandar Abbas is in thermal comfort for 46% of the year.

Although the Humidex index was first used for weather prediction, because of its ease of use and the lack of a need for complex measurement tools, its use in heat stress assessment in outdoor and indoor environments has gained attention[12]. Conti et al.[22]. investigated the number of deaths in 2004 for Italy and concluded that higher fatalities correlated with a higher Humidex value. Heidari et al.[12] aimed to validate the Humidex index for heat stress assessment and compare it with the WBGT index for outdoor workplaces in arid and semi-arid regions of Iran. They showed that the Humidex index provides a better assessment in moderately warm conditions. The results also showed that regardless of the type of climate, in the temperature and humidity range that was studied, the Humidex index was a suitable alternative to the WBGT index and was consistent with tympanic temperatures as a physiological response to heat stress[12].

Another index that was utilized in the present study is the THI. Results show that in the city of Arak, the highest and lowest mean THI during the years under consideration were calculated in July and January, respectively. Conditions were cold in January, February, March, November and December, cool in April. There was a thermal comfortable condition in May, September and October. In June, July and August conditions were warm. Cold stress existed in 51%, heat stress existed in 25% and thermal comfort existed in 24% of the days throughout the year. Based on the results of assessing tourism climate in Urmia using THI,

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by Javan[21], climatic conditions were comfortable in the five months of May, June, July, August and September. The month of October was cool and the months of November, December, January, February and March, were cold. The THI index was highest in July and lowest in January, which is consistent with the results of the present study[21].

In the Sari, THI was the highest value in August and the lowest in January. Conditions were cold in January, February, March and December, cool in November, comfortable in April and October while May, June, July, August and September, were hot. Also, heat stress was observed in 40% of the days while cold stress was in 42% of the days throughout the year. In the city of Bandar Abbas, the highest and lowest mean of THI was found in July and January. Conditions were comfortable in January, February and December, hot in March, April, October and November, very hot in May, June and September while conditions were sultry in July and August. Heat stress is observed in 75% of the days and thermal comfort is observed in 25% of the days throughout the year with no cold stress at all. In a study, Vl|duÛ[23] examined the THI index within the Oltenia Plain between 2000 and 2009 and concluded that 2000, 2001 and 2007 had the highest levels of THI which coincided with heat waves that had entered into the area and raised the temperature to 40EC.

In the city of Arak, the highest mean effective temperature index during the years under consideration was in July and the lowest was in January. Results indicate that thermal conditions were cold in January, very cool in February, March, April, October, November and December, cool in May, comfortable in June, August and September and hot in July. Throughout the year, 9% of the days are cold, 49% are very cool, 9% are cool and 23% were in thermal comfort conditions. In the Sari, the Effective Temperature index has the highest and lowest value in August and January, respectively. Conditions were very cool in January, February, March, April, November and December, comfortable in May and October, hot in June, July and September and very hot in August. Throughout the year, 45% of the days are very cool, 25% are hot and 14% are comfortable. In the Bandar Abbas, the highest and lowest mean of effective temperature index was observed in July and January, respectively. Thermal conditions were cool in January and December, comfortable in February, March and November, hot in April, very warm in October, sultry in June and September and extremely hot in July and August. Throughout the year, 23% of the days are comfortable in 60% of the days, different levels of heat stress exist.

The results of the study by Javan in the chabahar free zone show that the ET Index is lowest in January and December and conditions are comfortable in these months. Conditions are warm but relatively comfortable in February, March, April and November. Due to humid and sultry air, conditions are not comfortable in May, June, July and August. This is also present in December and October due to very hot conditions. Safaeipooret al.[24] assessed effective bioclimatic indices on evaluating human comfort in Shiraz City. they indicated that there is a comfortable condition in April, May, September and October. Conditions were hot in June, July and very cool in November, December, January, February and March[24].

Based on the results obtained from assessing the changing trend of thermal comfort indices in the city of Arak, cold stress has a higher priority and attention must be paid to vulnerable populations like those with cardiovascular diseases. Ma et al.[25] assessed the impact of the 2008 cold spell on mortality in Shanghai and found that the number of deaths due to coronary illnesses in people over the age of 11 increased by 13% during cold periods. Braga et al.[26] and Hampel et al.[27] also show a significant correlation

between cold weather and the number of deaths from respiratory illnesses. The air pollution in Arak must also be considered in this regard[28]. Results show that in the city of Sari, both heat stress and cold stress have a priority for adopting control measures. Based on the results, in the city of Bandar Abbas, heat stress is a priority and thus appropriate measures must be taken.

Another key issue is subjective and personal tolerance as people may feel differently under the same climatic conditions, therefore, it is not possible to consider a particular climate as suitable or unsuitable for everyone. Thermal comfort varies depending on ethnicity, age, type of activity, type of clothing, metabolic rate and acclimatization. It seems necessary to implement precise and innovative policies and programs following climate change and global warming and the ability to prevent and reduce the risks it poses. Meteorological organizations must predict and issue warnings for heatwaves and cold waves to reduce injuries and fatalities. Exposure to direct sunlight, not wearing bright and light clothing, dehydration and not drinking enough cool water or performing physically demanding activities can increase the health risks associated with heat stress and if these conditions are predictable, it is possible to reduce injuries and fatalities considerably.

CONCLUSION

The study aimed to assess the 15-year trend of the thermal comfort indices including Humidex, the THI and ET, which are calculated based on air temperature and relative humidity in three different climates of Iran. Based on our findings, in Arak city as a representative of the cold semi-Arid climate, cold stress has a higher priority, in the city of Sari as a representative of the humid subtropical climate, both heat stress and cold stress have a priority and In the Bandar Abbas city as a representative of the hot desert climate, heat stress is a priority for adopting control measures. So, it can be possible to determine high-risk zones by assessing the changes in thermal comfort and stress indices and implementing policies to prevent high exposure. Also, by adopting regulations regarding predictions and warnings issued by meteorological organizations, injuries and fatalities can be prevented.

SIGNIFICANCE STATEMENT

This study discovers that in the case of Humidex, Bandar Abbas has uncomfortable conditions in May and dangerous conditions in June, July, August and September. In the case of THI, Arak and Sari were in cold condition in January, February, March, November and December. In the case of ET Arak was in a cold condition in January and was very cool in February, March, April, October, November and December. Bandar Abbas was sultry in May, June and September while in July and August its condition was extremely hot. The data can be utilized for future planning, preventive measures and control procedures to protect people's health in outdoor environments.

ACKNOWLEDGMENT

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

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