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Trend Investigation of Thermal Comfort in Different Climates of Iran in Past Decades

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***Abstract* – Regarding climatic diversity in Iran and the dependence of many outdoor activities (occupational, recreational, tourism attraction, etc.) on climatic conditions, this study conducted aiming to evaluate thermal comfort fluctuations in Iran. Thermal comfort fluctuations in different climates of Iran were investigated between 1985 and 2014 using recorded meteorological data in 40 synoptic stations. The Mann-Kendall test and Sen's Slope were used to analyse the changing trends of the Humidex and to determine the actual slope of a trend over time, respectively. In overall, the southern areas of Iran have the longest period with unfavourable and extremely unfavourable climatic conditions in this study. Conversely, in the northern half of Iran, especially in North West areas, the appropriate summer season provides the best climatic conditions for outdoor activities.**

***Keywords* – Climate; humidex; thermal comfort; outdoor**

1. INTRODUCTION

Global warming and climate change have become one of the most controversial issues these days, affecting the health of people and threatening human life [1]. According to the definition of the United Nations Framework Convention, climate change is any variation in climatic conditions that differs with atmospheric compounds in the past and directly or indirectly affects the human activity [2].Global warming can profoundly impact people's physical activity patterns. It may influence people's work-related and leisure-time physical activity through rising temperatures, extreme weather conditions, and resulting changes in human activities (e.g., urbanization, agricultural and industrial production) [3]. In addition, climate change can affect the human activities in occupational outdoor settings[4]–[6] and tourists attraction [7]. According to the surveys, the first or second element that tourists consider when choosing a tourism destination is the climate information [8], [9].

Investigations conducted in Iran shows an increase in air temperature in the coming decades [10], [11]. Moreover, Heidari *et al*., reported most climatic regions of the country are in the

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unauthorized range of thermal stress between 12 AM and 15 in the summer [12]. Also, trend investigation of the temperature changes in the coming decades showed that most of the areas affected by climate change are the central and southern regions of the country, and the highest temperature increase is expected in most parts of the country for 2075 [4].

Assuming that climate has a critical role in the definition of activities and user assignment in outdoor environments, it is necessary to understand how the impact of environmental factors in order to increase thermal comfort [13].

Many efforts have been devoted to introducing environmental indices over the last decades to assess thermal comfort in outdoor environments [14]–[18]. One of these thermal stress indices is Humidex, which are introduced by Masterton and Richardson in 1979 for the relationship of thermal comfort conditions with two important Meteorological parameters including air temperature and relative humidity [19]. The formula of this index is based on two hypotheses related to the equilibrium system for body temperature: 1) The equilibrium point of the human body when exposed to heat in stagnant air nakedly, is in the range of 27 to 30 °C, and 2) the human body is not able to overcome overheating more than 32 °C in the presence of more than 75 % humidity [20]. Accepted value of this indicator to decrease excessive heat risks is 35 °C [21]. In addition, in the temperature range between 40–45 °C, most people feel uncomfortable and in temperature above 45 °C, many tasks must be limited. The studies have shown a good relationship between Humidex and Wet bulb globe temperature (WBGT) index, as a valid and standard heat index [20], [22].

Regarding diverse climate in Iran and many outdoor activities, which are influenced by global warming and climate change, this study was conducted aiming to evaluate thermal comfort situation and trend of the changes in different climates of Iran in past decades. Humidex index was used as it has a widely known unit, °C, as an indicator of thermal stress and/or comfort. This easily understood unit is of particular importance for users such as planners and policy makers, who most likely are unfamiliar with human biometeorological terminology.

2. METHODS

2.1. Climatic categorization and synoptic stations

DeMartonne climate classification was used [23] to categorize climates of Iran. This climatic classification has recently been used in many studies in Iran [4], [17], [24]. The aridity index is the basis of this classification, it uses temperature and precipitation to determine the climate type. Accordingly, six climatic categories were determined. One of the 6 categories, semi-humid, was excluded due to the lack of appropriate and available long-term meteorological data recorded in related synoptic stations. Finally, 40 synoptic stations were included in the study from studied climatic categories to achieve more accuracy. Digital elevation model map with a resolution of 30 meters was added to the Iranian climate classification map to show the altitude classes of different regions of Iran (Fig. 1).

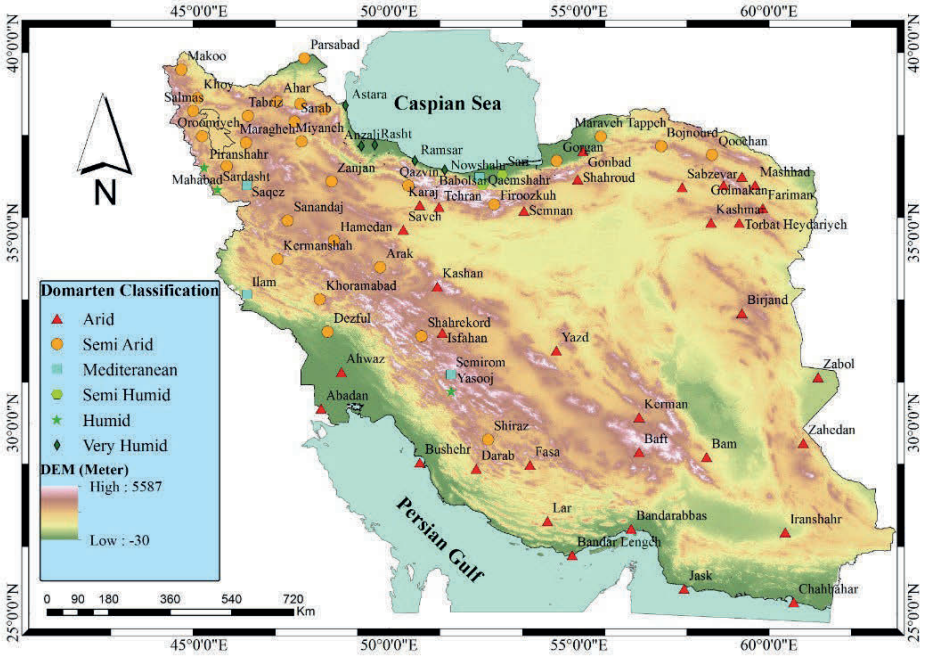


Fig. 1. Synoptic stations included the study from five climatic categories.

2.2. The Humidex Index

The Humidex 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. The interpretation of the range of this index is expressed as comfort (29≥HD ≥20), some discomfort (39≥ HD ≥30), great discomfort (45≥HD≥40), dangerous (54>HD≥46) and heat stroke imminent (>54).

The Humidex was calculated using Eq. (1) and Eq. (2):

$$HD = ta + \frac{5}{9} \cdot (Pas - 10), \tag{1}$$

$$Pas = 6.112 \cdot \left[10 \frac{7.5 \cdot ta}{237.7 + ta} \right] \cdot \frac{RH}{100}, \tag{2}$$

where *ta* is the air temperature in °C, *P* is the vapour pressure of water in millibar and *RH* is the relative humidity in percent [20].

2.3. Data collection and analysis

To investigate the changes in the humidex values in Iran, long-term metrological data of 40 synoptic meteorological stations for a 30-year period (1985–2014) were obtained from the meteorological organization of Iran.

To measure the change trend of the interest variables in the defined time series, the Mann-Kendall test was used [25]. This test has been widely suggested for general purpose

applications by meteorological organizations throughout the world [26]. This test was performed using the *Minitab v17.10* software to analyse the changing trends of the Humidex index, temperature and relative humidity during the period under study. In addition, in order to determine the actual slope of a trend over time, the Sen's Slope was used. All data analysis was conducted using SPSS v21 and graphs were made using *Microsoft Excel 2013*.

3. RESULTS

Mean of air temperature and relative humidity during a 30-year period in each climatic category are presented in Table 1. Among the summer months, July had worst thermal condition in nearly all stations. The mean and standard deviation of air temperature and relative humidity in stations, which fall in arid climate were 31.37±0.63 °C and 30.30±2.35 %, respectively (n = 20). These regions have experienced more thermal discomfort compared to other stations. Humid, very humid, Mediterranean and semi-arid were the next priorities. In addition, among the synoptic stations, Ahvaz had been in the worst thermal condition during summer, especially in July. The mean and standard deviation of air temperature and relative humidity for this station were 38.2±1.56 °C and 22.39±6.75 %, respectively. However, by taking account of the combination effects of air temperature and humidity, the station of Bandarabbas has encountered more heat discomfort. The mean and standard deviation of air temperature and relative humidity for this station were 34.1±1.1 °C and 67.3±9 %, respectively.

TABLE 1. THE MEAN AND STANDARD DEVIATION OF AIR TEMPERATURE AND HUMIDITY IN STUDIED CLIMATES FROM 1985 UP TO 2014 IN DIFFERENT MONTHS OF THE SUMMER

Climate category	**Synoptic stations**	**August (M±*SD*)**		**July (M±*SD*)**		**June (M±*SD*)**	
		Ta, °C	**RH, %**	**Ta, °C**	**RH, %**	**Ta, °C**	**RH, %**
Arid, A	Ahvaz (1), Bam (2), Bandarabbas (3), Birjand (4), Bushehr (5), Chahbahar (6), Darab (7), Fasa (8), Karaj (9), Kashan (10), Mashhad (11), Qom (12), Sabzevar (13), Semnan (14), Shahroud (15), Tehran (16), Torbat Heydariyeh (17), Yazd (18), Zabol (19), Zahedan (20)	30.0±0.63	30.91±2.17	31.37±0.63	30.30±2.35	29.99±2.66	29.86±0.73
Semi-arid, SA	Ahar (21), Arak (22), Ardebil (23), Gorgan (24), Hamedan (25), Kermanshah (26), Mahabad (27), Maku (28), Maragheh (29), Qazvin (30), Sanandaj (31), Shahrekord (32), Shiraz (33), Urmia (34), Zanjan (35)	24.75±0.87	38.53±3.30	25.60±0.65	38.92±3.00	22.93±1.04	40.30±4.00
Mediterranean, M	Saqez (36)	24.32±0.63	30.81±5.9	24.94±1.91	34.31±6.92	20.73±1.81	40.64±8.61
Himid, H & Very humid, VH	Babolsar (37), Yasuj (38), Anzali (39), Rasht (40)	26.25±0.87	66.83±3.85	26.36±0.79	65.39±4.50	24.14±1.00	65.81±5.3

Note: A: Aridity index <10; SA: 10< Aridity index <20; M: 20< Aridity index <24; H: 28< Aridity index <35; VH: Aridity index ≥35.

On the other hand, trends investigation of air temperature showed that an incremental trend of air temperature over the studied period. The comfort situation of studied synoptic stations from 1985 up to 2014 in different months of the summer showed in Table 2 and Fig. 2 based on the Humidex values. The results showed that in months of June, July and August, 60 %, 52.5 % and 60 % stations experienced 'comfort' situation. On the other hand, only 2.5 to 5 % of stations have experienced 'great discomfort' and/or dangerous situations. Other stations

were in 'some discomfort' situation. The highest average calculated Humidex was at the Bandarabbas station (48.50±2.0 °C) in July. Similarly, the Chabahar and Ahvaz stations had thermal situations from 'great discomfort' to 'dangerous', but in the next priorities. All of them are located at the southern band of Iran in the shores of the Persian Gulf and the Oman Sea. On the other hand, the lowest humidex was seen at the Ardebil station in North West of Iran (18.32±3.4 °C).

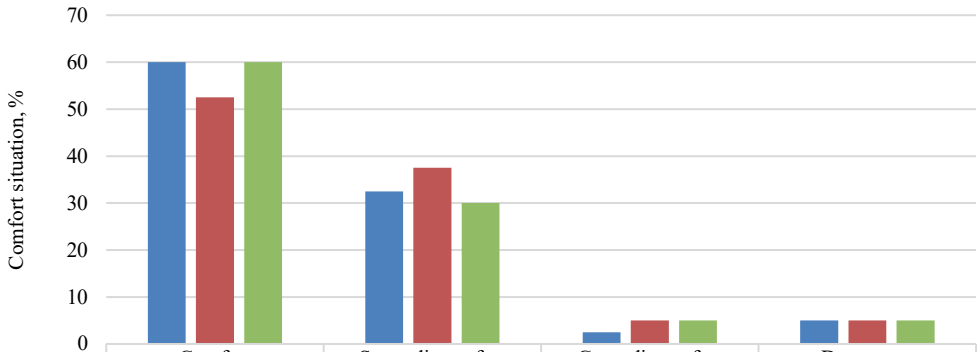
TABLE 2. THE COMFORT SITUATIONS BASED ON THE MEAN OF HUMIDEX VALUES IN STUDIED SYNOPTIC STATIONS FROM 1985 UP TO 2014 IN DIFFERENT MONTHS OF THE SUMMER

Comfort situation	**Synoptic stations ***		
	June	**July**	**August**
Comfort (20≤HD≤ 29)	(4), (7), (9), (11), (13), (15), (16), (17), (20), (21), (22), (23), (25), (26), (27), (28), (29), (30), (31), (32), (34), (35), (36), (38)	(4), (7), (11), (15), (17), (20), (21), (22), (23), (25), (26), (27), (28), (29), (30), (31), (32), (34), (35), (36), (38)	(4), (7), (8), (11), (13), (15), (17), (20), (21), (22), (23), (25), (26), (27), (28), (29), (30), (31), (32), (34), (35), (36), (38)
	*n*** = 24	*n* = 21	*n* = 22
Some discomfort (30≤HD≤ 39)	(1), (2), (8), (10), (12), (14), (18), (19), (24), (33), (37), (39), (40)	(2), (8), (9), (10), (12), (13), (14), (16), (18), (19), (24), (33), (37), (39), (40)	(2), (9), (10), (12), (14), (16), (18), (19), (24), (37), (39), (40)
	n = 13	*n* = 15	*n* = 12
Great discomfort (40≤HD≤ 45)	(5)	(1), (6)	(1), (6)
	n = 1	*n* = 2	*n* = 2
Dangerous (46<HD≤ 54)	(3), (6)	(3), (5)	(3), (5)
	n = 2	*n* = 2	*n* = 2

* The numbers in the parenthesis indicate the name of the synoptic stations (Refer to Table 1).
** Number of synoptic stations in each category

Table 3 shows humidex trend during different summer months over a 30-year period. At June, July and August, in 77.5 %, 62.5 % and 70 % of the stations, humidex index followed an upward trend, respectively. This trend was statistically meaningful in 40 %, 27.5 % and 37.5 % of stations for June, July and August, respectively (Fig. 3 and Table 3).

Accounting for Sen's Slope, the highest significant decrease in humidex was observed in the Arak station at June (−1.92 °C/decade) while the highest significant increase was in the Ardebil station at August (+1.43 °C/decade). In addition, many of stations in North West of Iran, which were in thermal comfort condition (as shown in Table 2), based on the Sen's Slope in Table 3, have accompanied with an enhancement in Humidex during studied period. On average, during the 30-year period under study, some parts of southern areas of Iran fall in the 'great discomfort' or 'dangerous' ranges, while the rest of the regions are in the 'comfort' or 'some discomfort' one.



	Comfort	Some discomfort	Grate discomfort	Dangerous
June	60	32.5	2.5	5
July	52.5	37.5	5	5
August	60	30	5	5

Fig. 2. Thermal comfort situation in different summer months (between 1985 and 2014).

TABLE 3. THE TREND ANALYSIS OF HUMIDEX IN DIFFERENT STATIONS OVER THE STUDIED PERIOD (1985–2014)

Sen's Slope Trend	**Synoptic stations ****		
	June	**July**	**August**
Upward	(1)*, (2), (3), (4)*, (5)*, (7), (8)*, (9), (10), (12)*, (14), (15), (16), (17), (21), (22)*, (23)*, (24), (25), (26)*, (27)*, (28)*, (29)*, (30)*, (31)*, (32), (34)*, (35)*, (36), (37), (39), (40)	(1)*, (3), (4), (5), (8), (10), (12)*, (14), (15), (17), (18), (23)*, (24)*, (25), (26), (27), (28), (29)*, (30)*, (33), (34)*, (35)*, (37), (39), (40)	(1)*, (2), (3), (4)*, (5)*, (6), (8), (9), (10), (11), (12), (15)*, (17)*, (20), (23)*, (24)*, (25), (26), (27)*, (28), (29)*, (30)*, (31), (34), (35)*, (37)*, (39)*, (40)*
	*n**** = 32	*n* = 25	*n* = 28
Downward	(6), (11), (13), (18), (19)*, (20), (33), (38)	(2), (6), (7), (9), (11), (13)*, (16), (19)*, (20), (21), (22)*, (31), (32), (36)*, (38)	(7), (13), (14), (16), (18), (19), (21), (22)*, (32)*, (33), (36), (38)
	n = 8	*n* = 15	*n* = 12

* Significant at the amount of less than 0.05.
** The numbers in the parenthesis indicate the name of the synoptic stations (Refer to Table 1).
*** Number of synoptic stations in each category

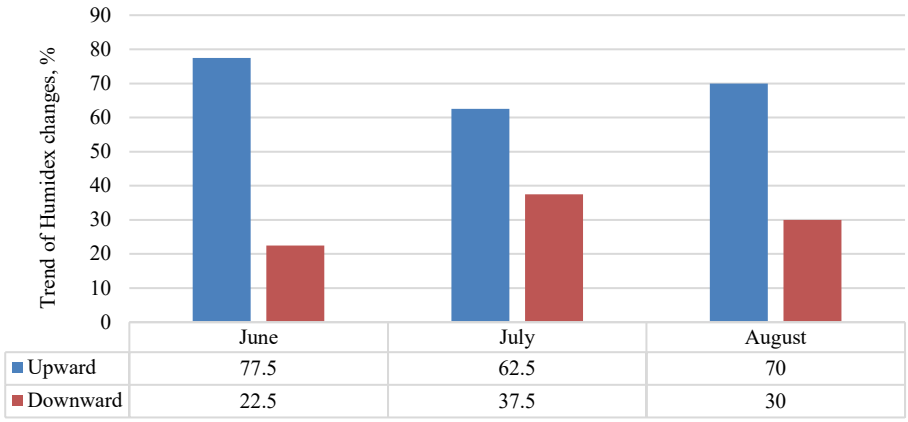
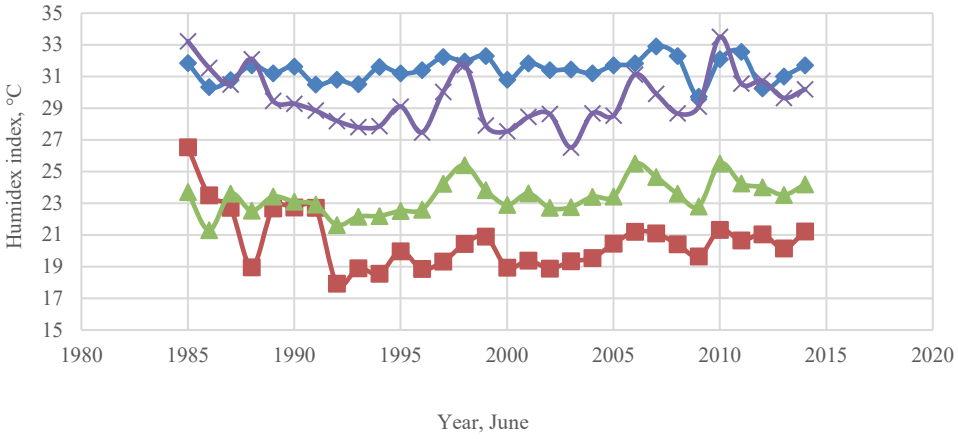
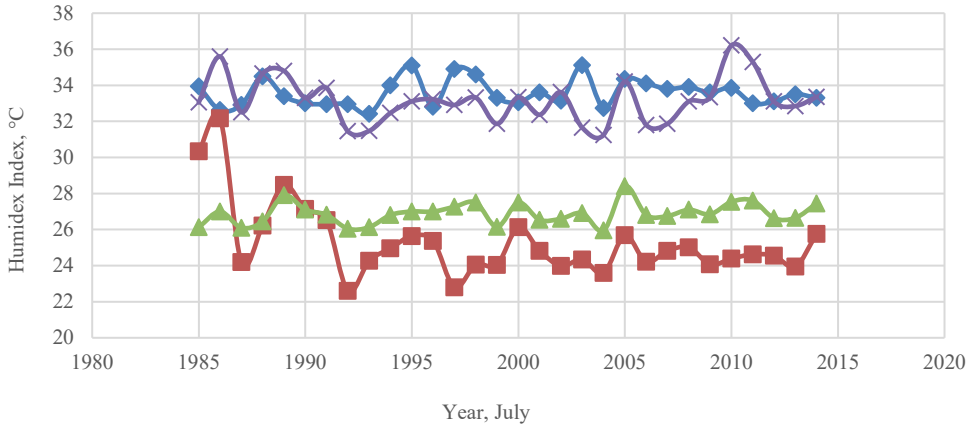


Fig. 3. Trend analysis of Humidex changes in different summer months (between 1985 and 2014).

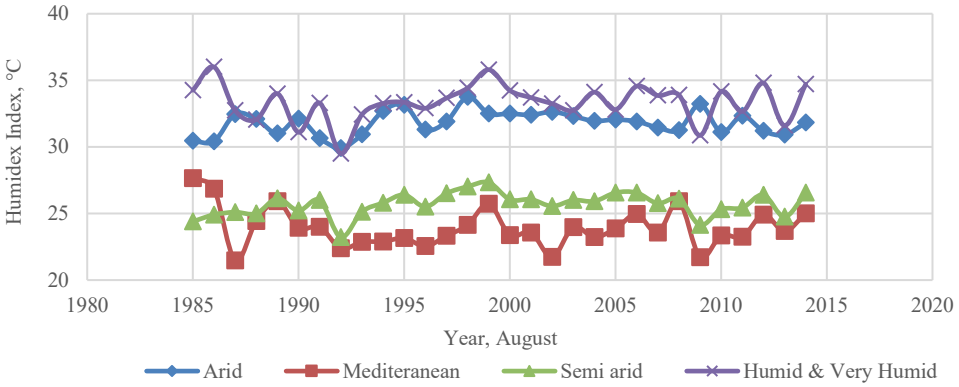
The humidex trend of the different climate regions at summer months in Iran from 1985 to 2014 is shown in Fig. 4. Fluctuations exist in different climate regions during the June, July and August in the years under study. In overall, in arid, semi-arid and humid regions, this trend is somewhat incremental while in humid and Mediterranean regions this trend is accompanied with a decrement.



(a)



(b)



(c)

Fig. 4. Fluctuations of Humidex values in different climates and summer months: a) June; b) July; c) August (between 1985 and 2014).

4. DISCUSSION

The study covered different climates of Iran in all summer months to offer a clear view of the changes in comfort situation throughout the Iran in past decades.

In overall, the weather conditions in Iran during the different summer months do not provide much change in the selected stations. However, as shown in Table 1, thermal condition in July generally was worst compared other months. In addition, the temperature trend investigation showed that a mostly incremental trend in the air temperature for most of the climates such as the arid, semi-arid and humid regions. However, the changing trends in relative humidity in all regions was decremental throughout the years under study. Heidari *et al.*, reported that a temperature increase with different intensities is expected in the next decades. In addition, the pattern of variations was almost the same for all stations studied [4].

According to Table 2, the highest Humidex values are observed in stations that had the lowest latitude, which may be due to the higher angle of sunlight causing higher

temperatures [27]. The stations with low latitude demonstrated by green colour in the map of Fig. 1. Revadekar *et al.*, showed that the trends of temperature extremes will be change with general warming in low latitude and elevation. So that, in the low latitude of South Asia, heat waves are expected to increase [28]. Therefore, parts of the southern band of Iran (Persian Gulf coast and the Oman Sea) fall within the 'great Discomfort' and the 'dangerous' category of the Humidex index.

Factors, such as vicinity to Persian Gulf coast and the Oman Sea, low latitude of the region, as well as high humidity along with high temperature has resulted in uncomfortable thermal situations in these areas. By moving to higher latitude or further away from the southern coast of the country, the Humidex values were decreased [27]. The temperature trends in Iran from 1960 to 2010, showed that the temperature has predominantly incremental trend in the coastal stations of the Persian Gulf [29]. However, in southern areas of Iran, the cities of Ahvaz, Bushehr and Bandarabbas have the longest period of time with unfavourable and extremely unfavourable climatic conditions for outdoor activities.

Conversely, in the northern half of Iran, the appropriate summer season provides the best climatic conditions for outdoor activities. High altitude, high latitude and mountainous nature of the western, north-western and north-eastern regions create special local conditions that during summer months, the effect of high pressure on the sea and the surface heating are moderated and a suitable climatic situation is provided [30]. In addition, the role of Caspian Sea as a high-pressure centre in the summer and distributing humid air to the prevailing winds can cause formation of Northeast wind at Anzali, Northwest wind in Babolsar and Western wind in Gorgan station [31]. According to the results of the Mann-Kendall test (Tables 3), at June, July and August, in 77.5, 62.5 and 70 % of the stations, humidex index followed an upward trend, respectively, and this trend was statistically meaningful in 40 %, 27.5 % and 37.5 % of stations for June, July and August, respectively (Fig. 3). In addition, the highest significant increase based on the Sen's Slope was in the Ardebil station at August (+1.43 °C /decade) while the highest significant decrease in humidex was observed in the Arak station at June (−1.92 °C/decade). Many of stations in north west of Iran, which were in thermal comfort condition (as shown in Table 2), based on the Sen's Slope in Table 3, have accompanied with an enhancement in Humidex index over time. However, these stations still locate in the comfort situation.

The changing trends of the Humidex, which is based on temperature and humidity, were accompanied with a gradually increase in arid and semi-arid regions and a reduction in Mediterranean and humid regions. The reduction trend continued until 1992 and then an upward trend can be seen for all months (Fig. 4). In the months of June, July and August, despite the uniform macro-climatic conditions of the central regions of the country, the effective role of local factors and mountains show different climatic conditions for outdoor environments in the geographical area between two large deserts (Lut and Dasht-e Kavir) compared with their neighbouring areas. In summer, the eastern heights in the cities of Mashhad, Birjand, Torbat Heydariyeh and mountains of Makran and South Zagros in Shiraz and Kerman stations create comfort to semi comfort climatic conditions for outdoor activities. The similar findings can be seen in the study of zoning of tourism climate in Iran using Tourism climate index (TCI) [30]. The results of the study showed that annual temperature changes followed an upward trend in 85 % of the stations. The highest rising temperature was observed at August. Tabari *et al*. found that the country's arid regions had increased from 18 % to 54 % over the consecutive years. In addition, reduction in precipitation and rising temperatures have caused creation of more arid regions in Iran in recent decades [32].

Nowadays, knowledge of weather conditions has become an important principle in outdoor activities for related policymakers. Forecasting the weather gives an opportunity to properly

plan outdoor activities for the coming months and seasons. Although Humidex index is initially used to predict weather condition, due to the fact that no complicated measuring devices are needed, its suggested and used by meteorological organizations in many countries for the assessment of thermal stresses of indoor and outdoor environments, forecasting services and issuing timely warnings to the general public [33]. Therefore, it can be expected that the use of forecasting maps prepared by local meteorological organizations based on the Humidex index can be very useful for planners and decision makers to plan the different outdoor activities.

5. CONCLUSION

Trends investigation of air temperature showed an incremental trend of air temperature over the studied period. Among the summer months, July had worst thermal condition in nearly all stations and arid regions have experienced more thermal discomfort compared to other climates. In overall, in southern areas of Iran, the cities of Ahvaz, Bushehr and Bandarabbas have the longest period of time with unfavourable and extremely unfavourable climatic conditions for outdoor activities. Conversely, in the northern half of Iran, especially in North West areas, the appropriate summer season provides the best climatic conditions for them. Overall, our findings revealed that the use of forecasting maps prepared by local meteorological data based on the Humidex index could be very helpful for planners and decision makers to plan different outdoor activities.

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