Environmental Health Engineering and Management Journal 2022, 9(4), 399-407
http://ehemj.com
doi 10.34172/EHEM.2022.43

Environmental Health Engineering and Management Journal

Original Article

Open Access Publish Free

Modeling and predicting trends of heat stress based on climate change phenomenon: A case study in a semi-arid climate

Mehdi Asghari[1], Gholamabbas Fallah Ghalhari[2], Hamidreza Heidari[3], Rahmatollah Moradzadeh[4], Sadegh Samadi[1], Reza Tajik[1], Mohammadjavad Ghanadzadeh[5*]

[1]Department of Occupational Health and Safety Engineering, School of Public Health, Arak University of Medical Sciences, Arak, Iran
[2]Faculty of Geography and Environmental Sciences, Hakim Sabzevari University, Khorasan-Razavi, Iran
[3]Environmental Health Research Center, Golestan University of Medical Sciences, Gorgan, Iran
[4]Department of Epidemiology, School of Public Health, Arak University of Medical Sciences, Arak, Iran
[5]Department of Environmental Health Engineering, Faculty of Health, Arak University of Medical Sciences, Arak, Iran

Abstract

Background: Climate change is one of the most complex human challenges in the future. One of the consequences of climate change is the exposure of people to heat stress, especially in the outdoor environments. The aim of this study was to model the changes in the trend of exposure to heat stress in outdoor environments in the coming decades in the context of climate change and global warming.

Methods: The Wet Bulb Globe Temperature (WBGT) index, Canadian Earth System Model (CanESM2), and the Statistical Down Scaling Model (SDSM) were used in a semi-arid climate. In this study, Arak station was considered as a representative of Iran's semi-arid climate. In this research, the daily data of the minimum and maximum temperatures, humidity, and WBGT index were used from 2011 to 2099.

Results: The minimum and maximum air temperatures in the study station show an increasing trend in three time periods. Also, based on the three studied scenarios, air temperature and WBGT index have an upward and positive trend and relative humidity has a downward and negative trend in the coming decades.

Conclusion: In general, increasing the exposure of people to heat stress at the study station in the coming decades and based on the simulations of atmospheric general circulation models (GCMs), will not be unexpected.

Keywords: Temperature, Humidity, Climate change, Global warming

Citation: Asghari M, Fallah Ghalhari G, Heidari H, Moradzadeh R, Samadi S, Tajik R, et al. Modeling and predicting trends of heat stress based on climate change phenomenon: A case study in a semi-arid climate. Environmental Health Engineering and Management Journal 2022; 9(4): 399-407. doi: 10.34172/EHEM.2022.43.

Article History:
Received: 21 January 2021
Accepted: 26 April 2022
ePublished: 3 December 2022

***Correspondence to:**
Mohammadjavad Ghanadzadeh,
Email: mghanadzadeh.7@gmail.com

Introduction

Climate is the most important environmental element affecting life on the earth (1). Climate is not fixed in a region and changes under the influence of two factors: Factors that cause annual climate change and factors that create long-term change trends. Climate change is one of the most complex challenges that humans will face in the future (2).

The studies of the Intergovernmental Panel on Climate Change (IPCC) in the Fifth Report showed that the Earth's surface temperature increased by 0.78°C (with a confidence interval of 0.72-0.85°C) in the period of 2003 to 2012 compared to the base period of 1850 to 1900 (3). The average global temperature in the period of 2018 to 2100 will increase by 0.5-1.8°C according to the RCP4.5 scenario and by 0.7-3.7°C according to the RCP8.5 scenario compared to the period of 1986 to 2005 (4). This warming trend, especially the warming of the mid-twentieth century to the present, is more likely due to the increasing concentration of greenhouse gases due to human activities. Even if greenhouse gas emissions are stopped now, climate change will continue until the end of the 21st century (5). The increase in the concentration of greenhouse gases in recent decades and the resulting rise in temperature have disturbed the balance of the planet's climate system and caused widespread climate changes in most parts of the world (6). Studies have shown that this phenomenon can have negative effects on various sectors including water resources, agriculture, environment, health (7), industry and economy (8-10).

The Middle East and the Mediterranean are known as sensitive regions for climate change. Climate change is the transformation of patterns and long-term weather conditions (11). One of the most important countries in the Middle East is Iran. Iran is located in an arid and semi-arid region and is mainly known for its low rainfall and high temperatures (12).

Global warming due to the increase in greenhouse gas concentrations and the resulting heat waves, especially in the hot seasons of the year, puts many people at risk of heatstroke and other effects of heat and death (9). In general, all members of society, especially the elderly and children, are vulnerable to heat (8). Investigating the environmental, economic, and social effects of global warming and climate change is of great importance. For this reason, long-term simulation of climate elements and taking the necessary measures to deal with the adverse effects of climate change have been considered by many international scientific communities (13,14). For this reason, general circulation models (GCMs) have been developed (15). Since in these models, climatic elements are simulated on a large spatial and temporal scale, to use these simulated elements on a smaller scale, the output of these models must be downscaled with various techniques. For this purpose, scientists have developed several methods, which together are called downscaling techniques (16).

Despite the importance of climate change and global warming, it has not been addressed in terms of heat stress in the outdoor environment, and studies have focused solely on temperature and precipitation changes, and heat stress in the outdoor environment has received less attention. To assess the amount of heat stress in outdoor environment, one environmental parameter or meteorological cannot be enough and it is necessary to use heat indicators (17).

Obviously, neglecting outdoor environment and atmospheric conditions can have various consequences, including creating and increasing the prevalence of heat stress, diseases and complications caused by heat, such as heatstroke, heat shock, and various skin disorders caused by heat. Heat can also directly cause accidents and reduce production and productivity by affecting the physical capacity, mental and cognitive function of individuals. Therefore, it is necessary to predict and evaluate thermal stress in such environments.

The present study aimed to model the trend of changes in the exposure to heat stress in outdoor environments in the coming decades with respect to the topic of climate change and global warming. For this purpose, Wet Bulb Globe Temperature index (WBGT), The second generation Canadian Earth System model (CanESM2) and statistical downscaling model (SDSM) have been used in a semi-arid climate.

The results of this study can be used for future planning, preventive strategies and control measures to maintain human health in environmental and urban planning. It should also be noted that the study of the trend of temperature changes and thermal indicators used during different years can be used as a guide, health and environmental management solution, because various studies have shown that severe temperature changes lead to various diseases, and even, death of people.

Materials and Methods

Study area

Arak station is located at latitude 34° 6’ N and 48° 46’ E. The altitude of this station is 1708 meters above the sea level. By investigating the data of Arak meteorological station, it was determined that Arak city has the climatic characteristics of the central plateau of Iran (Figure 1). Winters are cold and humid and summers are hot and dry, and winters are often long, lasting from 4 to 6 months. In general, desert climate with dry and hot winds and dry and rainless months in summer and cold winters, is one of the general characteristics of Arak city. Arak city is a semi-arid region according to De Martonne climate classification, cold dry based on Amberger climate classification, and a semi-arid and cold region based on Köppen climate classification (17).

Data collection and information

In the present study, Arak station was considered as a representative of semi-arid climate and the required data such as environmental parameters of the minimum and maximum temperatures, and relative humidity (RH) were obtained based on the meteorological data recorded during 1975 to 2005 as hourly and daily values.

The second generation Canadian Earth System model (CanESM2)

The Atmospheric General Circulation Models (AGCMs) are the most reliable tools for studying the effects of climate change on different systems and are also able to model climate parameters for a long-term period using the IPCC approved scenarios. In this study, the CanESM2 was used for modeling, which was developed by the Canadian Center for Climate Modelling and Analysis (CCCMA) under the auspices of the Canadian Environment Assessment Agency (18). The CanESM2 is a comprehensive and paired model, and the Fourth generation coupled global climate model (CGCM4). Moreover, it is a part of the coupled model intercomparison project phase 5 (CMIP5) and the fifth assessment report of the IPCC. In this model, the whole Earth is networked as 128 × 64 cells. Table 1 shows the specifications of the model (19).

Data scaling using the statistical downscaling model

The main weaknesses of the AGCMs models are their low spatial resolution, which requires the output of these models to be microscale before being used in the studies of the climate change assessment. There are two ways to overcome the disadvantage of low spatial resolution in the AGCMs models, one of which is the SDSM and another one is the dynamic downscaling model. Statistical

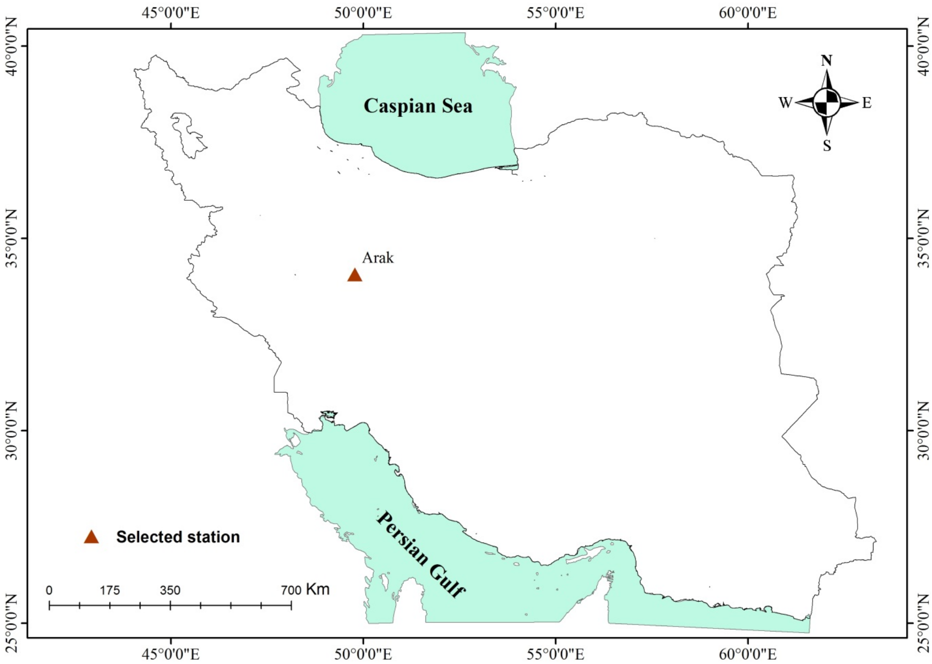

Figure 1. The geographic position of the selected station (Arak city) in Iran

methods require fewer parameters than dynamic methods, therefore, they have been more considered in studies of meteorological sciences. One of the most widely used models in statistical methods is the SDSM model (20).

Moreover, it is one of the most efficient statistical models for climate studies today, which was developed by Wilby et al as a tool for statistical exponential microscale in the United Kingdom (21,22). The basis of this model is multivariate regression and is used to predict climatic parameters such as temperature and rainfall in long-term. Comparison of the model with other methods of statistical exponential microscale shows that it has the necessary ability to predict climatic variables (23). In this study, SDSM 4.2.9 model was applied to exponential microscale the output data.

Scenarios used in the study

Three scenarios of optimistic (RCP 2.6), intermediate (RCP 4.5), and pessimistic (RCP 8.5) were used in this study. These scenarios are the difference between the radiant energy received from the sun and the energy returned to the atmosphere by the Earth. Positive induction (more input of solar radiation) increases and negative induction (more output of energy) decreases the temperature of the Earth. Radiation induction, as the most important cause of climate change, is used to evaluate and compare each of the natural and human causes of climate change (24). It should be noted that in RCP 2.6, as the lowest RCP, the total radiation induction will reach its peak of 20 W/m^2 by 2050, and after which it will follow a decreasing trend. In scenario RCP 4.5, which is a constant scenario with increasing total radiative induction power until 2100 (4.5 W/m^2) and with stable concentrations after 2100. Also, the RCP 8.5 scenario is continuously increasing the radiative induction power until the end of the 21st century and is approximately equal to 8.5 W/m^2 (25).

The use of modeling data to calculate wet bulb globe temperature (WBGT) for the coming decades

From the climatic point of view, four elements of air temperature, relative humidity, air velocity and radiation are involved in the formation of human comfort conditions. Among them, temperature and humidity are considered as basic parameters and have a greater impact on human health and comfort. Therefore, most of the heat stress indices are based on these two parameters (26). Therefore, in this study, two parameters of temperature and RH were used.

In this study, the WBGT index was used to evaluate heat stress. WBGT is a valid and standard index that has wide acceptance and applicability around the world (27). This index was introduced by Minard and Yaglue in 1957 and adopted with the ISO-7243 standard in 1989. WBGT index shows the thermal conditions as a number, considering the natural wet temperature (t_{nm}), dry temperature (t_a), and globe temperature (t_g). The index in

Table 1. The specifications of the CanESM2 model (18)

Model	Atmospheric resolution (longitude × latitude)	Ocean resolution (longitude × latitude)	Founding group	Historical/future simulation course	Simulation Scenarios
CanESM2	2.81°×2.81°	1.41°×0.94°	CCCMA	2006-2100	RCP 2.6, RCP 4.5, RCP 8.5

outdoor environments is calculated by equation 1 (28).

$$WBGT = 0.7\, t_{nw} + 0.2\, t_g + 0.1\, t_a \quad (1)$$

Due to the lack of measurement of t_g by meteorological stations, it is not possible to report heat stress conditions based on the WBGT index. Therefore, one should look for a model or relationship that can estimate the WBGT without the need for t_g parameter and complicated equipment. In this regard, the Australian Meteorological Agency has introduced a model for estimating the WBGT index, which has two parameters of t_a and water vapor pressure (equation 2). In this model, the water vapor pressure can be determined using two parameters of t_a and RH, which is shown in Equation 3. The validity of this index has been examined by Teimori et al, in outdoor environments (29).

$$WBGT = 0.567 \times ta + 3.94 + 0.393 \times E \quad (2)$$

$$E = \frac{RH}{100} \times 6.105 \times e^{17.27 \times \frac{t_a}{237.7 + t_a}} \quad (3)$$

Where t_a is average air temperature (°C), RH is relative humidity (%), and E is water vapor pressure (hPa).

In this study, Equation 2 was used to estimate the WBGT and the amount of temperature, humidity and WBGT index are forecasted on daily for the coming years from 2011 to 2099. The classification of the recommended values of this index is provided by the American College of Sports Medicine (ACSM), which is mentioned in Table 2. Finally, data were analyzed using SPSS 23 and Excel 2013 software.

Results

The values of the studied parameters including the minimum temperature (T_{min}), the maximum temperature (T_{max}), and relative humidity (RH) in the base period from 1976 to 2005 are shown in Table 3. In addition, modeling of these parameters during the coming decades (2011-2099) using three scenarios for the studied station are given in Table 4.

As shown in Table 4, according to the scenario RCP 2.6, the minimum temperature for decades of 2011 to 2040, 2041 to 2070, and 2071 to 2099 was associated with an increase of 2.6, 3, and 3.1°C, respectively, compared to the base period. The rate of rise in temperature varied between 0.055°C (for July) to 5.85°C (January).

According to scenario RCP 4.5, these increases were equal to 2.35, 3.42, and 4°C for decades of 2011 to 2040, 2041 to 2070, and 2071 to 2099, respectively, compared to the base period. According to the recent scenario, the rate of rise in temperature varied between 0.433°C (for July) to 6.1°C (for January).

Finally, based on the results of the scenario RCP 8.5, the raising of the minimum temperature in the periods of 2011-2040, 2041-2070, and 2071-2099 were 2.6, 4.4, and 6.4°C, respectively, compared to the base period. It should be noted that from 2011 to 2099, the temperature augmented from 1.66°C (for April and July) to 7.28°C (for January), compared to the base period.

The results of the maximum temperature parameter using the scenario RCP 2.6 showed that in the period of 2011-2040, it raised 3.4°C compared to the base period, in the period of 2041-2070, raised 4°C, and in the last decades of the 21st century, raised 4.1°C. The rate of increase in the maximum temperature varied from 1.4°C (for April) to 6.9°C (for January). Based on the scenario RCP 4.5, the maximum temperature for decades of 2011 to 2040, 2041 to 2070, and 2071 to 2099 compared to the base period was associated with an increase of 3.2, 4.64, and 5.35°C, respectively. In addition, between 2011-2099, an increase in the maximum temperature from 1.85°C (for April) to 7.4°C (January) was observed in comparison with the base period.

Also, the results of the scenario RCP 8.5 showed that in the period of 2011-2040, the increased maximum temperature was 3.5°C, in the period of 2041-2070, it was 5.8°C, and in the last decades of the 21st century, it was 8.4°C, compared to the base period. It should be noted that between 2011-2099, the maximum temperature augmented from 2.8°C (for April) to 8.8°C (for August and January) compared to the base period.

The results of the relative humidity parameter using

Table 2. Classification of WBGT index by the American College of Sports Medicine (30)

Conditions description	Risk level	WBGT index (°C)
Comfort – no risk	Low	<18
Warm – caution	Moderate	18-23
Hot – extreme caution	High	23-28
Very hot – danger	Very high	>28

Table 3. The mean and standard deviation of the studied parameters in the base period from 1976 to 2005

Months	T_{min} (°C)	T_{max} (°C)	RH (%)
Jun	-5.95±5.5	4.17±6.18	71.9±13.85
Feb	-4.0±5.87	6.96±4.9	65.28±15.7
Mar	1.11±4.3	12.95±5.25	55.85±16.85
Apr	7.1±3.7	19.95±4	45.85±15
May	10.75±2.9	25.25±4	40.7±14.86
Jun	15.42±2.4	32.2±3	28.58±9.5
Jul	19.1±2.27	35.52±2.56	27.25±8.2
Aug	14.32±8.36	30.5±9.28	22.18±17.25
Sep	13.05±2.63	30.7±2.95	27.0±7.74
Oct	7.63±3.23	22.68±4.1	41.4±15.87
Nov	2.0±1.98	14.4±3.95	57.6±15.2
Dec	-2.4±4.72	7.61±5.4	67.814±14.4

Table 4. Modeling of T_{min}, T_{max}, and RH over the coming decades using three scenarios

Months	Scenarios/ Decades*	T_{min}			T_{max}			RH		
		A	B	C	A	B	C	A	B	C
Jan	RCP2.6	-0.19	-0.047	-0.05	11.2	11.1	11.1	47.8	47.7	47.5
	RCP4.5	-0.86	0.650	0.925	10.25	12.1	12.6	49	47	46.15
	RCP8.5	-0.158	1.22	2.93	10.9	12.95	15.05	48.5	45.2	42.2
Feb	RCP2.6	0.71	1	1.3	12.25	12.25	12.7	46.1	44.9	44
	RCP4.5	0.5	1.4	1.76	11.52	12.92	13.6	45.6	43.7	43.37
	RCP8.5	1	2.3	3.5	12.6	13.8	15.55	45.2	42.9	40.8
Mar	RCP2.6	3.3	3.8	4.3	15.65	15.85	16.8	39.8	39.2	38.2
	RCP4.5	3.53	3.85	4.75	15.85	16.45	17.4	39.7	38.3	36.66
	RCP8.5	3.83	4.7	6.55	16.5	17.6	19.8	38.8	36.5	33.5
Apr	RCP2.6	7.1	7.87	8.33	20.3	21.5	22.3	32.1	31	29.8
	RCP4.5	7.3	8.4	8.85	20.6	22.1	22.7	32	29.35	29
	RCP8.5	7.2	8.9	10.2	20.6	22.8	24.95	31.95	28.5	25.8
May	RCP2.6	11.7	12.35	12.4	26.3	27.45	27.45	22.9	21.75	22.37
	RCP4.5	11.8	12.75	13.6	26.45	27.95	29.15	22.95	21.5	19.4
	RCP8.5	11.9	13.43	15.1	26.7	29	31.4	23.15	19.5	16.6
Jun	RCP2.6	16.7	17.3	17.2	33.75	34.2	34.2	12.55	12.05	11.7
	RCP4.5	16.53	17.35	18	33.6	34.5	35.4	12.15	11.8	10.3
	RCP8.5	16.57	18.3	20.3	33.35	35.8	38.25	13.3	10.35	5.4
Jul	RCP2.6	18.8	19.4	19.2	37.05	37.85	37.53	9	7.65	7.75
	RCP4.5	18.5	19.7	20.4	36.7	38.2	38.9	8.95	7.23	5.8
	RCP8.5	18.9	20.9	22.8	37.1	39.45	42	8.3	5.2	1.3
Aug	RCP2.6	18.34	18.9	19.05	36.53	37.55	37.6	10	9.66	9.68
	RCP4.5	17.75	19.2	20	35.85	37.9	38.8	12.05	8.85	7.2
	RCP8.5	18.2	20.3	22.8	36.63	39.45	42.65	10.15	7.26	2
Sep	RCP2.6	15.2	15.6	15.6	32.33	33.2	33.3	17.8	16.9	16.73
	RCP4.5	14.6	16.3	16.95	32.1	34.1	35	18.2	15.7	14.9
	RCP8.5	15.15	17.4	20.1	32.5	35.65	38.9	17.8	13.3	8.6
Oct	RCP2.6	10.7	10.8	10.8	26	26.6	26.3	27.5	26.9	27.3
	RCP4.5	10.25	11.35	11.83	25.95	27.35	27.9	28.2	26.45	25.75
	RCP8.5	10.55	12.7	15.3	26.1	29.05	32.2	27.8	24.4	19.8
Nov	RCP2.6	5.6	6	5.6	19.26	20	19.3	38.4	36.8	38
	RCP4.5	5.05	6.3	6.6	19	20.7	20.8	38	36.6	36
	RCP8.5	5.05	7.6	10.1	18.85	21.55	25.05	39.2	34.7	29.9
Dec	RCP2.6	1.23	1.75	1.5	13.3	14.1	13.3	45.5	44.4	45.6
	RCP4.5	1.2	1.95	2.6	13.35	14.3	14.9	46.1	44.7	43.3
	RCP8.5	1.3	3.2	5	13.45	15.5	18	45.5	42.4	39.65

*A: Years from 2011 to 2040; B: Years from 2041 to 2070, and C: Years from 2071 to 2099.

the scenario RCP 2.6 indicated that in the periods of 2011-2040, 2041-2070, and 2071-2099 compared to the base period, the values were associated with a decrease of 16.8%, 17.7%, and 17.8%, respectively. The highest reduction of relative humidity was related to January, February, and December, respectively. The decrease of 9.43% (September) to 23.92% (January) was observed in comparison with the base period. According to the scenario RCP 4.5, in the periods of 2011-2040, 2041-2070, and 2071-2099 compared to the base period, the values were associated with a decrease of 16.6%, 18.4%, and 19.5%, respectively. The highest reduction in the relative humidity belongs to January, February and December, which ranges from 10.3% (for September) to 24.2% (for January). Furthermore, based on the scenario RCP 8.5, in the periods of 2040-2011, 2041-2070, and 2071-2099, the mean of relative humidity was decreased as 16.8%, 20.15%, and 23.9%, respectively. The highest reduction of relative humidity was related to January, February, and December, respectively. Also, from 2011 to 2099, the decrease in relative humidity ranged from 13.34% (for September) to 26.28% (for January).

The average WBGT index in the studied station over the coming decades were examined using the three scenarios, the results of which are shown in Figure 2.

According to Figure 2A, the results of the scenario RCP 2.6 showed that the WBGT index has an upward trend until 2099; this growth of the index in January, February, and December is more significant. The findings of this study displayed an increase of 0.63 to 3.65°C in the amount of the index by the end of the last century compared to the basic decades. In summer season and the months of May, June, and July, there is a downward trend in the index.

With respect to the results (Figure 2B) obtained from the scenario RCP 4.5, the WBGT has also an upward trend until 2099. This rise in the index in January, February, and December is more considerable. Based on the scenario, an increase of 0.033 to 3.92°C in the amount of the index until the end of the last century was observed in comparison with the basic decades. In summer season and the months of June and July, there is a decrease in the amount of the index.

According to the results (Figure 2C) obtained from the scenario RCP 8.5, the WBGT has an upward trend until 2099, this increase in the index in January, February, November, and December is more significant. The results showed an increase of 0.55 to 4.7°C in the amount of the index until the end of the last century compared to the basic decades. It should be noted that in July, there is a decrease in the index.

Table 5 shows the indices of model evaluation. As shown in this table, the coefficient of determination (R^2) between the observed and modeled values for t_a and HR are 0.85 and 0.62, respectively, which indicate acceptable precision. The root-mean-square error (RMSE) for t_a and HR is 4°C and 10.7%, respectively. The standard error (SE) of the observed and modeled values for t_a and HR is 0.13°C and 0.11%, respectively, which shows the high accuracy of modeling. The absolute maximum error (MAE) for t_a and HR was obtained 5.9°C and 8.7%, respectively, which is acceptable.

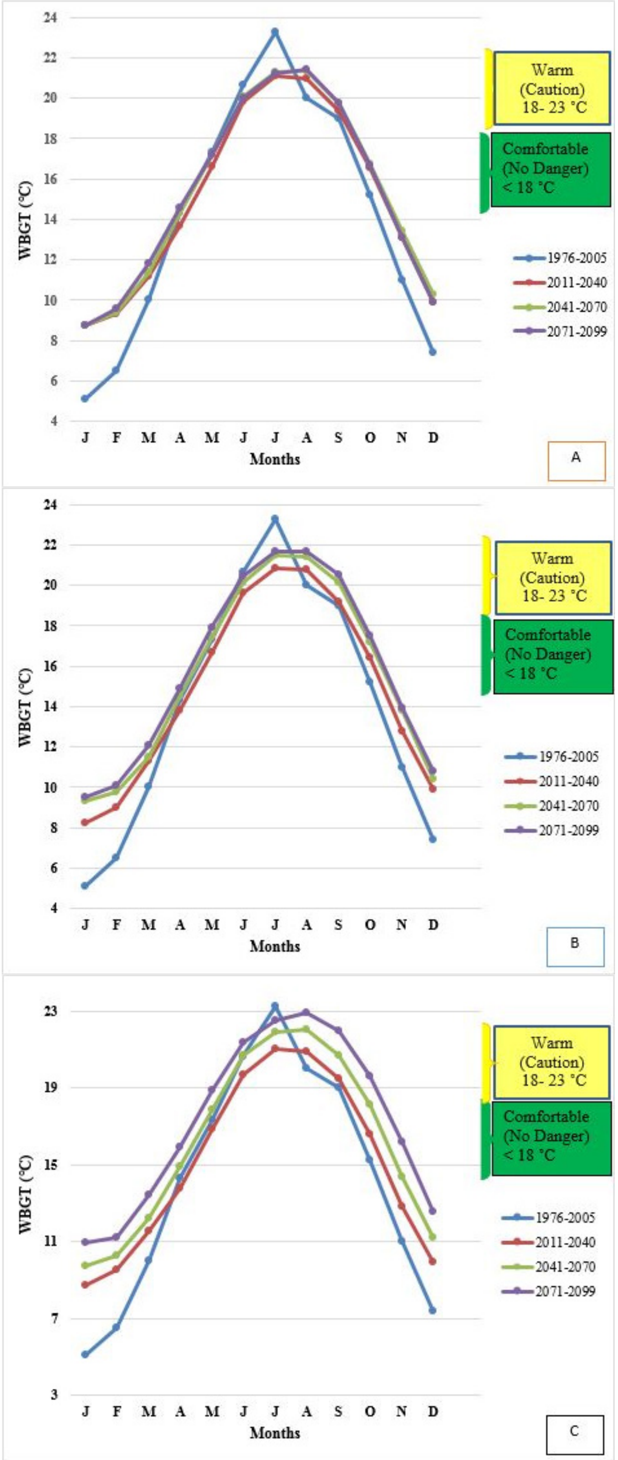

Figure 2. Comparative evaluation of WBGT index in the base and coming periods up to 2099 in different months of the year; A) The trend of the index changes using scenario RCP 2.6, B) The trend of the index changes using scenario RCP 4.5, and C) The trend of the index changes using scenario RCP 8.5.

Discussion

The phenomenon of climate change and global warming has become one of the biggest environmental problems today that has affected all members of society. Climate change is leading to rising heat waves, fires, air pollution, and war over water resources, infectious diseases, and so on. Given the trend of global warming in the present century, the importance of paying attention to the issue of heat stress and related disorders and diseases, such as heat shocks, is felt more than ever (31). Therefore, this study was performed to model the trend of heat stress based on the WBGT index in the coming decades using the general

Table 5. Evaluation of the produced data by the model in the studied station based on the observed data performance assessment of SDSM during validation period (1991–2005) for T_{mean}

Name	R^2	RMSE	SE	MAE
T_a	0.85	4	0.13	5.9
RH	0.62	10.7	0.11	8.7

atmospheric circulation model (CanESM2) and the SDSM microscale model in one of the climatic regions of Iran (Arak station) using three scenarios including optimistic scenario RCP (2.6), intermediate scenario RCP (4.5), and pessimistic scenario RCP (8.5). The results showed that in all months of the year, the minimum and maximum temperatures in the studied station increased over the coming decades based on the three scenarios studied. These increases were seen more in January, February, March, November, and December compared to the other months. Also, the results showed an increase in temperature in the RCP 8.5 scenario in the decades 2071-2099 compared to previous decades. Hoshyar et al. studied the outlook for the maximum temperature changes in another climatic region of the country (Urmia station in the northwest of Iran) using the CanESM2 model and the SDSM statistical microcirculation model. In this study, the trend of changes in the maximum temperatures during the basic statistical period (1961-2005), as well as the perspective of future changes in the maximum temperatures over a period of 30 years (2051-2021) in Urmia synoptic station were investigated. The results showed that during the baseline statistical period, the temperature has increased but its trend was insignificant. In addition, based on the results obtained from the data of the CanESM2 model, the maximum temperatures will increase, which is equal to 0.7°C compared to the base period. In terms of seasonality, the most and the least changes are related to summer (1.6°C) and winter (0.1°C), respectively (31). In another study using the LARS climate model, meteorological data from 1988 to 2005 were used to predict temperature changes in Tehran province in Iran, between 2010 and 2039. They found that the average monthly temperature would increase by about 0.2°C, with the highest increase in January (about 0.8°C). While in April, it gets colder by about 0.6°C, which is equivalent to a 4% decrease in temperature (32).

Fallah-Ghalhari et al (26) and Fallah-Ghalhari & Shakeri F (33) used the CanESM2 model to evaluate the effects of climate change on the minimum and maximum temperatures in Iran. The results showed that the highest increase in the mean of the maximum and minimum temperatures of Iran in the RCP 8.5 scenario and the period 2099-2071 will be equal to 6.69 and 6.61°C, respectively.

Humidity is one of the important climatic elements that has undeniable effects on various human activities and natural processes, especially in arid and semi-arid regions. Due to the fact that the occurrence of precipitation as a very important key element has a direct relationship with the humidity in the atmosphere or precipitation system, increasing temperature, which is accompanied by increasing the air humidity capacity, reduces the relative humidity and delays the precipitation process on an hourly scale. However, with increasing temperature and air humidity capacity, if there is a source of humidity, the specific humidity of the air rises and causes an increase in water vapor in the atmosphere. The water vapor in the role of a greenhouse gas can intensify global warming (34) .One of the indications of climate change is the change in daily temperature range (35). According to the results of this study, the temperature will increase in winter at Arak station. Given that temperature is inversely related to relative humidity, relative humidity is expected to decrease in winter. These results were exactly obtained in this study. As the relative humidity decreases, the water vapor content in the atmosphere decreases (36). Since water vapor plays an important role in reducing the day-night temperature range, with the reduction of water vapor, the day-night temperature in Arak station will increase in winter. In other words, the difference between day and night temperatures in winter will increase in the coming decades, and this may cause changes in climatic comfort conditions in this season, especially in outdoors. Therefore, proper planning should be considered in this field. According to the charts related to the studied scenarios, the WBGT index has an upward trend until 2099. This increase in WBGT index in January, February, and December is more significant. Also, in summer and May, June, and July, there is a downward trend in the index. However, regarding the decrease in the WBGT index in summer, it should be noted that the calculation of the index in this study was based on temperature and relative humidity. Therefore, in the summer months, especially July, the sever decrease in relative humidity causes a reduction in the WBGT index.

Fallah-Ghalhari et al evaluated the trend of changes in relative humidity in 41 synoptic stations in Iran in the period 1960-1990 and reported that the minimum and maximum relative humidity in 37 synoptic stations in Iran will decrease in winter, which is consistent with the results of this study (37). Habibi et al showed that the trend of average annual changes in the WBGT index during the statistical period of 1961-2009 in Tehran increases significantly. In addition, the model used in that study estimated an increase of about 1.55°C in the WBGT index by 2050. The results also showed that the mean monthly values of the WBGT index in March and October are located in the warm zone (caution, 24-28°C) and in June, July, August, and September in the hot zone (extreme caution, 28-24°C) (38). Willett and Sherwood examined the increase in heat stress thresholds using the WBGT index in 15 regions of the world considering climate change over the period from 1973 to 2003. The results showed that the trend of change is upward in all regions except the northeastern United States and northeastern Australia (39).

Conclusion

According to the results of this study, exposure to heat stress in the studied station during the statistical period has an increasing trend in accordance with global warming. It can have adverse effects on the health of people in the future, especially vulnerable people such as the elderly and children. Here, the trend of changes in the WBGT index until 2099 was modeled, which is superior to other studies conducted by simple time series models. In future studies, modeling is recommended to be done using several climatic models to compare the results of the models with each other to achieve a more accurate assessment for future planning.

Acknowledgements

This research was supported by Arak University of Medical Sciences (Grant No. 3679). The authors would like to appreciate the university cooperation as well as Iran Meteorological Organization for the provision of the required data.

Ethical issues

This study was approved by Arak University of Medical Sciences (Ethical code: IR.ARAKMU.REC.1399.164).

Competing interests

The authors declare that they have no conflict of interests.

Authors' contributions

Conceptualization: Mehdi Asghari, Gholamabbas Fallah Ghalhari, Mohammadjavad Ghanadzadeh.
Data Curation: Mehdi Asghari, Rahmatollah Moradzadeh, Reza Tajik.
Formal Analysis: Mehdi Asghari, Gholamabbas Fallah Ghalhari, Rahmatollah Moradzadeh, Sadegh Samadi.
Funding Acquisition: Mehdi Asghari, Mohammadjavad Ghanadzadeh.
Investigation: Mehdi Asghari, Gholamabbas Fallah Ghalhari, Reza Tajik.
Methodology: Mehdi Asghari, Gholamabbas Fallah Ghalhari, Rahmatollah Moradzadeh.
Project Administration: Mehdi Asghari, Gholamabbas Fallah Ghalhari, Mohammadjavad Ghanadzadeh, Sadegh Samadi,Hamidreza Heidari.
Resources: Mehdi Asghari, Hamidreza Heidari**.**
Supervision: Mehdi Asghari, Gholamabbas Fallah Ghalhari, Mohammadjavad Ghanadzadeh.
Validation: Mehdi Asghari, Gholamabbas Fallah Ghalhari, Rahmatollah Moradzadeh, Mohammadjavad Ghanadzadeh, Hamidreza Heidari.
Visualization: Mehdi Asghari, Gholamabbas Fallah Ghalhari, Mohammadjavad Ghanadzadeh.
Writing—Original Draft Preparation: Mehdi Asghari, Hamidreza Heidari.
Writing—Review and Editing: Hamidreza Heidari, Gholamabbas Fallah Ghalhari, Mohammadjavad Ghanadzadeh.

References

1. Fallah-Ghalhari G, Farhang Dehghan S, Shakeri F, Ghanadzadeh MJ, Asghari M. Assessing the monthly changes of heat stress indices in outdoor environment during a 15-year period: case of study in a dry and warm climate. Urban Clim. 2020;31:100538. doi: 10.1016/j.uclim.2019.100538.
2. Fan JL, Hu JW, Zhang X, Kong LS, Li F, Mi Z. Impacts of climate change on hydropower generation in China. Math Comput Simul. 2020;167:4-18. doi: 10.1016/j.matcom.2018.01.002.
3. Simmons AJ, Berrisford P, Dee DP, Hersbach H, Hirahara S, Thépaut JN. A reassessment of temperature variations and trends from global reanalyses and monthly surface climatological datasets. Q J R Meteorol Soc. 2017;143(702):101-19. doi: 10.1002/qj.2949.
4. Spinoni J, Vogt JV, Barbosa P, Dosio A, McCormick N, Bigano A, et al. Changes of heating and cooling degree-days in Europe from 1981 to 2100. Int J Climatol. 2018;38(Suppl 1):e191-e208. doi: 10.1002/joc.5362.
5. Nassiri P, Monazzam MR, Golbabaei F, Farhang Dehghan S, Shamsipour A, Ghanadzadeh MJ, et al. Modeling heat stress changes based on wet-bulb globe temperature in respect to global warming. J Environ Health Sci Eng. 2020;18(2):441-50. doi: 10.1007/s40201-020-00472-1.
6. Heidari H, Golbabaei F, Shamsipour A, Rahimi- Forushani A. Occupational heat stress in outdoor settings considering the regional climate change in the future decades in Iran. Iran Occupational Health. 2019;16(2):33-47. [Persian].
7. Nassiri P, Monazzam MR, Golbabaei F, Abbasinia M, Chavoshi M, Taheri F, et al. Exposure to heat stress in the workplace: a systematic review. Iran Occupational Health. 2018;15(2):111-28. [Persian].
8. Nassiri P, Monazzam MR, Golbabaei F, Shamsipour A, Arabalibeik H, Mortezapour AR, et al. Applicability of modified discomfort index (MDI) in outdoor occupational environments: a case study of an open pit mines in Tehran province. Iran Occupational Health. 2018;15(1):135-45. [Persian].
9. Asghari M, Fallah-Ghalhari G, Abbasinia M, Shakeri F, Tajik R, Ghannadzadeh MJ. Feasibility of relative strain index (RSI) for the assessment of heat stress in outdoor environments: case study in three different climates of Iran. Open Ecol J. 2020;13(1):11-8. doi: 10.2174/1874213002013010011.
10. Vargas-Amelin E, Pindado P. The challenge of climate change in Spain: water resources, agriculture and land. J Hydrol. 2014;518(Pt B):243-9. doi: 10.1016/j.jhydrol.2013.11.035.
11. Bedia J, Herrera S, Gutiérrez JM, Benali A, Brands S, Mota B, et al. Global patterns in the sensitivity of burned area to fire-weather: implications for climate change. Agric For Meteorol. 2015;214-215:369-79. doi: 10.1016/j.agrformet.2015.09.002.
12. Zoghi M, Ehsani AH, Sadat M, Amiri MJ, Karimi S. Optimization solar site selection by fuzzy logic model and weighted linear combination method in arid and semi-arid region: a case study Isfahan-IRAN. Renew Sustain Energy Rev. 2017;68(Pt 2):986-96. doi: 10.1016/j.rser.2015.07.014.
13. Bozorg-Haddad O, Zolghadr-Asli B, Sarzaeim P, Aboutalebi M, Chu X, Loáiciga HA. Evaluation of water shortage crisis in the Middle East and possible remedies. Journal of Water Supply: Research and Technology-Aqua. 2019;69(1):85-98. doi: 10.2166/aqua.2019.049.
14. Fallah-Ghalhari G, Farhang Dehghan S, Akhlaghi Pirposhteh E, Teimori G, Basati M, Asghari M. Applicability

of air enthalpy for heat stress assessment of outdoor environments in different climates of Iran. Theor Appl Climatol. 2021;145(3):1233-42. doi: 10.1007/s00704-021-03699-6.

15. Wilks DS. Use of stochastic weathergenerators for precipitation downscaling. Wiley Interdiscip Rev Clim Change. 2010;1(6):898-907. doi: 10.1002/wcc.85.
16. Ahmadi H, Fallah-Ghalhari G, Baaghideh M. Impacts of climate change on apple tree cultivation areas in Iran. Clim Change. 2019;153(1):91-103. doi: 10.1007/s10584-018-2316-x.
17. Asghari M, Teimori G, Abbasinia M, Shakeri F, Tajik R, Ghannadzadeh MJ, et al. Thermal discomfort analysis using UTCI and MEMI (PET and PMV) in outdoor environments: case study of two climates in Iran (Arak & Bandar Abbas). Weather. 2019;74(Suppl 1):S57-S64. doi: 10.1002/wea.3612.
18. Hua W, Chen H, Sun S, Zhou L. Assessing climatic impacts of future land use and land cover change projected with the CanESM2 model. Int J Climatol. 2015;35(12):3661-75. doi: 10.1002/joc.4240.
19. Javaherian M, Ebrahimi H, Aminnejad B. Prediction of changes in climatic parameters using CanESM2 model based on RCP scenarios (case study): Lar dam basin. Ain Shams Eng. J. 2021;12(1):445-54. doi: 10.1016/j.asej.2020.04.012.
20. Hassan Z, Shamsudin S, Harun S. Application of SDSM and LARS-WG for simulating and downscaling of rainfall and temperature. Theor Appl Climatol. 2014;116(1):243-57. doi: 10.1007/s00704-013-0951-8.
21. Fowler HJ, Blenkinsop S, Tebaldi C. Linking climate change modelling to impacts studies: recent advances in downscaling techniques for hydrological modelling. Int J Climatol. 2007;27(12):1547-78. doi: 10.1002/joc.1556.
22. Wilby RL, Dawson CW, Barrow EM. SDSM—a decision support tool for the assessment of regional climate change impacts. Environ Model Softw. 2002;17(2):145-57. doi: 10.1016/s1364-8152(01)00060-3.
23. Tavakol-Davani H, Nasseri M, Zahraie B. Improved statistical downscaling of daily precipitation using SDSM platform and data-mining methods. Int J Climatol. 2013;33(11):2561-78. doi: 10.1002/joc.3611.
24. Charre-Medellín JF, Mas JF, Chang-Martínez LA. Potential expansion of Hass avocado cultivation under climate change scenarios threatens Mexican mountain ecosystems. Crop and Pasture Sci. 2021;72(4):291-301. doi: 10.1071/cp20458.
25. Chou SC, Lyra A, Mourão C, Dereczynski C, Pilotto I, Gomes J, et al. Assessment of climate change over South America under RCP 4.5 and 8.5 downscaling scenarios. Am J Clim Change. 2014;3(5):512-27. doi: 10.4236/ajcc.2014.35043.
26. Fallah-Ghalhari G, Shakeri F, Dadashi-Roudbari A. Impacts of climate changes on the maximum and minimum temperature in Iran. Theor Appl Climatol. 2019;138(3):1539-62. doi: 10.1007/s00704-019-02906-9.
27. Heidari H, Golbabaei F, Shamsipour A, Rahimi Forushani A, Gaeini A. Consistency between sweat rate and wet bulb globe temperature for the assessment of heat stress of people working outdoor in arid and semi-arid regions. Int J Occup Environ Med. 2018;9(1):1-9. doi: 10.15171/ijoem.2018.1204.
28. Heidari H, Golbabaei F, Shamsipour A, Rahimi Forushani A, Gaeini A. Outdoor occupational environments and heat stress in IRAN. J Environ Health Sci Eng. 2015;13:48. doi: 10.1186/s40201-015-0199-6.
29. Teimori G, Monazzam MR, Nassiri P, Golbabaei F, Farhang Dehghan S, Ghannadzadeh MJ, et al. Applicability of the model presented by Australian Bureau of Meteorology to determine WBGT in outdoor workplaces: a case study. Urban Clim. 2020;32:100609. doi: 10.1016/j.uclim.2020.100609.
30. Epstein Y, Moran DS. Thermal comfort and the heat stress indices. Ind Health. 2006;44(3):388-98. doi: 10.2486/indhealth.44.388.
31. Houshyar M, Sobhani B, Hosseini SA. Future projection of maximum temperature in Urmia through downscaling output of CanESM2 model. Journal of Geography and Planning. 2018;22(63):305-25. [Persian].
32. Haghtalab N, Goodarzi M, Habibi Nokhandan M, Yavari AR, Jafari HR. Climate modeling in Tehran & Mazandaran provinces by LARSWG and comparing changes in northern and southern central Alborz hillside. J Environ Sci Technol. 2013;15(1):37-49. [Persian].
33. Fallah-Ghalhari G, Shakeri F. An assessment of Iran's seasonal temperature probability distribution variations in the future decades. Arab J Geosci. 2021;14(4):319. doi: 10.1007/s12517-021-06575-9.
34. Hashemi Masoomabad R, Gaffari Ghilandeh A, Mohammadi A. Spatial analysis of dispersion of educational land use in Ardebil using GIS spatial data. Journal of Urban Ecology Researches. 2020;11(21):91-106. doi: 10.30473/grup.2020.7474. [Persian].
35. Braganza K, Karoly DJ, Arblaster JM. Diurnal temperature range as an index of global climate change during the twentieth century. Geophys Res Lett. 2004;31(13). doi: 10.1029/2004gl019998.
36. Fallah-Ghalhari G, Mousavi Bayegi SM, Habibi Noukhandan M, Khoushhal J. Seasonal rainfall forecasting based on synoptical patterns using phasic sets theory. Geography And Development Iranian Journal. 2009;7(15):113-32. [Persian].
37. Fallah-Ghalhari G, Asadi M, Dadashi Roudbari AA. Spatial analysis of humidity propagation over Iran. Phys Geog Res. 2015;47(4):637-50. [Persian].
38. Habibi Mohraz M, Ghahri A, Karimi M, Golbabaei F. The past and future trends of heat stress based on wet bulb globe temperature index in outdoor environment of Tehran city, Iran. Iran J Public Health. 2016;45(6):787-94.
39. Willett KM, Sherwood S. Exceedance of heat index thresholds for 15 regions under a warming climate using the wet-bulb globe temperature. Int J Climatol. 2012;32(2):161-77. doi: 10.1002/joc.2257.