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Predicting climate change impact on hospitalizations of cardiovascular patients in Tabriz

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ABSTRACT

Atmospheric conditions in any place can affect people's health. In this regard, this study aimed to investigate the climatic conditions of Tabriz (in northwestern Iran) and their relationship with the admission rate of cardiovascular patients in this city. We sought to predict thermal stresses on the hospital admissions rate of cardiovascular patients for the 2030s to 2059. The results of two climate models of CanESM2 and GFDL and three scenarios of RCP2.6, RCP4.5, and RCP8.5 were used to predict climate changes in the coming decades. In the present study, the physiological equivalent temperature (PET) index was applied to monitor and predict thermal stresses. The findings revealed that the colder the PET class, the higher the average of admissions. Based on all climate models and scenarios, it was found that the increase in hospital admissions for the middle classes of the PET index will be more than that of the extreme classes. On the other hand, the effect of global warming will cause an increase in the number of cardiovascular patients at an average rate of 147 people per year.

1. Introduction

Extensive data exist on how the ecological factors of the natural environment (e.g., geographic location, diurnal cycles of life, or seasons) are important determinants of cardiovascular health. Atmospheric variables such as air temperature, air humidity, sun radiation, cloudiness, air pollution, or electromagnetic properties of the atmosphere interact with living organisms in multiple ways and can affect the cardiovascular system of human beings to the point of compromising their wellbeing and even their life (Janjani et al., 2020; Bai et al., 2020; Ho et al., 2021; Fdez-Arroyabe et al., 2020).

The relationship between environmental factors and cardiovascular health has been studied both from epidemiological and experimental perspectives.

The experimental studies have allowed for a better understanding of the physiological mechanisms that are involved behind the effects on cardiovascular health; we will delve further into the results of these types of works when discussing our findings. On the

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other hand, the epidemiological studies have had diverse approaches analyzing both the short-term and long-term effects of environmental temperature.

In recent years, several authors have performed time series studies to analyze the relationship between morbidity / mortality and air temperatures (by using generalized linear models and non-linear models) (Vanos et al., 2014; Sahani et al., 2022). For example, a time-series analysis of the acute effect of weather on respiratory and CVD was conducted in 12 USA cities (Braga et al., 2002). Its results showed that the effect of hot days was twice as large as that of cold days for myocardial infarctions whereas the hot-day effect was five times smaller compared to the cold-day for all CVD deaths. The harvesting effect only occurred for hot days.

Specifically, some studies have focused on extreme weather situations (Carmona et al., 2016). In the context of Climate Change, the frequency of heat and cold waves has increased and the knowledge about their effect on the cardiovascular system has gained interest. For example, it is remarkable how, in a study performed in Kerman (Iran), the authors found that the risk of mortality was further attributed to heat waves rather than other non-optimum temperature rates (Aboubakri et al., 2019). Furthermore, in relation with extreme air temperatures, some authors have focused their studies in identifying vulnerable groups (such as elderly people with cardiovascular diseases) (Revich and Shaposhnikov, 2016) or the effects under specific physiological status, for example when vigorous exercise is being performed. (Casas et al., 2016).

Nevertheless, although until now we have talked about the impact of air temperature or extreme air temperature on health, some researchers have started to use biometeorological indices to estimate the sensation that human beings perceive in a specific environment (integrating different variables that people are exposed to, not only air temperature). In this line, a study developed in five regions of the Iberian Peninsula focused on the impact of the winter thermal environment on hospital admissions from circulatory system diseases using three different biometeorological indices (i.e., Universal Thermal Climate Index, Net Effective Temperature, and Apparent Temperature) concluded that low air temperatures are a significant risk factor in this temperate region regardless of the index employed (Santurtún et al., 2020). Specifically, the effects of Apparent Temperature on admissions by Acute Myocardial Infarction was also evaluated in Northern Spain (Royé et al., 2019a). PET (Physiologically Equivalent Temperature) index is a bioclimate thermal index which has been frequently used to determine the human thermal comfort, but its relationship to cardiovascular health has rarely been studied (Pecelj et al., 2021).

Global warming due to anthropogenic emissions of pollutants into the atmosphere is possibly the primary planetary problem we currently face. Emissions scenarios are used as theoretical frameworks to model how meteorological variables will perform over the coming decades. The two efforts were designed to be complementary. The representative concentration pathways (RCPs) set pathways for greenhouse gas concentrations and, effectively, the amount of warming that could occur by the end of the century. Whereas the shared socioeconomic pathways (SSPs)set the stage on which reductions in emissions will – or will not – be achieved. The SSPs also define different baseline worlds that might occur in the absence of any concerted international effort to address climate change, beyond those already adopted by countries. These exclude any commitments to enact new policies, such as those within the Paris Agreement up to 2025 and 2030 (Riahi et al., 2017). The SSPs feature multiple baseline worlds because underlying factors, such as population, technological, and economic growth, could lead to very different future emissions and warming outcomes, even without climate policy. While the RCPs were finished in time to be used in the IPCC Fifth Assessment Report, developing the more complex SSPs has been a much longer and more involved process. The SSPs were initially published in 2016, but are only now just starting to be used in the next round of climate modeling – known as the Coupled Model Intercomparison Project version 6, or CMIP6 – in preparation for the IPCC's sixth assessment report (van Ruijven et al., 2014; Yang and Cui, 2019).

The main goal of this study is to evaluate the relationship between the bioclimatic conditions, using PET, and the incidence of CVDs-related hospital admissions in Tabriz, Iran. Tabriz was chosen because few studies of the impact of climate change on CVD associated to ambient comfort in a medium size city with a BSK (dry steppe) climate, characterized by the Köppen classification. Furthermore, we aimed to estimate the expected impact in the number of CVD hospital admission due to climate change under different scenarios. The outcomes of this study can help to define climate change health-related policies of mitigation and adaptation through urban planning for the city of Tabriz what can be a reference for other medium size cities in the region.

2. Area of study

Tabriz is the capital of the East Azerbaijan province in the northwest of Iran. Due to the industries in the city and its surroundings, as well as its high population and traffic, it has always been considered as a polluted city of Iran. In addition, it had a population of 1,558,693 people in 2017, of which about 50% were women and 50% were men (Statistical Center of Iran, 2017). Tabriz is divided into 10 municipalities with a total area of 11,685 ha and is surrounded by mountains from the north and the south. Sahand volcano with 3710 m high and Mount Eynali (2308 m) are located in the south and north of Tabriz, respectively. The average height of Tabriz is 1410 m above sea level. Likewise, Tabriz Meteorological Station is situated in the northwest of Iran at 38 degrees and 5 min north latitude, as well as 46 degrees east and 17 min east longitude. Further, its altitude is 136 m above sea level and WMO407060 is the international code of Tabriz station. Regarding the type of climate, this station is part of the BSk or has a cold and dry climate based on the Köppen climate classification (Asakereh and Akbarzadeh, 2018). Moreover, the average annual temperature of Tabriz is 12.9 °C, and January and July are the coldest (−8.26 °C) and warmest (26.60 °C) months, respectively. Additionally, the average annual relative humidity (RH) of this city is 51%, and the minimum (33%) and maximum (69.60%) average monthly RH belong to August and January, respectively. Fig. 1 displays the geographical location of Tabriz, Iran.

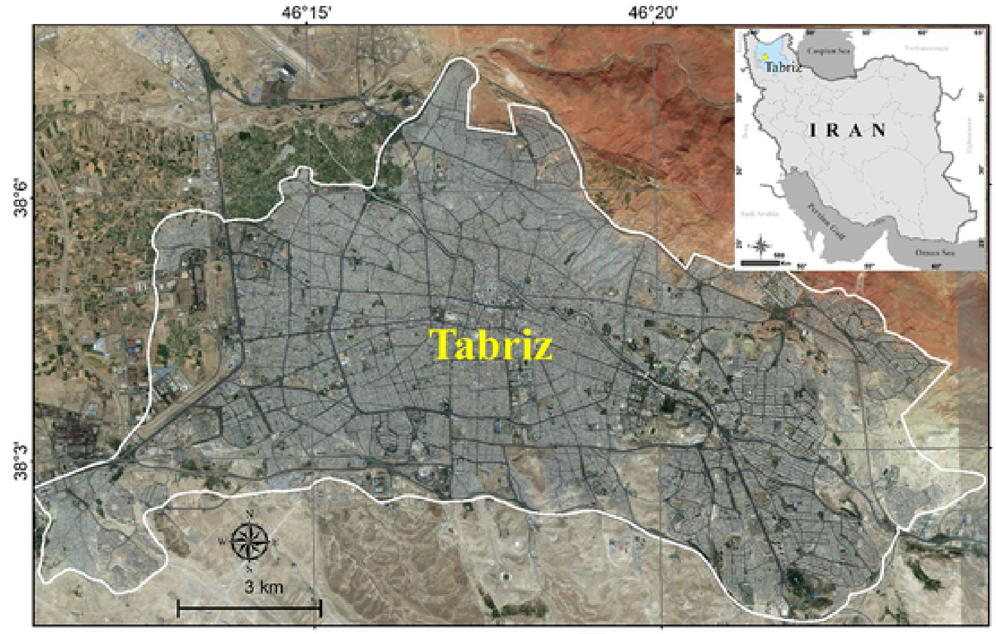

Fig. 1. Geographical location of Tabriz.

3. Materials and methods

In this study, two types of data were used to assess the bioclimatic condition and its relationship with the admission rate of cardiovascular patients in Tabriz. In other words, a set of climatic variables of Tabriz Synoptic Station and the admission statistics of the cardiovascular patients of Tabriz Shahid Madani Heart Hospital were selected for analysis. Climatic variables included mean daily temperature (°C), wind speed (WS, m/s), cloudiness (octa), and RH (%), along with daily statistics on the number of cardiovascular patients. Although the related variables of Tabriz station were available for a long period, due to the lack of admission-related information of cardiovascular patients, a joint period (28.3.2007 to 22.2.2017) was selected to examine the relationship between them. Therefore, two databases of climatic variables and statistics were separately prepared, which were related to the admission of cardiovascular patients in Tabriz.

The climatic conditions of Tabriz were identified on a mean daily based on the database of climatic variables. Climatic data quality control was performed to identify the randomness of the data using Kolmogorov-Smirnov (K-S) test and sign test methods. In this study, RayMan software was employed to determine the climatic conditions. The applied bioclimatic index in this paper included physiological equivalent temperature (PET), the details of which are as follows:

3.1. Pet

The Munich energy balance model for the human body was considered as the basis for calculating PET as Eq. (1):

$$M + W + R + C + ED + ERe + ESw + S = 0 \quad (1)$$

where M, W, R, and C represent the metabolic rate (internal energy production), the physical work output, the net radiation of the body, and the convective heat flow, respectively. In addition, ED, Ere, ESw, and S are the latent heat flow for evaporating water diffusing through the skin (imperceptible perspiration), the sum of heat flows for humidifying and heating the inspired air, the heat flow due to evaporation of sweat, and the storage heat flow for heating or cooling the body mass, respectively (Matzarakis and Amelung, 2008). PET was computed for 35-year-old male subjects who had an average height of 1.75 cm and weight of 75 kg weight. Furthermore, the value of 0.9 clo and 80 W were taken into consideration as average cloth insulation and the average amount of activity, respectively (Matzarakis and Mayer, 1996; Hoppe, 1999).

3.2. Predicting climate changes in the coming decades

The applied data encompassed historical and future projections of temperature (T), relative humidity (%), total cloud fraction (CLT), and wind speed (WS) for the synoptic station of Tabriz. Further, historical data included observational records that were obtained from the meteorological organization of Iran and the archived data of the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-5 Reanalysis with a resolution of 0.5 degrees during 1987–2017. Moreover, the future projections of climate data including the NOAA Geophysical Fluid Dynamics Laboratory Earth System Model (Version 2G GFDL-ESM2G) and the second generation Canadian Earth System Model (CanESM2) outputs relying on the Coupled Model Intercomparison Project 5 (CMIP5) models are accessible via the Earth System Grid Federation (ESGF) network.

Similarly, the spatial resolution of CanESM2 was around 2.81 with approximately uniform longitude and latitude and that of GFDL was 2 and 2.5 degrees for latitude and longitude, respectively. Conversely, downscaling was necessary for converting these coarse-resolution GCM outputs in order to fine spatial-scale data. Additionally, a statistical multivariate bias correction method (MBC) was employed to downscale the daily data of GCM outputs. In this regard, the MBCp function was used, which is embedded in the R package of "MBC" (Cannon, 2018). The MBCp (Cannon, 2016) is an MBC method that improves the dependence structure of Pearson correlation. Further, 20-year (1987–2006) and 11-year (2007–2017) periods were taken into account for model calibration and validation, respectively. Finally, the model was evaluated by Nash-Sutcliffe (NS), normal root mean square error (NRMSE), and correlation.

It is noteworthy that the data of three scenarios (i.e., RCP2.6, RCP4.5, and RCP8.5) were employed for each GCM in this study, and the desired projects were made for 2030–2059.

3.3. Statistical modeling of cardiovascular patients' referrals based on thermal sensation

In this part, several steps were followed to model the number of CVD referrals. Initially, the PET index was calculated as the mean daily for the observation period of 28.3.2007 to 22.2.2017. To facilitate the work, a number was assigned to each of the PET thermal sensing classes. It is noteworthy that the PET index has nine bioclimatic classes (Table 1). Then, to calculate the average number of hospital admissions per bioclimatic class, the frequency of hospital admissions for each bioclimatic class is divided by the frequency of the occurrence of the desired bioclimatic class for each year. For example, the bioclimatic conditions of class 2 (equivalent to $-10.7\ ^\circ\mathrm{C} < \mathrm{PET} < -0.7\ ^\circ\mathrm{C}$) were experienced 50 times in 2007, and there were 141 cardiovascular hospital admissions for this bioclimatic class. Therefore, the number of hospital admissions is divided by the frequency of the occurrence of bioclimatic conditions, which is 2.82. It should be noted that this value confirms the average number of hospital admissions of cardiovascular patients for the second category of the PET index in 2007. Thus, this process was performed for all bioclimatic classes during the study years, when 70 records were obtained according to the previously mentioned statistical period (28.3.2007 to 22.2.2017). Next, using Response surface (RS) and Grade 4 polynomial regression (PR) methods, the mean variable values of the number of cardiovascular patients' referrals (as a dependent variable) were modeled based on the frequency of the occurrence of bioclimatic conditions (as an independent variable) for the observation period. Finally, the number of hospital admissions of cardiovascular patients in each bioclimatic class was predicted for the observation period by multiplying the frequency of bioclimatic classes by the average number of hospital admissions (referrals). Then, the predicted values (number of references per bioclimatic class) were compared and validated with experimental data based on the statistical methods (Fig. 2). In the fourth step, the PET index was computed for the study period of 1.1.2030 to 31.12.2059. Similar to the frequency of observations, the occurrence of each bioclimatic class for each year was determined as well. Finally, the extracted relationships between the mean hospital admissions of cardiovascular patients and the frequency of bioclimatic class occurrence classes previously obtained in the third step for observational data were used to predict the average cardiovascular patient referrals of each bioclimatic class. In fact, the number of bioclimatic classes is available as an independent variable for the next period. Accordingly, the average number of hospital admissions and then the total frequency of visits for each bioclimatic class can be calculated using the extracted relationships from the third step. It is worth mentioning that the prediction process of the cardiovascular patient (hospital admissions) was performed according to two models (i.e., CanESM2 and GFDL) for three scenarios of RCP2.6, RCP4.5, and RCP8.5.

3.4. Introduction of the RS and PR methods of grade 4

Some between designs only apply first-order of main effect terms for predictor parameters. More precisely, the values for every predictor parameter must be independent of each other and merely elevated to the first power. Contrarily, in other between-designs, higher-order terms are probably utilized through elevating the rate of the main predictor parameters to power > 1 (e.g., in PR designs) or via setting up interplays between predictor parameters. The designs that solely encompass several level combinations for the

Table 1
PET for different grades of thermal sensation and physiological stress on human beings for Iran. (Farajzadeh (2017) and Sharafkhani et al. (2018)).

Number of PET classes	Level of thermal stress	Thermal perception for PET	PET (°C) in Iran
1	Extremely cold stress	Very cold	< −10.7
2	Strongly cold stress	Cold	−10.7 to −0.7
3	Moderately cold stress	Cool	−0.8 to 8.8
4	Slightly cold stress	Slightly cool	8.9–17.7
5	No thermal stress	Comfortable	17.8–27
6	Slight heat stress	Slightly warm	27.1–35
7	Moderate heat stress	Warm	35.1–43
8	Strong heat stress	Hot	43.1–50.8
9	Extreme heat stress	Very hot	> 50.8

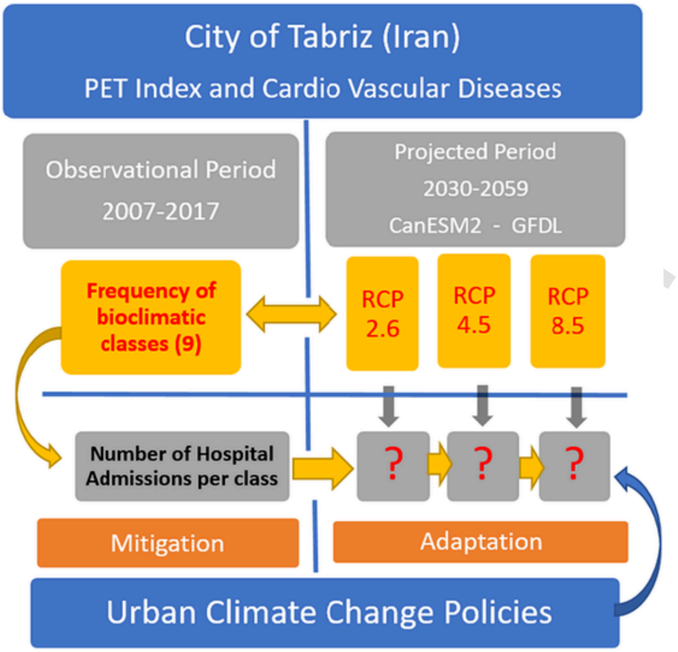

Fig. 2. Flowchart of various stages involved in research study.

categorical predictor parameter are referred to as fractional factorial designs. Complete factorial designs are considered as one of the most frequent ANOVA designs.

PR designs include the main and higher-order effects for continuous predictor parameters while demonstrating no interaction effects between predictor parameters. Accordingly, the following equation (Eq. (2)(was designed in the current study.

$$Y = b_0 + b_1 P + b_2 P^2 + b_3\ P^3 + b_4\ P^4 \tag{2}$$

Quadratic RS regression designs have several features that are related to PR and fractional factorial regression designs. Likewise, quadratic RS regression designs integrate the effects of PR designs with degree 2 and the 2-way interaction effects of the predictor parameters. Thus, the following equation (Eq. (3) (was developed in this research.

$$Y = b_0 + b_1 P + b_2 P^2 \tag{3}$$

For both Eqs. (2) and (3), the variable P is actually the same as the climate predictor variable, which here is the PET values, and b is the regression coefficient.

It should be noted that Fig. 2 shows the different stages of research.

4. Findings

4.1. Validation of data related to climate downscaling methods

In this study, NS, NRMSE, and correlation statistical methods were used to validate the results of CanESM2 and GFDL models, the outputs of which are illustrated in Fig. 2. Based on the outputs of both GCM models, the findings of all the applied statistical tests indicate low modeling errors while high reliability of the simulated data for all climatic components. In general, there is an extremely slight difference between the two models of CanESM2 and GFDL in the results of statistical tests, and thus it is impossible to certainty claim which the model has a better performance compared to the other. Although a highly negligible difference exists between the results of temperature and RH, according to NRMS and Nash statistics, the least modeled error belongs to the RH component for the CanESM2 model. Based on the Pearson correlation, the best result is obtained with $r = 0.998$ for temperature. It is noteworthy that the error of temperature and RH was lower than that of cloudiness, especially WS, which is similar to the result of GFDL-based modeling. On the other hand, the outputs of the GFDL model revealed that the best modeling data were related to RH for NRMS and Pearson correlation while the minimum error belonged to the temperature component for Nash with a value of 0.996 (Fig. 3).

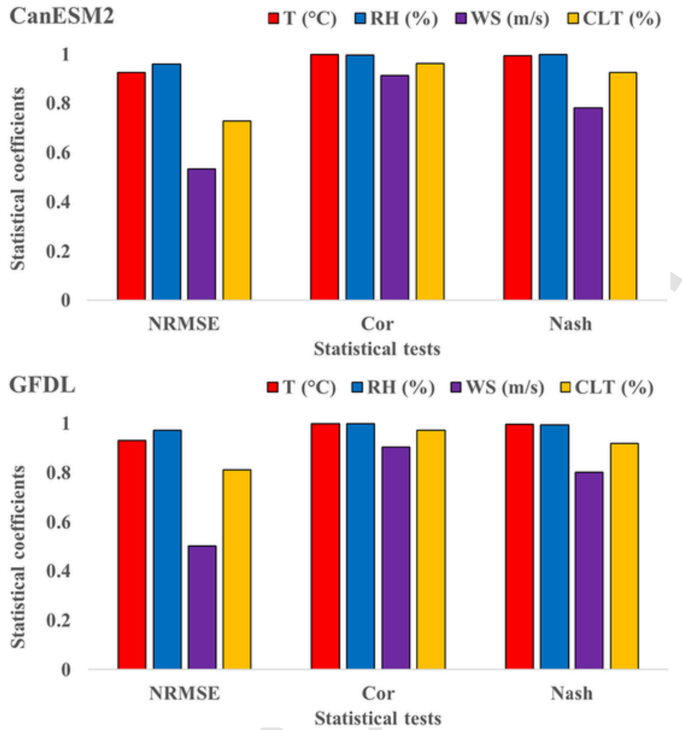

Fig. 3. Statistical evaluation of the error of climatic models used for Tabriz according to the period 2007 to 2017.

4.2. Evaluation of Tabriz bioclimatic patterns for the observation period and future

The conditions and bioclimatic pattern of Tabriz were evaluated based on the data related to the observation period and the future. As shown in Fig. 4, there is no experience of hot and extremely hot bioclimatic events for Tabriz for the observation period. On the other hand, the total frequency of events of the slightly cool to extremely cold classes is nearly 78.7% of the total frequencies while the total frequency of hot events related to the slightly warm to warm classes is only 1% of the frequencies. Overall, the maximum frequencies with 24.5% belong to the cool class, followed by the comfortable class that occupies about 20.3% of the total frequencies (Fig. 4).

Based on the findings of the bioclimatic event pattern for the 2030s to 2059 and the average of all three study scenarios for the CanESM2 model, 72.55% of the frequencies belonged to the slightly cool to extremely cold classes. However, the total frequency of hot events related to the slightly warm to warm classes has accounted only for 3.6% of the events given that hot and extremely hot bioclimatic classes have not been experienced for this period either. Simultaneously, the maximum frequency (26.28%) was related to the cool class and the comfortable class accounted for about 23.86% of the events. The comparison of different scenarios also demonstrated that RCP2.6 with values of 3.3, 23.1, 21.3, and 24.2% experienced higher values than other scenarios for the extremely cold, cold, and comfortable classes while RCP8.5 with a frequency of 27.6, 22.3, and 5% for cool, slightly cool, and slightly warm classes showed more values compared to other scenarios (Fig. 4).

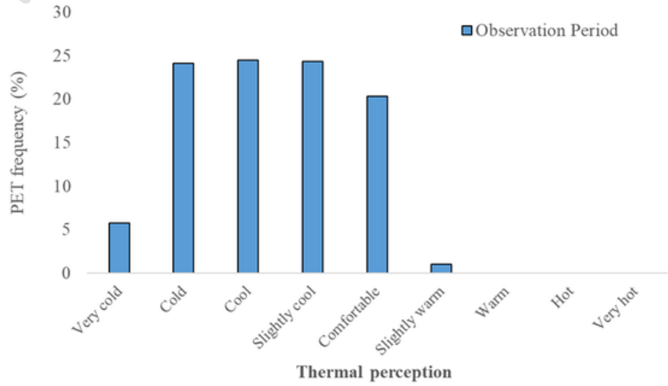

Fig. 4. Frequency percentage of different bioclimatic classes of the PET index for the observation period.

The following section discusses the results related to the pattern of the occurrence of bioclimatic conditions using the outputs of the GFDL model. The obtained data and the average of all three study scenarios represented that 52.41% of the frequencies belong to the slightly cool to extremely cold classes, implying a decrease of 20.14% compared to the CanESM2 model. Similar to the observation period and the findings of the CanESM2 model, there was no incident experience for the hot and extremely hot bioclimatic classes. Accordingly, the total frequency of hot events was only related to the slightly warm class, accounting for 3.11% of the total events so that nearly 0.5% of the frequency of this class decreased in comparison with the CanESM2 model. Meanwhile, the highest frequency (24.3%) was related to the cool class, and the comfortable class accounted for approximately 21.9% of the events. It was also revealed that RCP2.6 represented higher values (i.e., 4.8, 24.5, and 22.7%) compared to other scenarios for extremely cold, cold, and slightly cool whereas the cool class (25%) for the RCP4.5, along with comfortable (22.1%) and slightly warm (4.4%) classes for RCP8.5 were more frequent in comparison with the other two scenarios (Fig. 5).

4.3. *Projection of the effect of thermal comfort conditions on the referral (hospital admissions) pattern of cardiovascular patients*

The preliminary evaluation related to the gender of cardiovascular patients (hospital admissions) of Tabriz in the period indicated that men and women accounted for 53% and 47% of the total patients, respectively, showing that the number of referred men (hospital admissions) was more than that of women. However, according to the number of cardiovascular patients' hospital admissions based on age, there were no referrals for people under 35 years of age in this period so that five age groups could be presented based on Fig. 6. Based on the outputs, the total number of referrals (hospital admissions) for this study period was 26,778 people, of which 6.2 and 17.1% of the referrals were in the age groups of 35–49 and 50–59 years. In addition, 30.3, 24.8, and 21.5% of them belonged to the age group of 60–69, 70–79, and 80 years old, respectively.

As mentioned earlier, the lowest number of hospital admissions was experienced in all months for the age group of 35–49 years. Nonetheless, the maximum frequency of hospital admissions was experienced with 241 people in August for this age group and altogether with 80 people, the lowest hospital admissions were experienced in March and May. Based on the findings, the age group of 60–69 had the highest number of referrals in all months. It should be noted that November and July were reported to have the highest and lowest number of hospital admissions with 830 and 589 people for this age group, respectively. Then, the age group of 70–79 years in the next rank experienced the most hospital admissions. For this age group, October and July with 696 and 428 individuals had the maximum and minimum hospital admissions, respectively. Details of other age groups during different months are depicted in Fig. 6.

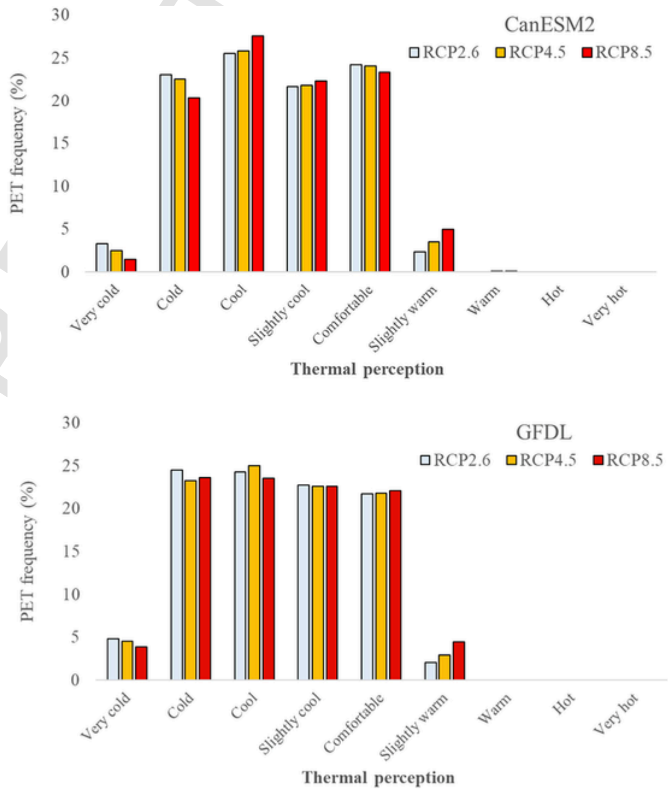

Fig. 5. Frequency percentage of different bioclimatic classes of the PET index according to different climatic models and scenarios.

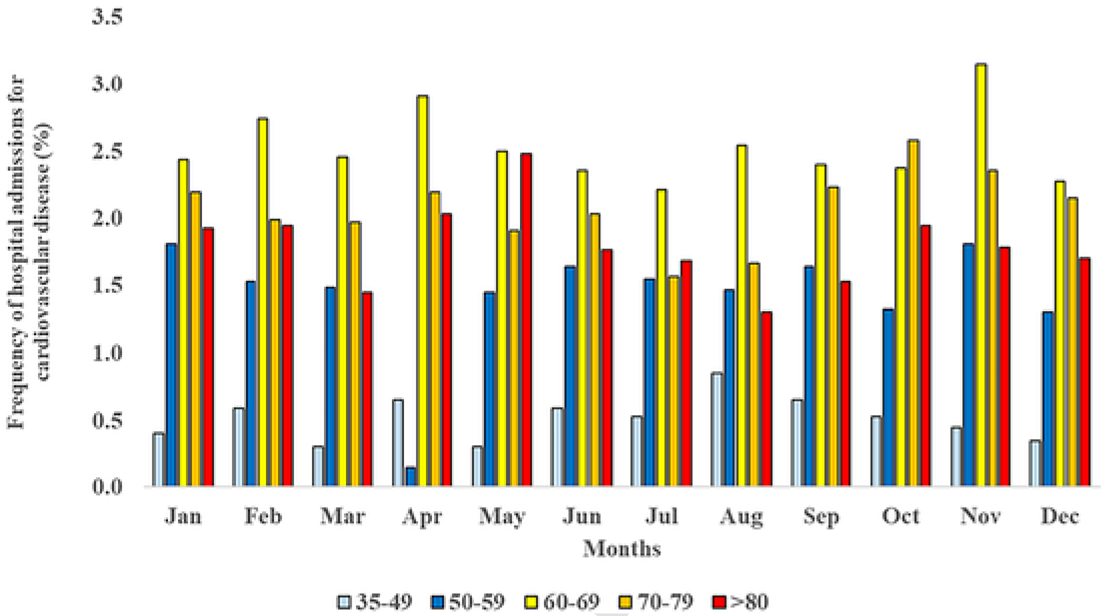

Fig. 6. Frequency (%) of the hospital admissions of cardiovascular patients based on age during different months of the year.

Based on Fig. 7, the hospital admission rate has decreased (increased) in the warm (cold) classes when the PET index has experienced the maximum (minimum) values. As can be seen from Fig. 7, there is a strong and significant relationship ($r = 0.84$) between PET classes and the hospital admission rate.

As previously described, the average number of cardiovascular hospital admissions per bioclimatic class per year was calculated so that 70 records were obtained relying on the statistical period of observation years. Then, the relationships between the average number of hospital admissions (dependent variable) and the frequency of the occurrence of each bioclimatic class (independent variable) were identified using the two methods RS and PR of grade 4. Next, the number of cardiovascular patients' referrals was predicted and compared with experimental and real values. Table 2 provides data on the evaluation of the performance of both RS and grade 4 PR statistical models according to NS, mean absolute error, RMSE, Durbin-Watson statistical methods, and R-square (R^2). Although there is a slight difference between the two statistical methods of RS and PR, test statistics show less errors based on the PR method compared to the RS method. Conversely, the modeling results demonstrate simultaneously negligible differences for both methods. Fig. 8 illustrates the observed and predicted values of the number of cardiovascular patients' referrals for bioclimatic classes

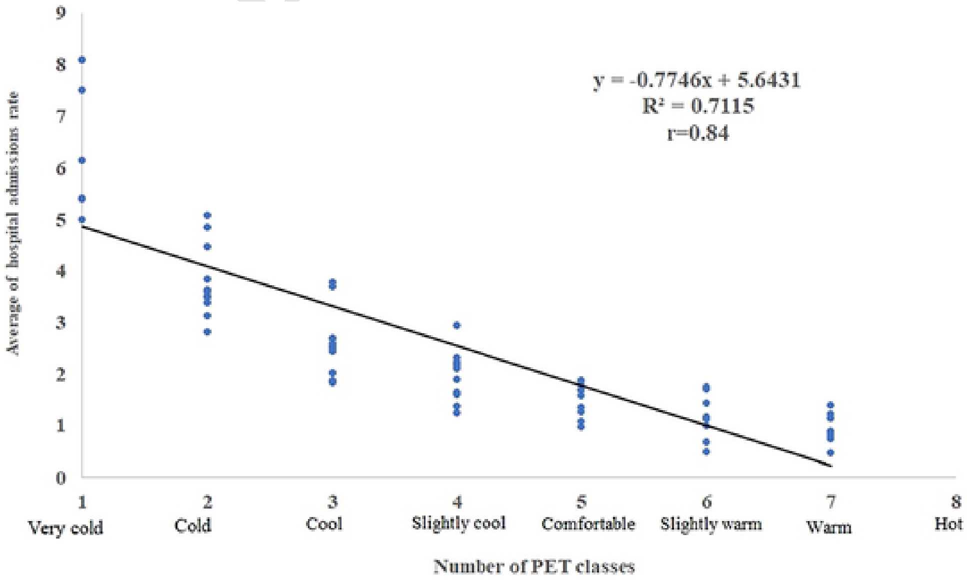

Fig. 7. Average of hospital admission rate for each bioclimatic class over the years of study.

Table 2
The effectiveness of the applied statistical models in predicting the referral number (hospital admissions) of heart patients for the observation period.

Calibration	Regression model	
	Response surface	Polynomial regression
NS	0.797	0.817
MAE	0.699	0.615
RMSE	1.061	0.956
R^2	0.797	0.817
DW	1.465	1.229

in each year using the two above-mentioned methods. Based on the obtained data, the value of R^2 for these methods are 0.82 and 0.87, respectively.

Due to the efficiency of the applied statistical methods in predicting cardiovascular patients' referrals for the observation period, these relationships were generalized for the next period (2030–2059), and the number of their referrals (annual average) for each bioclimatic class was predicted accordingly. Based on the observational period, the minimum number of cardiovascular patients' referrals was related to slightly warm and extremely cold classes with an average frequency of 21 and 141 people per year (average each year), respectively. On the other hand, the maximum number of referrals was experienced with 655 people per year for the slightly cool class. However, no referral experience was observed for warm, hot and extremely hot categories because no incident experience was recorded for these three bioclimatic classes in Tabriz.

Table 3 presents data related to the CanESM2 model and RCP scenarios. According to the findings of the RS method, due to the climate change in the statistical period of 2030–2059, the maximum hospital admissions for RCP2.6 (with a mean of 759 people per year) belonging to the cool class, which was 119 people (3.6%), increased its rate compared to the observation period. On the other hand, the highest percentage increase in hospital admissions rates (4%) was related to the cold class. The average number of hospital admissions per year was 733 people for this class, which increased by 129 people per year compared to the observation period. Meanwhile, according to this scenario, there will be no reference experience for warm to extremely hot classes. Contrarily, the slightly warm class with 65 people (per year) had the lowest number of hospital admissions, which indicated an increase of about 1.6% in comparison with the observation period. However, the findings showed that the highest decrease in hospital admission rates was recorded as 142 people (−6.3%) for the slightly cool class. So that for this class there will be with a mean of 513 people per year.

Conversely, the patterns slightly changed based on RCP4.5 and RCP8.5. It is observed that jointly for these two scenarios, the highest percentage of hospital admissions belonged to the cool class. Further, the average number of hospital admissions per year (for cool class) was 769 people for RCP4.5, which implied an increase of 3.7% (129 people) compared to the observation period while the average number of hospital admissions belonging to the cool class per year was 769 people for RCP8.5, indicating an increase of 5.8% (183 people) in comparison with the observation period. The findings simultaneously showed that the highest reduction rate of hospital admissions was related to the slightly cool class for these two scenarios, including −6.4% (140 people) and −8% (126 people) for RCP4.5 and RCP8.5, respectively. According to all of the scenarios (Fig. 9), extremely cold, slightly cold, and comfortable classes will experience a decrease in hospital admissions compared to the observation period.

This part focuses on the findings of PR. Based on all three study scenarios, the maximum number of hospital admissions was related to the cool class while the number of hospital admissions and their percentage increase were calculated for RCP2.6 (84 people, 1.4%), RCP4.5 (94 people, 1.6%), and RCP8.5 (145 people, 3.6%) on average per year compared to the observation period, respectively. The minimum number of hospital admissions was assigned to the slightly warm class (49 people) per year in RCP2.6, which increased by 1% (28 people on average each year) when compared with the observation period. However, the minimum number of hospital admissions belonged to the warm class for RCP4.5 and RCP8.5, showing that there will be an average of 7 people concerning hospital admissions per year for both scenarios regarding this bioclimatic class. In addition, no reference experience was recorded for this bioclimatic class for the observation period.

According to the findings, the maximum rate of the increase of hospital admissions will be experienced for RCP2.6 and RCP4.5 compared to the observation period for the comfortable class, implying an increase in the rate of 3.3% (125 people) and 3% (120 people) for RCP2.6 and RCP4.5, respectively. Contrarily, regarding RCP8.5, the maximum increase rate of hospital admissions was related to the cool class (3.6%, 145 people) for each year. Based on the obtained data, the maximum reduction rate of hospital admissions for RCP2.6 and RCP4.5 (−3.2% for both) belonged to the slightly cool class. However, the maximum reduction rate of hospital admissions for RCP8.5 in the highly cold class was −4.1% (103 people). Moreover, cardiovascular hospital admissions jointly decreased for extremely cold and slightly cool classes for all scenarios whereas for RCP8.5, a decreasing rate was also observed regarding future periods for the cold class in addition to the above-mentioned classes (Fig. 9).

The findings of the GFDL model are discussed in this section. The hospital admission values of cardiovascular patients for different scenarios are shown based on the RS statistical method (Table 4). According to the climate change of the statistical period (2030–2059), the maximum number of cardiovascular patients referring to RCP2.6 and RCP8.5 scenarios belonged to the cold class. As regards the RCP2.6 scenario, the average annual patient admission (for the cold class) was 797 people, which increased by 5.6% (175 people) compared to the observation period. However, the average annual number of hospital admissions (for the cold class) was 751 people with respect to the RCP8.5 scenario, showing a 4.7% (147 people) increase in comparison to the observation period. For the RCP4.5, the maximum number of hospital admissions with 742 people (per year) belonged to the cool class, which repre-

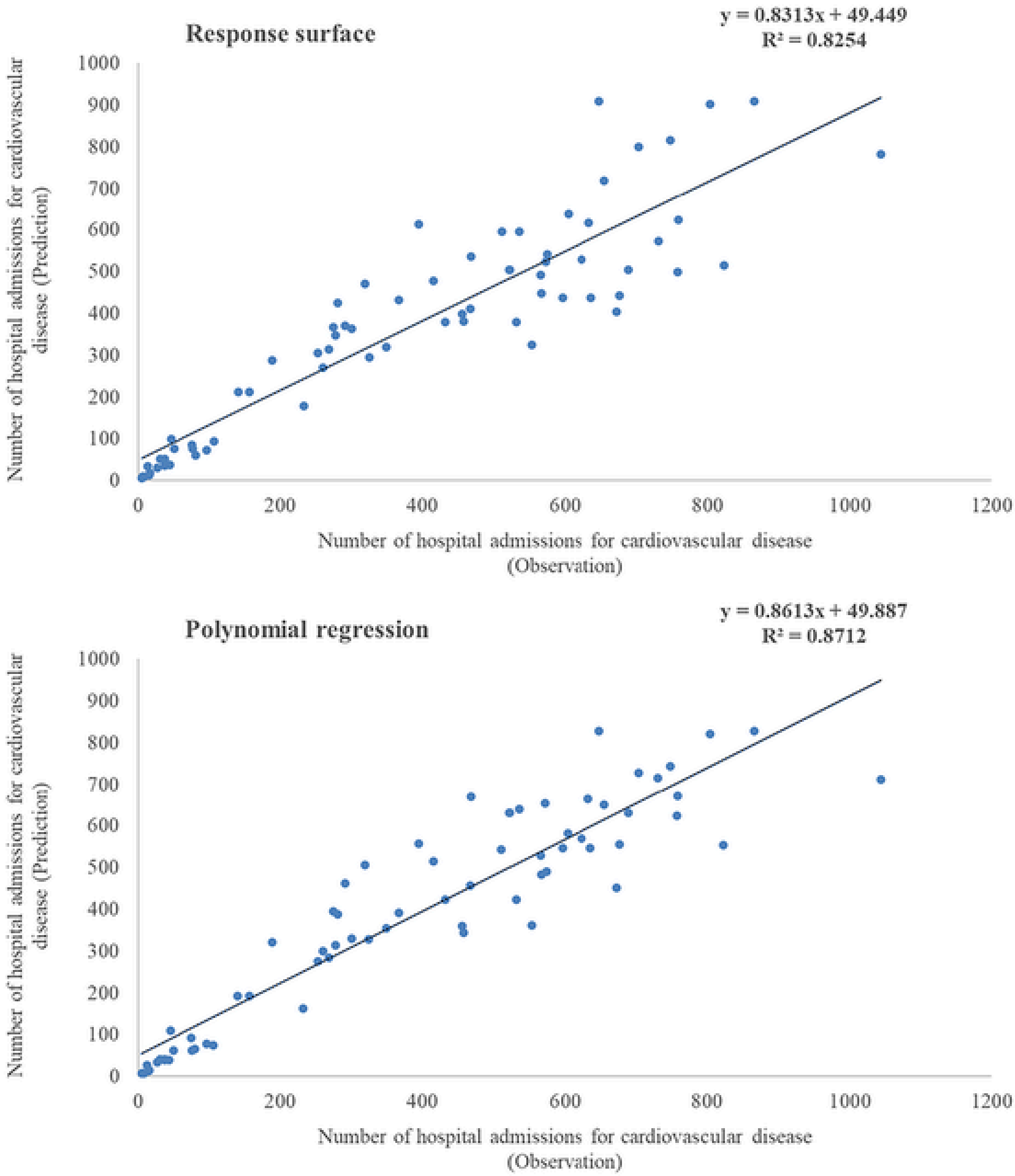

Fig. 8. Comparison of predicted values with the actual values of the number of cardiovascular patients' hospital admissions using two statistical methods of RS and PR.

sented a 2.8% (102 people) increase in the rate of hospital admissions when compared to the observation period. Meanwhile, the maximum rate of an increase in hospital admissions was assigned to the cold class for all three study scenarios compared to the observation period, which was 4.1% (135 people) for the RCP4.5 scenario.

For RCP2.6 and RCP4.5 scenarios, the minimum number of hospital admissions (61 and 84 people) belonged to the slightly warm class, showing an increase of 1.5% (for RCP2.6) and 2.3% (for RCP4.5) for this class in hospital admissions compared to the observation period. However, the lowest frequency was projected with an average of 92 people per year for the extremely cold class for RCP8.5, indicating a − 2.3% decrease in hospital admissions in comparison with the base period. According to all three discussed scenarios, the highest decrease in the rate of hospital admissions was related to the slightly cool class, which amounted to −5.5% for RCP2.6 and RCP4.5, respectively, and the corresponding value was −5.4% for RCP8.5 with a slight difference compared to the other two scenarios. Based on the findings, for all scenarios, cardiovascular hospital admissions decreased in the highly cold, slightly cool, and comfortable classes for future periods (Fig. 10).

Table 3
Results based on three scenarios of the CanESM2 climate model with two regression methods for future periods based on bioclimatic classes.

PET classes	Rate of hospital admissions (average number of people per year(						
		CanESM2 (response surface)			CanESM2 (polynomial regression)		
	Observation period	RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
< −10.7	141	81	68	36	84	71	38
−10.7 to −0.7	604	733	714	643	651	634	571
−0.7 to 8.8	640	759	769	823	724	734	785
8.8 to 17.7	655	513	515	529	615	618	634
17.8 to 27	483	490	485	470	608	603	584
27 to 35.1	21	65	97	142	49	73	107
35.1 to 43	0	0	14	14	0	7	7
43 to 50.8	0	0	0	0	0	0	0
> 50.8	0	0	0	0	0	0	0

Table 4 provides data related to the GFDL model and the PR statistical method. According to the RCP2.6 scenario, there was an extremely slight difference between the maximum number of hospital admissions for cold and cool classes with 692 and 691 people (per year), respectively. Conversely, the increase rate was 1.5% and 0.1% for cold and cool classes, respectively. Regarding RCP4.5, the maximum number of clients with an average of 708 people per year and an increased rate of 0.8% (68 people) belonged to the cool class. However, for RCP8.5, the maximum number of hospital admissions was projected for both cold and cool classes with 666 people. Contrarily, this increased rate was 0.9% (61 people) and 0.1% (26 people) for cold and cool classes compared to the observation period, respectively. It should be noted that despite the lowest number of hospital admissions for the slightly warm class, the maximum rate of increase was recorded for this class base on all scenarios. Additionally, the outputs showed that the maximum decrease rate of hospital admissions with −2.2%, which was observed for all scenarios for RCP2.6, RCP4.5, and RCP8.5, was assigned to the slightly cool class. The obtained data revealed that the maximum reduction in the rate of cardiovascular patients' referrals was related to the slightly cool class for all the studied scenarios. Interestingly, this reduction rate was projected at −2.2% for all these scenarios. Overall, there was a joint decrease in the rate of hospital admissions in extremely cold and slightly cool classes for all three scenarios for future periods (Fig. 10).

5. Discussion and conclusion

Based on the findings, Tabriz has never experienced hot and extremely hot bioclimatic classes. On the other hand, the potential for experiencing cold classes is greater compared to warm bioclimatic classes. According to the data related to the observation period, the total frequency of cold classes (slightly cool to cold) included 78.7% of the study days while the results of GFDL and CanESM2 models showed that 72.55% and 52.41% will experience this bioclimatic range from the 2030s to 2059. The findings concerning the CanESM2 model show that, based on the average of all three RCP scenarios and given the climate change of the coming decades, the frequency of cool, comfortable, and slightly warm classes, the amount could be increased by 1.8, 3.6, and 2.6%. On the other hand, for extremely cold, cold, and slightly cool classes, the frequency reductions of 3.4, 2.2, and 2.4% are predicted for the coming decades. However, the findings of the GFDL model revealed that the incidence frequencies for comfortable and slightly warm classes will increase by 1.6% and 2.6% based on the overall average of all three RCP scenarios compared to the observation period. On the other hand, there will be a decrease in frequencies for extremely cold bioclimatic classes (1.4%), cold (−0.4%), cool (0.2%), and slightly cool (1.7%) in comparison with the observation period.

Finally, there is a strong and significant relationship between PET classes and hospital admission rates, with the latter increasing in the cold classes, especially when the PET index experiences its minimum values. Similar to these results, other authors have shown that low temperatures and cold stress have a direct and significant effect on cardiovascular disease and mortality (Sartini et al., 2016; Ikäheimo, 2018; Valtonen et al., 2021). For example, in a study by Zhang et al. (2021) for Ganzhou (China), it was found that extremely low temperatures substantially increased the relative risks (RR) of cardiovascular mortality. The effect of cold temperature was delayed by 2–6 days and persisted for 4–10 days. However, the risk of cardiovascular mortality related to extremely high temperatures was not significant ($p > 0.05$).

In another study, effects of extreme temperatures on cardiovascular emergency hospitalizations were performed for Catalonia, Southern Europe (Ponjoan et al., 2017a). The results of this work showed that overall incidence of cardiovascular hospitalizations significantly increased during cold spells (Incidence rate ratios = 1.120; confidence intervals 95%: 1.10–1.30) and the effect was even stronger in the 7 days subsequent to the cold spell (Incidence rate ratios = 1.29; confidence intervals 95%: 1.22–1. 36). Conversely, cardiovascular hospitalizations did not increase during heatwaves, neither in the overall nor in the stratified analysis.

However, the climatic conditions of an area is determinant in its effects on human health (the ability of individuals to adapt to changes in air temperature or to extreme air temperatures does not depend only on the weather situation but also on the climate that will affect the physiological adaptation of the individual) and this is why the results described in Catalonia (Spain), where the climate is Mediterranean, or in Ganzhou (China), with a humid subtropical climate, may not correspond with those found in this work (Hondula et al., 2015).

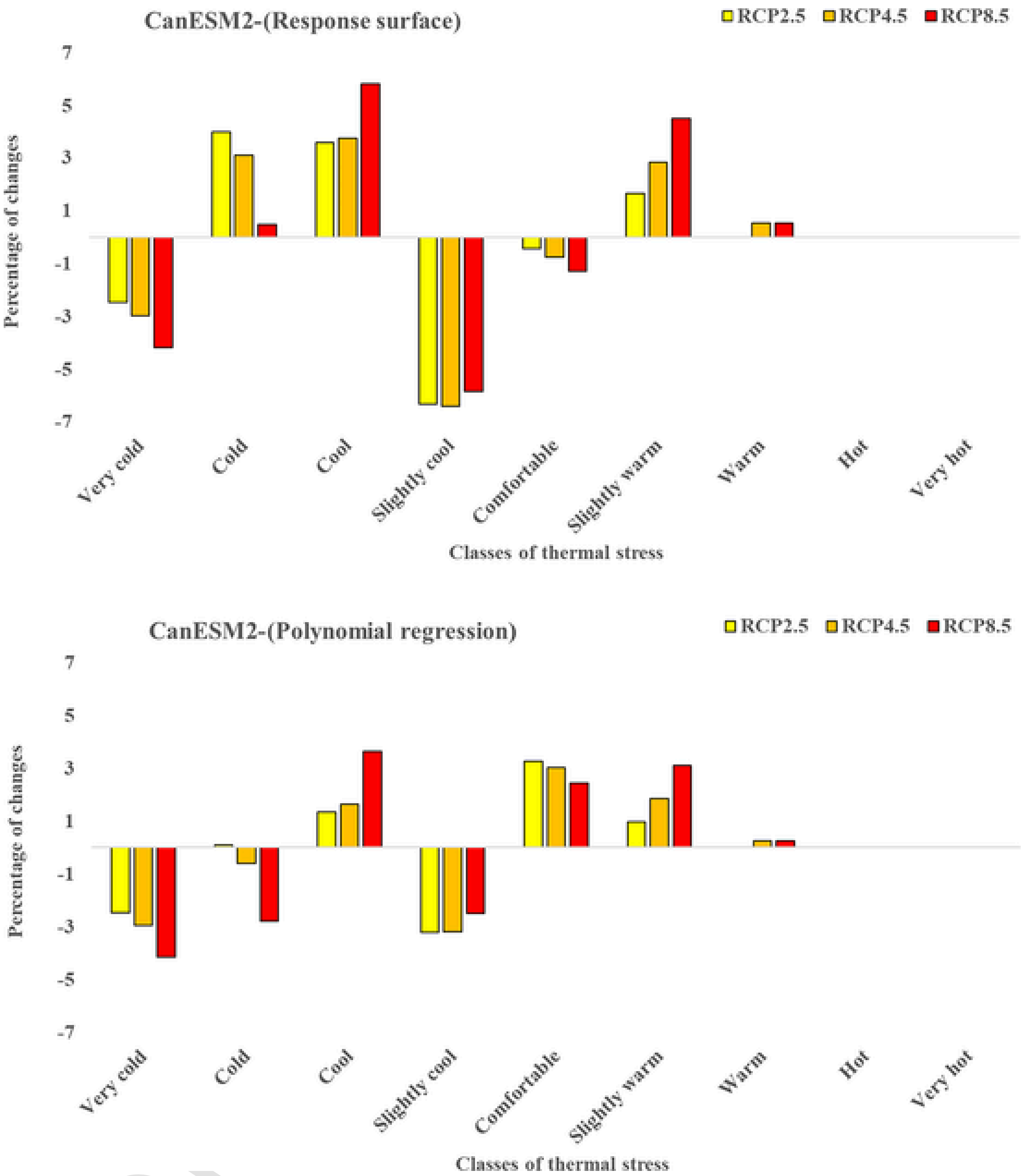

Fig. 9. Percentage of incremental and decreasing changes in cardiovascular patients referring to the hospital in comparison to the observation period based on the CanESM2 model and various RCP scenarios.

Moreover, even when comparing results from the same country, differences between regions must be considered; indeed, it is remarkable that Roshan et al. (2018) reported that the Tabriz station is one of the coldest stations in Iran. Not many studies have yet been carried out on the subject of our study in this country, however, some authors have reached results similar to ours. For example, Mohammadi and Karimi (2018) showed that there is a significant relationship (at a 95% confidence level) between extremely cold conditions and an increasing number of hospital admissions of cardiovascular patients in Kermanshah in western Iran based on equivalent (Tek) and effective (ET) temperature indices. They further found that cold climatic conditions were more effective for PET and predicted mean vote indices compared to other conditions in the reception of cardiovascular patients. Hassanlouei et al. (2013) also examined the relationship between air temperature and heart attacks in Rafsanjan, in southeastern Iran, and concluded that low temperatures and mortality due to myocardial infarction in Rafsanjan had a significant relationship. The findings of another study in Ahar, a county in East Azerbaijan Province in Iran, revealed an inverse, significant, and average association between temperature and death due to myocardial infarction. Likewise, Khanjani and Bahrampour (2013) studied the relation between temperature and mortality in Kerman, a city with desert climate in the central south of Iran, and concluded that cardiac deaths increased by 0.6% with

Table 4
Results based on three scenarios of the GFDL climate model with two regression methods for future periods based on bioclimatic classes.

PET classes	Rate of hospital admissions (average number of people per year(						
		GFDL (response surface)			GFDL (polynomial regression)		
	Observation period	RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
<−10.7	141	115	108	92	121	113	96
−10.7 to −0.7	604	779	739	751	692	656	666
−0.7 to 8.8	640	724	742	698	691	708	666
8.8 to 17.7	655	537	538	537	644	644	643
17.8 to 27	483	439	440	444	546	547	551
27 to 35.1	21	61	84	124	45	63	93
35.1 to 43	0	0	0	0	0	0	0
43 to 50.8	0	0	0	0	0	0	0
>50.8	0	0	0	0	0	0	0

each 1 °C decline in temperature. Based on their results, there was an approximately linear relationship between temperature and cardiac deaths, and the number of cardiac deaths represented a reduction by an increase in temperature, which is probably because individuals are getting accustomed to desert climates over the years in this area.

Although the studies cited so far refer to correlations described in different places, the physiological mechanisms that explain why admissions and deaths from cardiovascular causes rise in low temperatures are increasingly better understood. When we speak of cardiovascular diseases, we include very diverse processes with different pathophysiological mechanisms. However, ischemic heart disease and stroke are some of the leading causes of death, morbidity and disability (Oliveira et al., 2015) and the cold could be a trigger of these processes. The cold can produce vasoconstriction, increased cholesterol and triglyceride concentrations (Gordon et al., 1998), variations in both fibrinogen levels and plasma viscosity (Stout and Crawford, 1991) as well as some microbiological variations such as seasonal patterns of influenza epidemics and respiratory infections (Grau et al., 2006; Royé et al., 2019b).

At this point, we proceed to discuss the results of our predictions at the climatic level and their impact on cardiovascular health. Based on the findings of other studies (e.g., Farajzadeh and Matzarakis, 2009; Farajzadeh et al., 2015; Farajzadeh et al., 2015; Roshan et al., 2020a, 2020b), Tabriz station has a dominant cold bioclimatic pattern that is subject to climate changes. In the coming decades, this bioclimatic pattern will undergo changes. Thus, the increase of warm stress for the coming decades is one of the most important changes in the bioclimatic pattern of Tabriz, which confirms the findings of the present study. Based on the average of all climate models and scenarios, it was revealed that the abundance of the slightly warm bioclimatic class will be increased by 2.4% for the coming decades. Therefore, this increase of slightly warm class can affect the increasing rate of cardiovascular patients' hospital admissions. The results of this study further represented that the maximum frequency of CVD hospital admissions was due to cold stress events. Based on observation data, the maximum frequency (25.7% and 25.2%) of hospital admissions belonged to the slightly cool and cool classes. Considering the results of the CanESM2 model for all study scenarios, the maximum hospital admissions of cardiovascular patients were related to the cool class so that the share of this class (28.4%) of hospital admissions was more than other bioclimatic classes. According to the findings, the cold (0.7%), cool (3.3%), comfortable (1.1%), slightly warm (2.5%), and warm (0.3%) classes of PET will experience an increase in cardiovascular admissions for decades to come while the extremely cold (−3.2%) and slightly cool (−4.6%) classes will experience a decrease in admissions. Extracts from the GFDL model indicated that cold and cool classes will experience maximum hospital admissions (26.6% and 26.2%) of the total hospital admissions. The obtained data from this model indicated that the slightly cool class has the highest reduction percentage of referrals at a rate of −3.8% compared to the observation period. Regarding the GFDL model, the rate of hospital admissions is decreasing for extremely cold, slightly cool, and comfortable classes, whereas no referrals are still observed for warm, hot, and extremely hot classes. As regards other bioclimatic classes, the referral rate will represent an increase.

Although, as we have shown, this work has numerous strengths, some limitations must be addressed. When talking about cardiovascular processes, very diverse diseases on which ambient temperature can have different effects are grouped together. In addition, no demographic variables (such as sex or age) for the hospitalized patients or other individual risk factors with known effects on cardiovascular health (such as tobacco use or obesity) have been included in our study, and neither have other environmental factors (e.g., atmospheric pollution).

Finally, the findings of the present study indicated an increase (An average increase of 147 people per year compared to the observation period) in the rate of hospital admissions of cardiovascular patients in Tabriz due to future climatic changes. Therefore, the obtained data showed that the admission rate of cardiovascular patients in proportion to the extremes classes of the PET index will decrease, followed by an increase in the number of hospital admissions of the middle classes of PET. This awareness of the impact of future climate change on the hospital admission rate of this type of disease can be used as a basis for preparing guidelines and programs to reduce the negative effects of climate change on the health of people in the community. It is noteworthy that the lack of studies to assess the effects of global warming on the health of society has received less attention for Iran. However, the findings of this study can be considered in the development of programs to apply risk management in the field of climate change and the health of the study population so that to reduce the negative effects of climate change in the health sector.

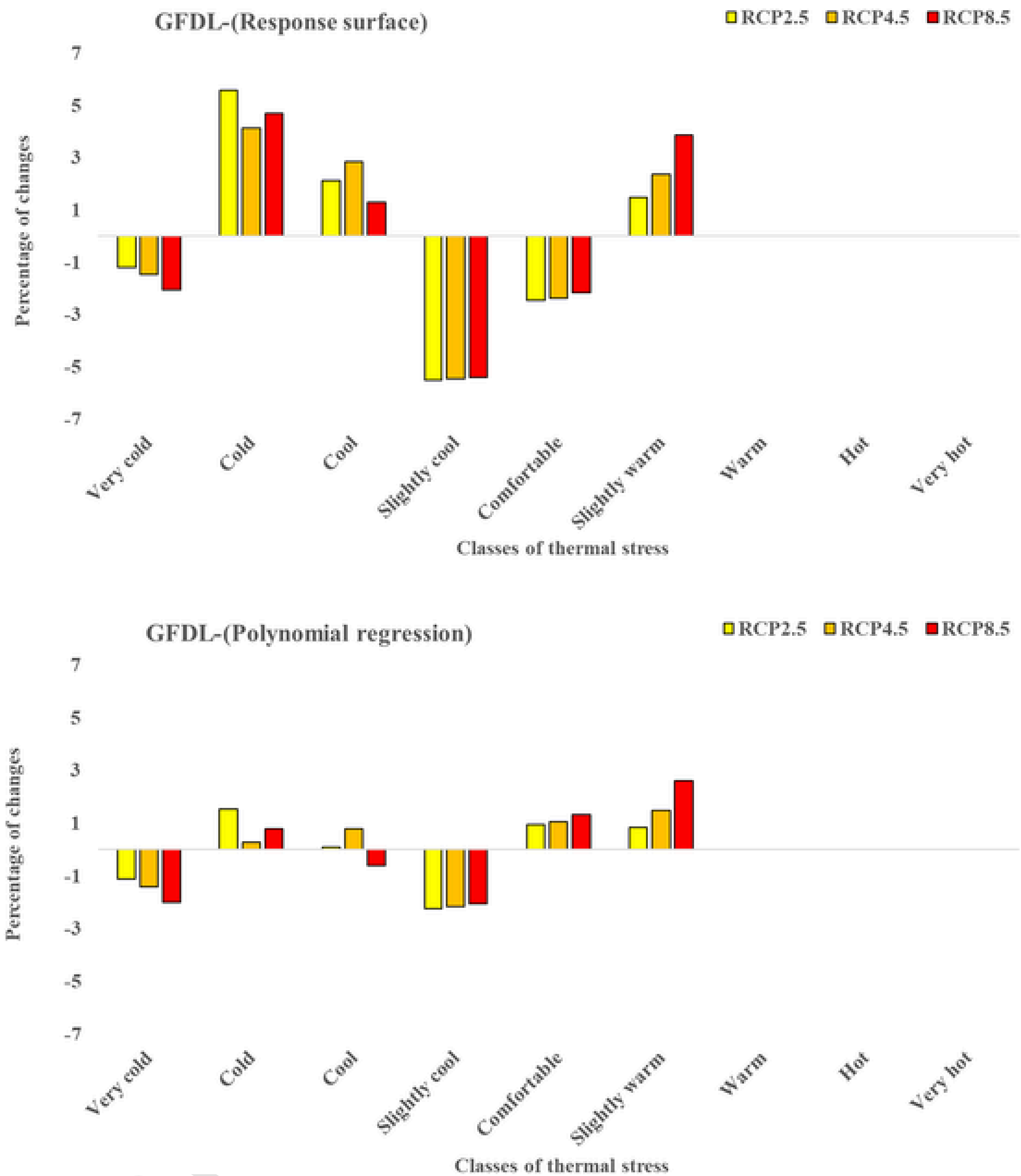

Fig. 10. The percentage of incremental and decreasing changes in the number of cardiovascular patients referred to the hospital compared to the observation period according to the GFDL model and different RCP scenarios.

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Wu et al., 2021

CRediT authorship contribution statement

Gholamreza Roshan: Methodology, Visualization, Writing – original draft. **Abdolazim Ghanghermeh:** Writing – review & editing. **Vahid Mohammadnejad:** Writing – review & editing. **Pablo Fdez-Arróyabe:** Writing – review & editing. **Ana Santurtún:** Writing – review & editing.

Declaration of Competing Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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