Temporal and spatial analysis of thermal stress and its trend in Iran

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Abstract
The study was conducted to determine thermal stress and its trend in Iran. The atmospheric variables of 304 synoptic stations, including mean temperature, relative humidity, wind speed and cloudiness, for the period 1961–2010, were used to identify the thermal stress conditions in Iran. These data were prepared on a daily basis from the Iran Meteorological Organization. Physiologically equivalent temperature (PET) and standard effective temperature (SET*) were used to identify thermal stress. Also, thermal stress was studied with a simple linear regression method and at a 95% confidence level. The results of the study revealed that in Iran each location can experience different types of environmental conditions throughout the year. At a specified time, thermal stresses of different intensities can be seen. The other results showed that the mountainous regions, especially the highlands of the northwest, along with the Zagros and Alborz mountains, had the highest coefficient of variability (> 50%). Also, the southern regions of Iran have both monthly and annual scales with the least coefficient of variability (< 20%) in bioclimatic conditions. In general, a diversity of bioclimatic conditions is evident in Iran both temporally and spatially. The other part of the study determined that heat and cold stress and heat comfort had a positive trend (fewer than 60 stations) in parts of Iran, a negative trend in some other parts (more than 50 stations), and no specific trend in the remaining parts (more than 250 stations). Most of the northern stations, especially on the Caspian coast, have been shown to have a positive trend in the event of cold stress. Indeed, extreme bioclimatic conditions (very cold and hot conditions) have been rising in both the southern and northern latitudes of the country. Even in southern parts, a positive trend of cold and very cold conditions can be observed at some stations.

Keywords
bioclimatic condition, bioclimatic indices, cold stress, heat stress, Iran, thermal comfort
The science of studying the effects of climate on living organisms is called bioclimatology (Munn, 1987). Most human activities are affected by weather and climatic elements. In general, each bioclimatic region provides the conditions for the development of a specific ecosystem (Leathwick et al., 2003). Different planning in the health, agriculture and tourism sectors is not feasible without considering the weather and climatic conditions of each location. With the growth of population, intense consumption and the reduced natural resources of the Earth, atmospheric conditions have undergone significant changes due to human activities. Adjusted extreme bioclimatic conditions can lead to many problems in the environment. For example, many atmospheric pollutants are generated by the high consumption of energy in the heating and cooling sector, as well as the provision of food and facilities for the population of the planet (Nauges and Weejer, 2017). Climatic changes and the presence of thermal stress in recent years have attracted the attention of researchers to bioclimatic research (Basarin et al., 2018). Due to the rapid increase in greenhouse gas emissions, the interest in this subject is also increasing (Anup, 2017). Bioclimatic research conducted worldwide has a far wider thematic diversity. Recognition of the bioclimatic conditions in each location has been done with specific objectives. The results of bioclimatic research are often used across a wide range of fields, such as ecology, agriculture, architecture, urban planning, tourism, health and transportation (O’Donnell and Ignizio, 2012). An awareness of the bioclimatic conditions of each location has particular importance. Therefore, the climate of a place in general, and sometimes each element of the atmosphere, is studied individually. Many studies have been performed on extreme temperatures and precipitation (Frich et al., 2002). The results of these studies suggested that frost days have shown a significant decrease around the world. On the other hand, the frequency of heavy precipitation events is increasing (IPCC, 2013).

Generally, thermal stress is associated with many environmental issues of interest to researchers. In the health sector, the relationship between the incidence of disease, mortality and thermal stress in different parts of the world has been confirmed by researchers (Schwartz et al., 2004; Michelozzi et al., 2007; Analitis et al., 2008). The results of such research indicate that bioclimatic conditions have both a direct and an indirect effect on community health (Rivero et al., 2015; Mohammadi and Karimi, 2018). The tourism industry is one activity whose success is a function of weather and climatic conditions (De Freitas, 2003; Matzarakis et al., 2013; Anup, 2017).

Today, tourism is an important factor in sustainable development of societies (Matzarakis and Nastos, 2011). Indeed, many of the major tourist areas of the world have achieved success due to favourable climatic conditions (Didaskalou and Nastos, 2003; Hamilton and Lau, 2005). For example, Rodríguez-Algeciras et al. (2020) confirmed the role of climate information in the development and success of Barcelona’s tourism industry. The importance of atmospheric conditions in architecture and urban planning is also evident. In building design and urban planning, atmospheric elements such as solar radiation, solar radiation angle, humidity and temperature are of special interest to researchers (Nikolopoulou and Lykoudis, 2006; Thorsson et al., 2007).

Any atmospheric element individually and in relation to each other can be a function of the type of materials, the direction of the building and the passageways. Indeed, for energy management and reducing its consumption, which can affect climate change, the weather elements and climatic conditions in architecture should be taken into account (Givoni, 1976). Considering the changes and fluctuations of atmospheric elements over time, many studies have been conducted to identify the trends of climate and climatic conditions. Nastos and Matzarakis (2013) studied the trend of bioclimatic conditions of Athens University Campus in Greece based on the physiological equivalent temperature (PET) index. The results of their research revealed that the extreme thermal fluctuations had a significant increase. In similar studies, using the PET index, the thermal comfort trend was examined by Gulyás et al. (2006) and Bouyer et al. (2007), respectively, on the town of Szeged, Hungary, and at the Stade de France, Paris, and Atatürk Olympic Stadium, Istanbul. Cao et al. (2016) and Wang et al. (2019) studied the thermal comfort of some cities in China. In these studies, predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) indices were used. The results suggested that the thermal comfort in the studied cities varies considerably from spatiotemporal aspects. Staiger et al. (2019) have introduced appropriate indices for human bio-meteorological studies. They believe that the four PET, standard effective temperature (SET*), universal thermal climate index (UTCI) and perceived temperature (PT) indices are useful for such studies. Due to the influence of climate on many human activities, the recognition of bioclimatic conditions has been considered by researchers in the field of atmospheric sciences. Nevertheless, few studies have been conducted on recognizing the bioclimatic conditions and its trend in Iran. These studies have been conducted with different perspectives such as tourism (Kamyabi and Tarhami, 2013), architecture (Jahanbakhsh and Ismailpour, 2004; Ahmadi and Shaemi, 2013), medicine
and health (Mohammadi and Karimi, 2018), and on small areas of Iran. However, in none of these studies has the bioclimatic conditions of the whole of Iran and its trend been studied. The present research fills the gap of such studies. Based on numerous bioclimatic indices, the bioclimatic conditions of Iran are identified and then the trend of each of the bioclimatic conditions is studied.

2 | DATA AND METHODS

Iran is a vast country (1.648 million km²) in the southwest of Asia. With its high mountains and lowlands area, Iran is one of the countries with the highest climatic diversity in the world and it has the complete four seasons. In fact, the climatic diversity of Iran is due to its large area, complex topography and also its location in the path of different air masses during the year. The role of the Zagros and Alborz mountains ranges in the spatial arrangement of temperature and precipitation is significant. That is why the border areas of Iran’s climate largely follow its topography. In addition to local factors such as roughness, altitude, latitude and distance from the seas, the other elements such as Azores high, Siberian high and westerly winds are the most important factors in controlling Iran’s climate.

This research was performed in order to understand the bioclimatic conditions of Iran and its trend. To achieve the research objectives, a combination of atmospheric data and the geographical co-ordinates of 304 stations were used in Iran (Figure 1). The atmospheric data used included air temperature (°C), relative humidity (%), wind speed (m·s⁻¹) and cloudiness (Octas). These climatic variables were prepared as the daily mean of 304 synoptic station data from January 1, 1980, to December 31, 2010, from the Iran Meteorological Organization. Atmospheric data at each station may have shortcomings. In the present study, for each station, the days that lacked data were identified. Days with a lack of data were excluded. Finally, only days that had complete data for atmospheric variables were analysed.

The bioclimatic conditions (in relation to human thermal sensation) depend on the geographical location, atmospheric variables, vegetation and physiological characteristics of humans (Lin and Matzarakis, 2011). Under the same conditions, different physiological characteristics (age, sex, height, weight) can create a different heat sensation (Giamalaki and Kolokotsa, 2019; Wang et al., 2019). Therefore, in addition to the atmospheric variables and geographical location which vary for each location, constant co-efficients were used for human cover (clothing) and physiological characteristics (Yochihara et al., 1993). Data mentioned in the RayMan software were analysed. Generally, to study thermal comfort in urban situations and any climatic region, using this software is necessary. Another advantage of RayMan is that it is available for general use.

In recent years, various methods and models have been developed to study bioclimatic conditions, for which various indices are used, which can be calculated using atmospheric variables based on empirical and mathematical equations. In the present study, the bioclimatic conditions in each station were calculated based on the PET and SET* indices. To estimate bioclimatic conditions using the mentioned indices, climatic variables and different physiological variables were used.

FIGURE 1  (a) Location of Iran in the Northern Hemisphere; and (b) altitude map of Iran and the geographical positions of some of its synoptic stations
3 | ESTIMATING THERMAL STRESS BASED ON BIOCLIMATIC INDICES

The most famous bioclimatic indices express the human feelings to the thermal environment. These indices are defined in the standard laboratory environment. The SET* index is one of these common indices. It is the standard temperature a person experiences in humidity conditions of 50%, wind speed < 0.1 m/s⁻¹, an average radiation temperature equal to the average air temperature, activity met 1, and the clo coverage of 0.6%. The SET* index was first introduced by Gagge and Nishi (1977) and then accepted by the ASHRAE Institute in 1986. This index is based on thermal balance equations in combination with personal factors and the amount of metabolism (Gagge et al., 1986). The PET index is one of the other indicators used to assess bioclimatic conditions. It is based on the heat balance of the human body. Air temperature, wind speed, relative humidity and global solar radiation are the most important elements in the calculation of this index. This index was recommended by Part (2008) in order to assess the thermal component of different climatic regions. Also, the PET index is based on the Munich Energy-Balance Model for Individuals, which describes the human body's thermal conditions physiologically (Fanger, 1972; Höppe, 1999). This index is based on degrees Celsius. Therefore, tourists and planners of the tourism sector can easily use the results of this index. To calculate the bioclimatic conditions based on the SET* and PET indices, a very complex calculation is required, which is time-consuming.

In this research, RayMan software was used to calculate and estimate the bioclimatic conditions of Iran. In addition to atmospheric variables, personal physiological conditions were also considered in the bioclimatic calculations (height: 175 cm, weight: 75 kg, age: 35 years, gender: male or female, activity: 80 w; clothing: 0.9 clo) (Matzarakis et al., 1999). To calculate the bioclimatic conditions, the RayMan model has been confirmed by many researchers (Matzarakis et al., 2010). In the present study, the bioclimatic conditions of 304 synoptic stations of Iran were calculated, and Iran’s bioclimatic map was then prepared based on monthly and yearly time scales. Bioclimatic maps are essential for the rapid detection of climatic territories (climatic regions) and global patterns of vegetation cover (Pesaresi et al., 2014). In order to know more about changes in the environmental conditions at spatiotemporal scales, the maps of Iran’s variability co-efficient were also plotted and analysed. Finally, the trends in the bioclimatic conditions of Iran’s stations were also identified.

4 | ESTIMATING THE TREND OF BIOCLIMATIC CONDITIONS BASED ON SIMPLE LINEAR REGRESSION

Having estimated the bioclimatic conditions of Iran’s synoptic stations, a trend analysis of the bioclimatic conditions of synoptic stations was also carried out. There are various methods for trend analysis. In this research, a simple linear regression (bivariate regression) method at 95% confidence level was used to identify the bioclimatic conditions. Regression is a statistical test that examines and models two variables (independent and dependent). In linear regression, there are two variables with a quantitative scale (distance or relative), which is an independent variable (time) and another dependent variable (bioclimatic condition). Indeed, in simple linear regression, causal relationships of variables are examined. In this type of regression, the values of the dependent variable (bioclimatic conditions) are estimated from the independent variable (time) using a linear equation (James and Haneley, 2016). Therefore, linear regression is an acceptable prediction method, while also being the simplest method for describing the fit of a function (Kotu and Deshpande, 2015). The mathematical equation for the simple linear regression is (Zou et al., 2003):

\[ Y = \beta_0 + \beta_1 X + \varepsilon \]  

where \( Y \) and \( X \) represent the scores for the bioclimatic condition variable on the criterion and predictor variable, respectively; the parameters \( \beta_0 \) and \( \beta_1 \) are constants describing the functional relationship in the variables; \( \beta_1 \) identifies the change along the \( Y \) scale expected for every unit changed in fixed values of \( X \) (represents the slope or degree of steepness); \( \beta_0 \) identifies an adjustment constant due to scale differences in measuring \( X \) and \( Y \); and \( \varepsilon \) represents an error component for each bioclimatic condition. The portion of the \( Y \) score that cannot be accounted for by its systematic relationship with values of \( X \).

5 | RESULTS

5.1 | The annual average of Iran’s bioclimatic conditions

There is a great deal of similarity between the annual bioclimatic conditions estimated by the PET and SET* indices. The studied indices have classified bioclimatic conditions in nine conditions: very cold, cold, cool, slightly cool, comfort, slightly warm, warm, very warm and hot. The estimated annual average bioclimatic
conditions of Iran revealed that the cold and very cold conditions have not been experienced. Generally, according to the studied indices, hot conditions are reported only in a very small part of Iran (adjacent regions of the Persian Gulf and the coasts of Bushehr). Also, in the highlands of the Alborz Mountains, Zanjan, Kurdistan, Hamadan, cool conditions have been observed. In the north and northwest of Iran, slightly cool conditions have been reported. Thermal comfort condition can be seen in a relatively wide domain of Iran, including the northwest, a small part of the west, as well as in eastern and central parts. In the vicinity of areas with thermal comfort, a slightly warm condition is sporadically distributed in the northeastern and central parts of Iran. The warm condition has been reported in parts of the south and southwest and lowlands of central Iran. Severe heat stress (very warm and hot conditions) has been experienced only in regions of southern and southwestern Iran (Hormozgan, Khuzestan and Bushehr provinces). Generally, the average annual bioclimatic conditions based on the studied indices revealed that the central lowlands and southern latitudes of Iran (south, southeast and southwest) showed different intensities of heat stress. However, in the highlands and northern latitudes, slight cold stress (slightly cool and cool conditions) proved to be dominant.

A slight cold stress can be observed in parts of central Iran (Kerman province), due to the high altitude of the region, and the northwest as well as sporadically in the Alborz and Zagros mountains. Thermal comfort can also be seen in the adjacent areas. The areas where thermal comfort has been reported include high-altitude areas and northern latitudes of Iran (Figure 2).

5.2 The variations in annual bioclimatic conditions in Iran

The climate is fluctuating everywhere. These fluctuations are not equal in all places. For this reason, the coefficient of variability of climate conditions in Iran was calculated. The annual variability coefficient of Iran’s bioclimatic conditions indicated that the coefficient of variation was very high (about 50%) in parts of the northwest, northeast and along the highlands. Indeed, the high variability coefficient of these areas suggests that during the year, different climatic conditions have been observed in the regions. More simply, during the year, one can see completely different bioclimatic conditions in these areas. Therefore, the diversity of the experience of the bioclimatic conditions in the mentioned areas has led to a high coefficient of variability. Specifically, the coefficient of variability of the bioclimatic conditions has decreased towards the lower elevation regions and southern latitudes of Iran: it has been estimated to be < 15% in Ilam province to the southeast. In these areas, we cannot see all nine bioclimatic conditions throughout the year. Some of these bioclimatic conditions such as very cold and cold conditions have never been reported in these regions. For example, very cold, cold and even cool bioclimatic conditions have not been reported in such areas. On the other hand, in these areas, heat stress has been reported in

![Figure 2](image_url)
different intensities throughout the year. Even in winter, heat stress has been experienced in many parts of southern Iran. In other parts of Iran, the co-efficient of variation has been 15–30%. The estimated variation co-efficients for PET and SET* indices are very close. Nevertheless, based on the two indices, the regions with the maximum and minimum variability co-efficients almost match each other (Figure 3).

5.3 | The trend of Iran’s bioclimatic conditions

According to the studied indices, bioclimatic conditions are classified into nine major groups. In the present study, the daily environmental conditions of 304 synoptic stations along with the frequency of their occurrence in each month and each year were calculated. The trends in the bioclimatic conditions of Iranian synoptic stations were then determined by simple linear regression at a 95% confidence level. The trend maps of each bioclimatic condition of Iran’s synoptic stations are presented individually.

5.4 | The trend of very cold bioclimatic conditions

Based on the PET index, the trend of very cold bioclimatic conditions is similar in many synoptic stations. Many of the northwestern stations in Iran towards the north of Fars province have shown a positive trend. In other words, the very cold bioclimatic conditions in these areas have often increased. However, there are other stations in which the very cold bioclimatic conditions had shown a negative trend or no trend. An important point in examining the trend of very cold bioclimatic conditions is that some of the stations where the nature of their climate is warm have shown an ascending trend in very cold bioclimatic conditions. For example, stations in Ilam and Khuzestan provinces have experienced a growing trend. The positive trend of very cold bioclimatic conditions does not mean a general cooling of the area; rather it suggests that the number of occurrences of the present-day bioclimatic conditions has grown compared with the past.

Therefore, it can be concluded that climatic anomalies have occurred in this area. Kurdistan province is one of the cold regions of Iran. In this region, eastern stations have shown an ascending trend of very cold bioclimatic conditions. There is a clear difference between the estimation of the bioclimatic conditions of the PET index with the SET* index. On the other hand, based on the SET* index, very cold bioclimatic conditions have been without trend in most of Iran’s synoptic stations. In general, in northwestern Iran, stations with a positive and a negative trend can be observed, while other stations have not shown a definite trend (Figure 4).

5.5 | The trend of cold bioclimatic conditions

According to the studied indices, cold bioclimatic conditions in the north and northwest of Iran have shown a

![Figure 3](image-url) Average annual the co-efficient of variation of bioclimatic conditions in Iran based on the indices studied: (a) standard effective temperature (SET*); and (b) physiologically equivalent temperature (PET)
growing trend. However, cold bioclimatic conditions in many stations have experienced no trend. The SET* index has a different estimate than the other two indices. Based on this index, many of the northern stations have shown a descending trend in the occurrence of cold bioclimatic conditions. The spatial distribution of cold bioclimatic conditions has not been regular across the different regions of Iran. In Isfahan, Yazd and Fars provinces, one can observe stations with positive, negative and no trends. In general, most of the stations on the southern half of Iran often indicated trend-free bioclimatic cold conditions, but there are also stations where the trend has had a significant rise at the 95% confidence level. A comparison of the measurement indices showed that the cold bioclimatic condition of most of the northern and western stations of Iran have an ascending trend. However, there are also stations with a diminishing trend and without trend (Figure 5).

**FIGURE 4** Trend of very cold bioclimatic conditions in synoptic stations: (a) standard effective temperature (SET*); and (b) physiologically equivalent temperature (PET)

**FIGURE 5** Trend of cold bioclimatic conditions in synoptic stations: (a) standard effective temperature (SET*); and (b) physiologically equivalent temperature (PET)
5.6 | The trend of cool bioclimatic conditions

Based on the PET index, cool conditions had a positive or no trend in the northern half of Iran. Only three stations in the northern half of the country in the provinces of Tehran and Semnan have shown a descending trend (negative trend). Further, based on these indices, many stations in the northwest of Iran had no trend in the cool conditions. In comparison, in the southern part of Iran, there are many stations with a declining trend. The SET* index showed a different estimate of the other index. According to this index, many stations in the southwest (especially in Ilam, Khuzestan and Fars provinces) have a decreasing trend. In contrast, in the northwest of Iran, an ascending trend has been observed in the cool bioclimatic conditions (Figure 6).

5.7 | The trend of slightly cool bioclimatic conditions

According to the studied indices, there is no significant trend in the slightly cool bioclimatic conditions in most of Iran’s stations. There are scattered stations with a positive trend and negative trends in the country. According to the PET index in the southwest and south of Iran, and the Caspian Sea coast, there are many stations with positive trends. The SET* index also showed that cool conditions had a positive trend in parts of Kerman, Sistan and Baluchistan, Isfahan, Chaharmahal and Bakhtiari, and the northeast of Iran (Figure 7).

5.8 | The trend of thermal comfort bioclimatic conditions

The study of comfort conditions based on the indices showed that most of the stations in Iran had no significant trend. Nevertheless, some stations in Iran have seen a negative trend as well. Based on all indices, some of the southern parts of Iran have shown a positive trend. It seems that these conditions have often occurred during the cold seasons (fall and winter). There are also stations in the northern part of the country reporting a decline in their thermal comfort condition. Perhaps the diminishing trend of thermal comfort conditions in the northern stations of Iran can be attributed to the rise of heat and cold stress in the region. Indeed, in the north of Iran, thermal stress has increased significantly (Figure 8).

5.9 | The trend of slightly warm bioclimatic conditions

The growing or falling trend of slightly warm conditions in Iran has been very irregular. Based on the indices studied, in some of the northern and northwestern stations of Iran, one can observe a descending trend of slightly warm conditions. However, in these areas, there are still stations with a rising slightly warm condition. In western Iran, there are stations with a positive and a negative trend. Generally, the no significant trend of slightly warm conditions has been reported in most stations in Iran (Figure 9).

**FIGURE 6** Trend of cool bioclimatic conditions in synoptic stations: (a) standard effective temperature (SET*); and (b) physiologically equivalent temperature (PET)
5.10  The trend of warm bioclimatic condition

The trend of warm bioclimatic condition in synoptic stations of Iran is very irregular. In general, northwestern stations in Iran often have a positive trend in the occurrence of warm conditions. However, in this part there are also many stations with a negative trend. On the other hand, southwestern and central Iran have not shown any significant trend. A positive trend has been reported in some stations in Sistan and Baluchistan province. In general, the number of stations with no significant trend in the Iran is more than that of positive and negative stations (Figure 10).

5.11  The trend of very warm bioclimatic condition

The analysis of the trend of very hot conditions based on the indices showed that in the north of the country, many
stations have a descending trend. Most of these stations are located in the west and northwest of Iran. Nevertheless, stations with a positive trend can be observed in the same region. According to the PET index, southern regions reported a significant rise in very warm conditions. However, according to the SET* index, the southern stations of Iran had no specific or positive trend in the occurrence of very warm conditions (Figure 11).

5.12 | The trend of hot bioclimatic conditions

The trend of diminishing hot conditions can be observed according to the indices studied in most parts of Iran. In the province of Kerman as well as in the northwestern and western provinces, there has been a significant decline in the occurrence of hot conditions. On the other

**FIGURE 9**  Trend of slightly warm bioclimatic conditions in synoptic stations: (a) standard effective temperature (SET*); and (b) physiologically equivalent temperature (PET)

**FIGURE 10**  Trend of warm bioclimatic conditions in synoptic stations: (a) standard effective temperature (SET*); and (b) physiologically equivalent temperature (PET)
hand, a positive trend in the occurrence of hot conditions has been observed in some stations. Finally, hot conditions in southwestern and central Iran had no significant trend (Figure 12).

In general, comparing the studied indices, most of the bioclimatic conditions at different stations during the study period were without trend. On the other hand, some stations have shown a positive or a negative trend in each of the bioclimatic conditions. Based on the PET index, 36 stations reported a positive trend and 23 stations reported a negative trend. In contrast, 245 stations did not show any significant trend in the event of very cold conditions. The SET* index also showed that very cold conditions in 288 synoptic stations of Iran were without trend, while nine and seven synoptic stations experienced positive and negative trends, respectively. In general, very cold, cold, cool, slightly cool, comfort and slightly warm conditions had a positive trend in several stations. In contrast, warm, very warm and hot conditions showed a negative trend in many stations. Details of the number of...
stations and their bioclimatic conditions are given in Table 1.

| Bioclimatic conditions | Indices | Positive trend | No trend | Negative trend | Sum stations |
|------------------------|---------|----------------|----------|----------------|--------------|
| Very cold              | PET     | 36             | 245      | 23             | 304          |
|                        | SET*    | 9              | 288      | 7              | 304          |
| Cold                   | PET     | 51             | 237      | 16             | 304          |
|                        | SET*    | 39             | 241      | 24             | 304          |
| Cool                   | PET     | 38             | 249      | 17             | 304          |
|                        | SET*    | 62             | 215      | 27             | 304          |
| Slightly cool          | PET     | 29             | 261      | 14             | 304          |
|                        | SET*    | 25             | 263      | 16             | 304          |
| Comfort                | PET     | 19             | 272      | 13             | 304          |
|                        | SET*    | 32             | 255      | 17             | 304          |
| Slightly warm          | PET     | 23             | 264      | 17             | 304          |
|                        | SET*    | 29             | 256      | 19             | 304          |
| Warm                   | PET     | 24             | 257      | 23             | 304          |
|                        | SET*    | 17             | 268      | 19             | 304          |
| Very warm              | PET     | 24             | 235      | 45             | 304          |
|                        | SET*    | 23             | 244      | 37             | 304          |
| Hot                    | PET     | 23             | 214      | 67             | 304          |
|                        | SET*    | 20             | 215      | 69             | 304          |

Metzger et al. (2012) identified the world's bioclimatic regions. According to their research, there are 18 bioclimatic regions. Similar researches were performed by Rivas-Martínez (2008) and Pesaresi et al. (2014). In the present study, the bioclimatic regions of Iran were identified on monthly and annual scales.

A simple linear regression method was used to estimate the bioclimatic conditions of interest. The significance of the bioclimatic conditions was evaluated at a 95% confidence level. The estimated bioclimatic maps of Iran on the annual scale were not significantly different from each other. Based on these maps, the heat stress was observed in different intensities from southern parts of Ilam province along the western and southwestern parts of Iran to the south of Sistan and Baluchistan province. In these areas as well as in lowland areas (central and the northern coast of the Iran), heat stress has been reported in different intensities. On the other hand, heat stress has been less severe in the northern and northeastern parts of Iran.

An annual assessment of the bioclimatic conditions showed that the highland regions have colder conditions than lowland areas of Iran. Therefore, it can be concluded that the elevation factor has a more of a determinant role in specifying the bioclimatic conditions of Iran than latitude. The annual average bioclimatic maps showed that in Iran, very cold, cold and hot conditions...
were not observed. Based on the studied indices, the slightly warm and warm conditions have been experienced across a broad scope of Iran. On average, these conditions have been reported in > 30% of Iran. Regarding the wide range of areas affected by heat stress, it can be stated that in most parts of Iran, heat stress with different intensities has a higher degree of dominance than cold stress. However, the monthly analysis of bioclimatic conditions has a significant difference with the annual mean of bioclimatic conditions. Indeed, according to monthly statistics, it can be stated that over the course of the year, different bioclimatic conditions prevail over Iran.

According to the results, the mountainous regions, and especially the highlands of northwest of Iran, plus the regions along the Zagros and Alborz mountains, have had the maximum monthly variability co-efficient. This result is consistent with Çalışkan et al. (2013), which emphasizes the role of altitude and albedo in the variability of bioclimatic conditions of the region. The high coefficient of variability in these areas means that at any time of the year (monthly scale), different bioclimatic conditions have been experienced in Iran. Therefore, due to the experience of various bioclimatic conditions, these areas have a high co-efficient of variability. In contrast, the southern regions of Iran have the minimum co-efficient of variability on both the monthly and annual scales. Since these regions have never reported very cold and cold conditions, they are therefore relatively flat in the climate and the low co-efficient of variation of these areas can be justified.

After identifying the bioclimatic conditions, for all stations in Iran, the annual trends of the very cold, cold, cool, slightly cool, comfort, slightly warm, warm, very warm and hot conditions were analysed. Based on a simple linear regression at a 95% confidence level, the trend of very cold conditions indicated that most stations in Iran are without a significant trend. However, stations in the northeast, north and northwest proved to have a positive trend. In contrast, some stations (including some stations in the north provinces, east and west of Isfahan province, and north of Fars province) reported a negative trend in very cold conditions. In general, the number of stations with a positive trend of very cold conditions was higher than that of the negative-trend stations.

Very cold conditions are among the extreme weather conditions. It can be said stated that although very cold climatic conditions in most Iranian stations do not have a significant trend, the number of stations with a positive trend is reported to be more than that of negative-trend stations. The trend of cold conditions was also studied in Iran. The results showed that some stations in the northwest, west and southeast have a positive trend, while some did not show any significant trend. The number of stations with a negative trend in cool conditions was less than that of stations with a positive trend and no trend. The positive trend of cool conditions has often been observed in northwest, north and west of Iran. According to the very cold, cold and cool conditions, it can be said that Fars province was one region of Iran where cold stress conditions were of a descending trend (heat stress has been rising). This result is in line with the findings of Rozbicka and Rozbicki (2020) and Shevchenko et al. (2020). In these researches, heat stress has been rising. The slightly cool condition at most stations in Iran has been reported without a trend. However, in Khuzestan province, many stations can be seen with a positive trend.

The distribution of stations with a positive trend, a negative trend and without a trend in Iran is very irregular, where one can see all three modes in every part of the country. The thermal comfort condition is similar to the slightly cool condition. Most of the Iranian stations have not shown any particular trend in the occurrence of this bioclimatic condition. However, in the northwestern and southern parts of the country, there is a positive trend in a significant part of the stations. The slightly warm condition in many stations has not shown any significant trend. However, in the province of Kerman, East Azerbaijan, Sistan and Baluchistan, it is possible to observe a descending trend of slightly warm conditions. Stations in Fars province and northeastern Iran have been shown to increase the positive trend in the occurrence of slightly warm conditions. Warm conditions in most of the northern stations, Zanjan and Kurdistan provinces have had a negative trend. However, some stations in Tehran, Karaj and Fars provinces have had a positive trend. In general, stations without a trend in Iran are more than positive and negative stations. The very warm condition has a decreasing trend in the northwest, west and northeast. Very warm conditions in most of the southern parts of Iran did not show any significant trend. This result is not in line with the findings of Hadi Pour et al. (2019), where the south of Iran and its mountainous regions in the northeast were more affected in terms of the changes in several bioclimatic indicators. The hot condition has been decreasing in most stations in Iran. Very warm conditions in the highland stations along the Zagros and Alborz mountains have a significantly more pronounced decline compared with other regions. The results of Banc et al. (2020) are consistent with the results of the present study. In fact, in low-lying areas, there is an ascending trend in hot conditions. The results of the present study showed that the trends of different bioclimatic conditions in most synoptic stations in Iran are not statistically significant. Nevertheless, severe bioclimatic
conditions (hot and very cold) have been growing in both southern and northern latitudes. This result is in line with the results of Nastos and Matzarakis et al. (2013). In some of the southern stations, one can see the positive trend of cold and very cold conditions. Reviewing the studies on bioclimatic conditions in Iran showed that most of them have examined part or parts of Iran (one or more stations or one province). For example, Jahanbakhsh (1998) and Zolfaghari (2008) studied Tabriz’s bioclimate using different indices. Mohammadi and Saeedi (2008), Tavuosi and Sabzie (2013), and Mohammadi (2015) evaluated the bioclimatic conditions of Qom, Ilam and Kurdistan provinces, respectively. The results are in line with those of Mohammadi and Saeedi (2008) and Tavuosi and Sabzie (2013). In the present study, the maps prepared according to the SET* index are in line with Naseri (2018). In general, the results of the present study are in line with the SET* index only and other indices in Naseri (2018) (such as the UTCI, ET and PET) are not consistent with the present research. A comparison of the results of the present study with those mentioned shows that there are slight differences in the estimation of bioclimatic conditions. This difference could be due to the different data volume and the number of stations studied as well as the methods used. In addition, no research has been conducted on the trend of bioclimatic conditions of Iran to compare the results of the present study.

7 | CONCLUSIONS

The results of the present research have many applications in various fields. In the field of medicine, it is suggested that daily, monthly and annual maps of Iran’s bioclimatic conditions be provided to health centres, so that these organizations can provide guidelines for those who are sensitive to warm and cold stresses in accordance with the bioclimatic conditions of each place. Indeed, this will reduce the number of hospital visits and diseases associated with these bioclimatic conditions. In architecture and the design of accommodations, it is possible to choose the type of building materials in each location according to the prevailing climatic conditions. A consistency between the materials as well as the design of buildings and bioclimatic conditions can be very effective in energy use. Also, in the tourism sector, it is suggested that organizations and institutions related to tourism activities should prepare maps to select the best places and desired areas for tourism-related activities. Indeed, for everyone traveling to Iran for any purpose, bioclimatic maps can be the best guide for choosing tourist destinations. In general, an awareness of Iran’s bioclimatic conditions in terms of spatiotemporality can be a comprehensive guide for tourists visiting Iran.

Finally, looking at the bioclimatic conditions of Iran, one can identify areas with severe bioclimatic conditions (hot and very cold). People living in these areas are in need of more energy so they can adapt to the acute bioclimatic conditions and to have more desirable lives. By identifying these regions, organizations in charge of the energy sector can give more subsidies to areas with severe bioclimatic conditions in the field of energy. In contrast to areas with good bioclimatic conditions, excessive energy consumption should be subject to fines for excess energy usage. This is an important step towards development and social justice. For example, due to hot conditions (very severe heat stress) in the southern parts of Iran during May–October, the high energy consumption of these areas is justified and reasonable. At the same time, the northern and northwestern parts of Iran, due to the dominance of slightly cool, climatic comfort and slightly warm conditions, high energy consumption cannot be accepted.

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