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Original Article

The Past and Future Trends of Heat Stress Based On Wet Bulb Globe Temperature Index in Outdoor Environment of Tehran City, Iran

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Abstract

Background: The workers who are working in the open and warm environments are at risk of health effects of climate and heat changes. It is expected that the risk is increase with global warming. This study aimed to investigate the changes of Wet Bulb Globe Temperature (WBGT) index in the past and to predict their trend of future changes in Tehran, capital of Iran.

Methods: The meteorological data recorded in Tehran, Iran during the statistical period between 1961 and 2009 were obtained from the Iran Meteorological Organization and based on them, WBGT index was calculated and processed using Man-Kendall correlation test.

Results: The results of Man-Kendall correlation test showed that the trend of changes of annual mean WBGT during the statistical period under study (1961-2009) has been significantly increasing. In addition, the result of proposed predictive model estimated that an increase of about 1.55 degree in WBGT index will be seen over 40 years from 2009 to 2050 in Tehran.

Conclusion: Climate change in Tehran has had an effect on person's exposure to heat stresses consistent with global warming.

Keywords: Climate change, Heat stress, WBGT, Global warming

Introduction

Heat exposure in the working environments is an important part of occupational health that often ignored (1, 2). Exposure to heat can cause many adverse health effects such as death due to heat stroke, damage to major organs, and physiological functions (3).

The people living in the big cities feel more heat exposure due to the formation of urban heat islands, besides, because the urban areas are a few degrees warmer than surrounding areas of the city (4).

However, the workers working in such cities in the outdoor environments like open pit mines, oil, gas and petrochemical industries, tourism, construction, and so on are exposed to more heat than the general population due to their more activity. In the absence of preventive measures in outdoor environments, reduced their activity will be used as a solution which will of course reduce economic productivity and income (5).

Nowadays, scientists around the world are seeking to predict the future climate to use it as a tool for estimating the global and local effects of climate change and to formulate health strategies. However, these studies have focused primarily on meteorological parameters such as the trend of temperature changes (6, 7) while the evaluation of heat stresses in the working environments is needed to be performed based on a combination of different climatic parameters (8) and thus, it could not be possible to assess about heat stress load based on just a meteorological factor (9).

Several indices have been designed to assess the level of heat exposure, which among them WBGT (10, 11) has allocated the most studies to itself in comparison with other indices such as PET and SET (12) which are sensitive to only one parameter. Kjellstrom et al studied the heat exposure and its effects in Southeast Asia. They used available weather station data to describe the thermal conditions of the region based on WBGT index. Accordingly, during the warmer month of the year such as March, afternoon WBGT levels are high enough to cause lower labor productivity and by 2050, the situation for many outdoor jobs will be worse (13)**.** Levels of WBGT index are increasing therefore this can cause further heat stress in workplaces and the risk of heat induced illnesses will increase (5, 14).

The current study aimed to investigate the trend of changes in the level of heat exposure of outdoor environments' workers based on WBGT index during the statistical period between1961 to 2009 and to predict the trend of future changes by 2050.

Materials and Methods

Study area

In terms of geographical location, Tehran metropolis lies between 51° 8' and 51° 27' east longitude as well as between 35° 34' and 35° 50' north latitude. The city's average elevation from the sea level is about 1400 meters. The highest and lowest temperatures in Tehran have been recorded in the months of June to July and December to January, respectively. Tehran's annual prevailing wind blows from the West and its cold and fast winds blow from the West and northwest.

Collecting the data and information

The data needed for this study were obtained from the Country's Meteorological Organization. These data included the meteorological data recorded in the Tehran's Mehrabad meteorological station during the statistical period from 1961 to 2009 contained the hourly values of environmental parameters such as temperature, relative humidity, dew-point temperature, Wet Bulb Temperature, air pressure, water vapor pressure, cloudiness, air velocity at a height of 2 meters. In order to calculate the WBGT heat stress index, the daylight h values of environmental parameters were imported into Bioklima v.2.6 software package and the calculations were performed by software according to the following formula: WBGT = 0.567t + 0.393e + 3.94 where that t is the air temperature (°C) and e is relative humidity(15). After the calculation of the daylight h values of WBGT index, daily time average and monthly average of this index was calculated.

Data analysis

Nowadays, trend analysis is one of the tools for determining the climate change. There are different methods for analyzing the trend divided into two categories: Parametric and nonparametric methods. Since the climate variables are in the form of Stochastic, i.e., their distribution is random; Man-Man-Kendall nonparametric test is used in this study to analyze the trend of heat stress index. Time series models were employed to predict the future changes of heat stress index. The main purpose of the analysis of time series is to find the changes' model and to predict future. One of the techniques for forecasting the behavior of time series is Box-Jenkins method. The Box-Jenkins method is based on a large range of forecasting models for a time series. The general category of models for a time series in the Box - Jenkins methodology is Autoregressive Integrated Moving Average Model, known to ARIMA in the statistics (16, 17).

Two general forms of ARIMA models include non-seasonal ARIMA (p, d, q) and seasonal ARIMA (P, D, Q) × (p, d, q); where p, q are autoregressive and non-seasonal moving average parameters, respectively. *P* and Q are also autoregressive and seasonal moving average parameters, respectively. The two other parameters, namely d and D, are the differential parameters for stationary time series. The differential operators used for dynamic time series include $\Delta = 1 - B$ (B is a backward jump operator) and $\Delta^d = (1-B)^d$ for seasonal differences.

As Box and Jenkins noted, three main stages of ARIMA include model identification, model fitting and model accuracy diagnosis.

The main purpose of the identification stage is to get the values of q, d, P for general linear ARIMA model and to obtain initial guess values of the parameters.

Model fitting involves finding the possible estimations for unknown parameters of the given model. The series model parameters will be estimated by drawing the autocorrelation and partial autocorrelation plots of the first series after the identification of time series model.

Model accuracy diagnosis is associated with analyzing the quality of model identified and estimated. After identifying and estimating the model parameters, it is necessary to evaluate the adequacy of the model by investigating whether model assumptions are established. The basic assumption is that the residuals series have a normal distribution with mean zero and constant variance. In addition, the randomness of residuals could be investigated by checking the autocorrelation and partial autocorrelation plots of the residuals series.

Further, the Akaike information criterion (AIC) is a criterion for selecting an optimal model among several appropriate models. The criterion specifies the number of model parameters and according to principle of parsimony, the model which has minimum AIC coefficient besides having appropriate conditions, should be selected (18,19).

The trend of changes of heat stress WBGT index over time suggested that these changes are of seasonal changes.

The seasonal changes evidence the periodic behavior of a variable, i.e., the behavior that typically occurs every year in the same season with almost the same intensity.

So, it was decided to use seasonal ARIMA model to predict the future changes in heat stress index of WBGT using its trend of past changes in the statistical period between1961 to 2009.

Results

Table 1 shows the results of Man-Kendall correlation test for the WBGT heat stress index based on months of the year, the seasons and their annual average.

Table 1: Man-Kendall correlation test for the WBGT heat stress index based on months of the year, the seasons and annual average

	Fall				Summer				Spring				Winter				Total
Parameter	**Total**	**December**	**November**	**October**	**Total**	**September**	**August**	**July**	**Total**	**Jane**	**May**	**April**	**Total**	**March**	**February**	**January**	
WBGT	S^+	+	+	S^+	S^+	S^+	S^+	S^+	+	S^+	+	S^+	S^+	S^+	+	+	S^+

S means significant and positive, the negative and zero shows that the trend is ascending, descending or without change, respectively.

As shown in Table 1, the trend of WBGT changes during the period under review (1961-2009) is often significantly increasing. Consequently, time series models were used for modeling the future trend of changes.

SAMIRA (1, 0, 2) (0, 1, 1) model provides a better prediction of WBGT index changes than other models during the period under review (1961-2009). The results of applying this model to predict future changes of WBGT index is shown in Fig. 1. Autocorrelation and partial autocorrelation coefficients of residuals are not significant in any delays. Therefore, the proposed model is an appropriate model. Fig. 2 gives the fitting of proposed model to observed data and the predicted trend of Tehran's WBGT index by 2050.

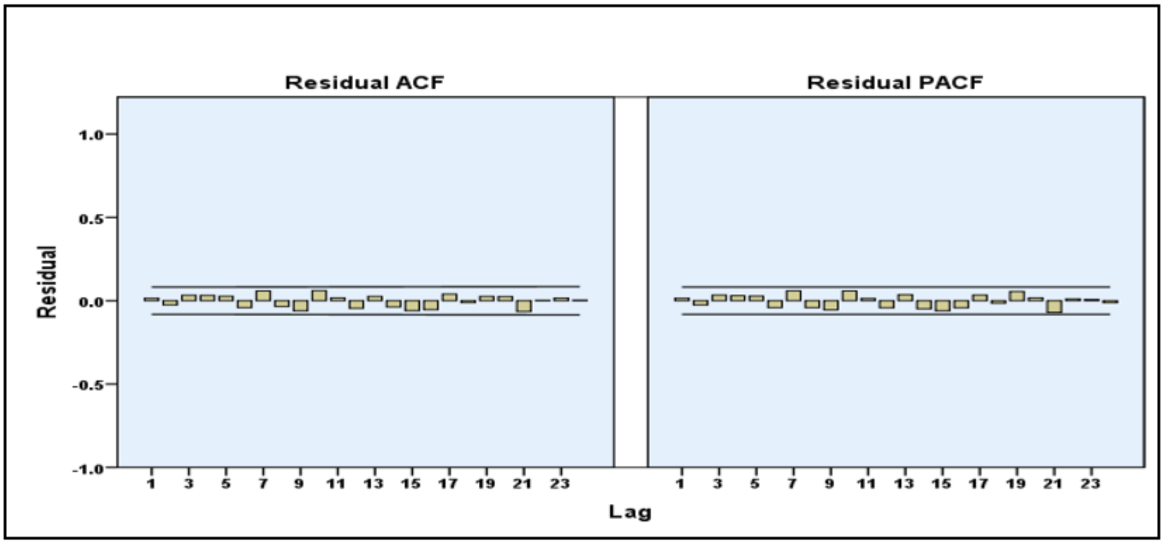

Fig. 1: Time series ACF and PACF plots of Tehran's WBGT index.

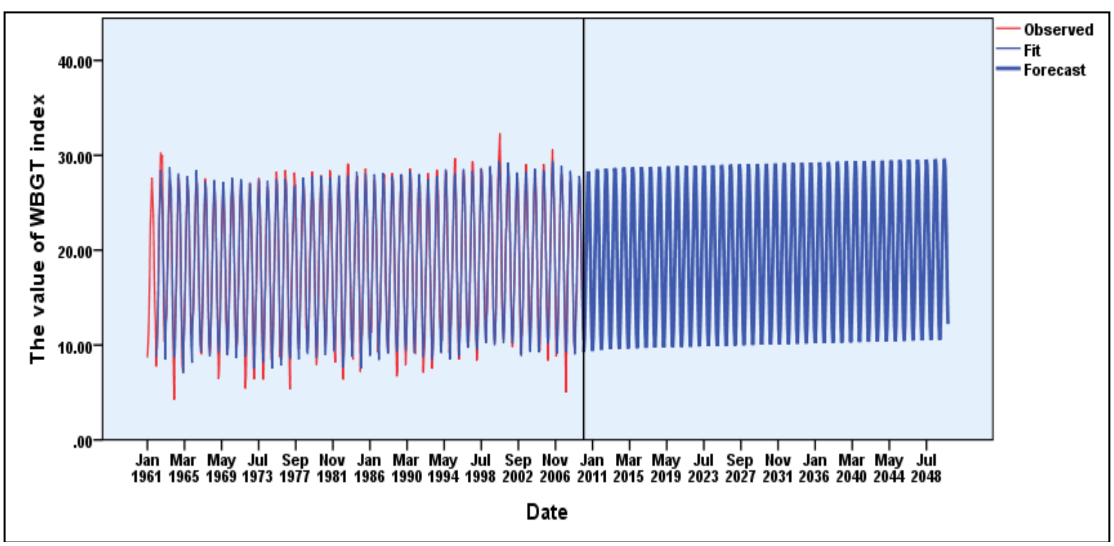

Fig. 2: The fitting of proposed model to observed data and the predicted trend of Tehran's WBGT index.

The goodness of fit of values predicted by proposed model was tested using Pearson correlation coefficient. According to test, the actual values of monthly average WBGT index in Tehran and fitted values amounted to 0.982, which is significant in less than 5% level of error ($P \leq 0.05$).

Fig. 3 shows that correlation between the actual values and values predicted by model equals to 0.964. The correlation demonstrates the goodness of fit of values predicted by the model. The trend of changes of annual average WBGT index in Tehran and a trend predicted by proposed model are displayed in Fig. 4. Fig. 5 shows the changes of monthly average WBGT index in Tehran based on the seasons of year.

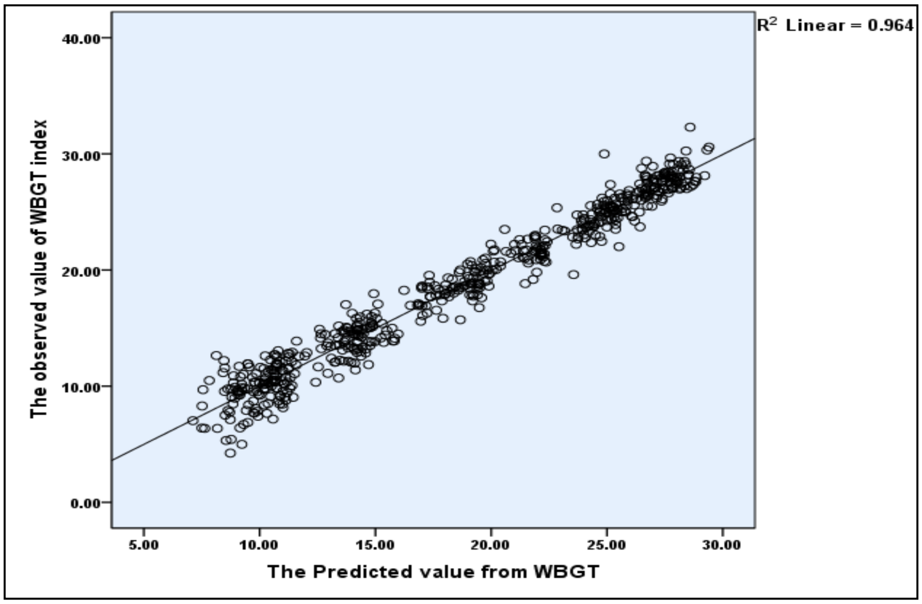

Fig. 3: The correlation between the values predicted by the proposed model and the actual values

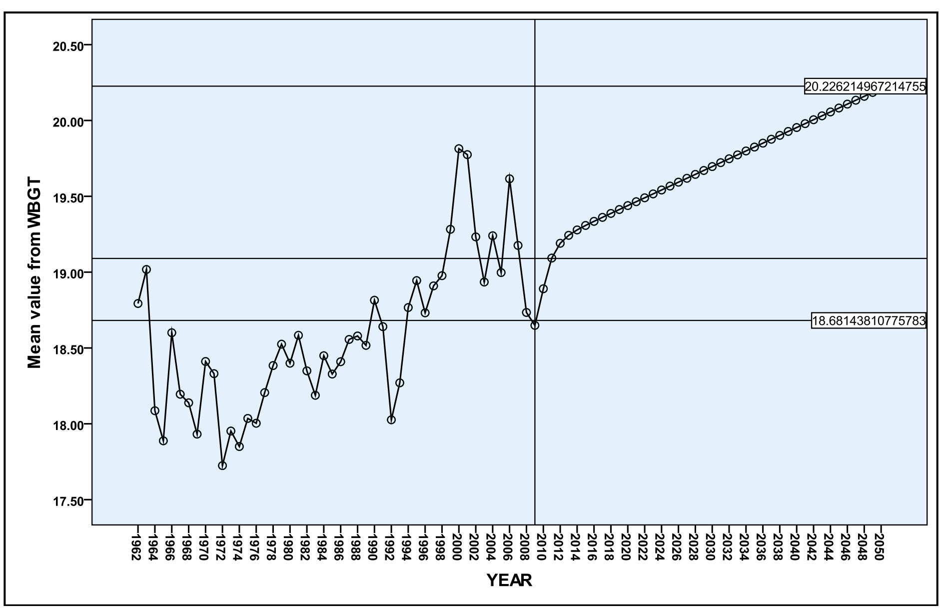

Fig. 4: The trend of changes of annual average WBGT index in Tehran and trend predicted by proposed model

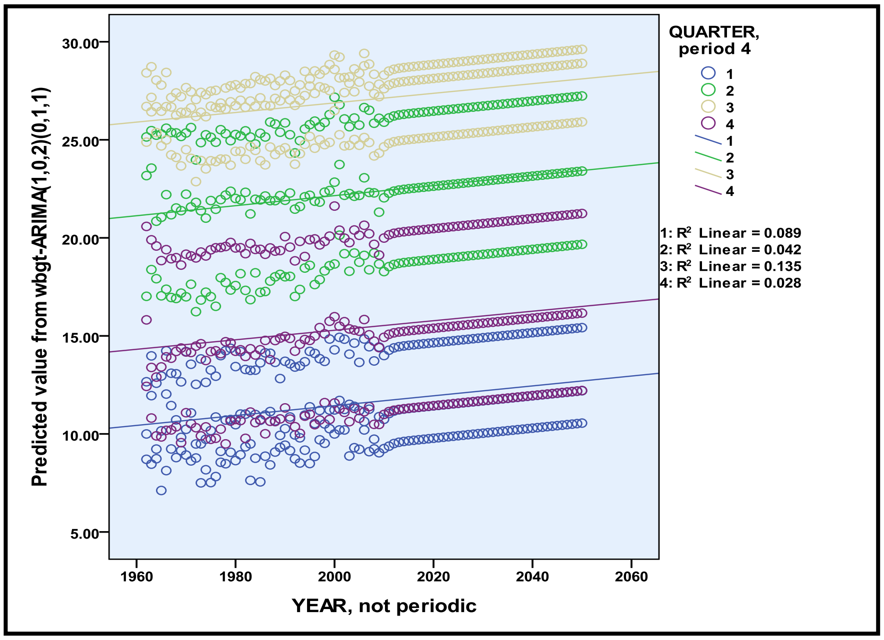

Fig. 5: The changes of monthly average WBGT index in Tehran based on the seasons of year

The changes of WBGT index have been increasing for all seasons. The highest rate of changes has been observed in summer season with the R^2value of 0.135 followed by winter, spring and fall seasons with the R^2values of 0.089, 0.042 and 0.028, respectively.

The monthly average values of WBGT index for different periods of the years are shown in Fig. 6. The monthly average value of WBGT index for all months for period from 1961 to 1985 have been less than theirs value for time period between1985 to 2009.

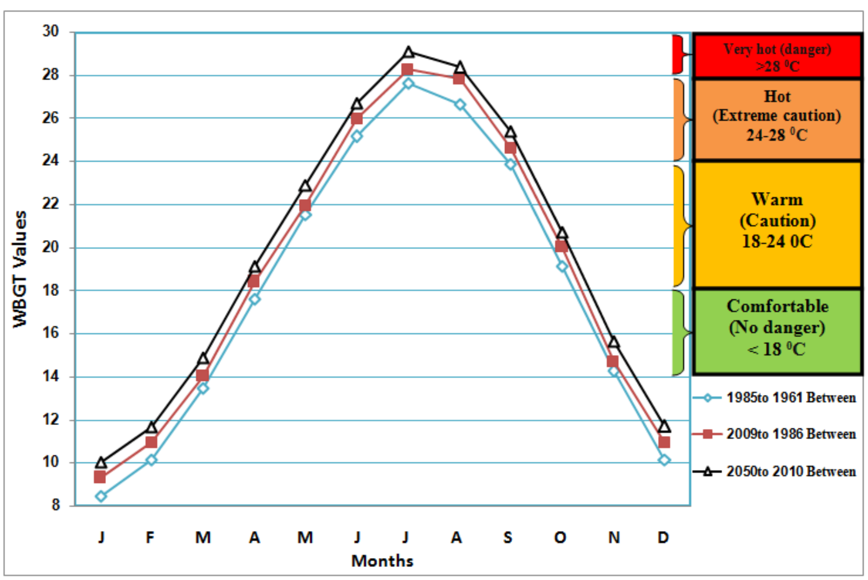

Fig. 6: The monthly average value of WBGT index for different periods

Discussion

The results indicate that the values of WBGT index have increased over the past few years. The trend observed for WBGT index changes during the study period (1961-2009) has been increasing for all months, seasons and annually. The trend has been significantly increasing for the months of April, June, August, September and October. Further, the seasons of summer, fall and winter exhibit a significant increasing trend of changes.

It is observed that since the beginning of the study period in 1961, the changes of annual average WBGT index in Tehran has had a rising trend. Based on proposed model, an increase of about 1.55 degree in WBGT index will be seen over 40 years from 2009 to 2050 in Tehran.

Fig. 6 shows that the monthly average values of WBGT index for 24 years ranging from 1961 to 1985in March and October are in Warm zone (Caution, 18-24 °C)and in June, July, August and September are in hot zone (Extreme caution, 24-28 °C).

These values for the years ranging from 1985 to 2009 have increased in all months. So that the average values of WBGT index for April as same as October and March is in warm zone (Caution, 18-24 °C), also the average values of WBGT index in June, and August are in very hot zone (danger, >28 °C).As shown in Fig. 6, the predicted average values of WBGT index by the model have increased in all months, especially in the warmer months (June, July, August and September).Further increase in the summer also as shown in Fig. 4. Given that the outdoor workers (such as open pit mines, oil, gas and petrochemical industries, tourism and construction) are more active in these months thus increase in the risk of heat stresses by creating some restrictions for these workers would affect the efficacy, health and safety of them.

In order to determine the relationship between different studies, we need to perform investigations that are more accurate. Using WBGT index, the increasing thresholds of heat stresses were investigated for 15 regions of the world taking into account the climatic changes during the statistical period from 1973 to 2003 (20). The trend of changes is increasing for all regions except north eastern U.S and northeastern Australia. The authors used Hadcam3 model to determine the regional variations of average summer temperature, relative humidity and WBGT under the A1B scenario for 2020 and 2050. The results showed an increase of WBGT for all regions, while the changes of temperature and relative humidity were varied depending on the climate of the region (20).

Unlike aforementioned study, the current study used a time series model to predict the trend of WBGT index changes. Because, the purpose of current study was to evaluate the effects of climate change on the workers' exposure to heat stress in outdoor environments during daylight h, using the Hadcam3 models that take into account average round-the-clock environmental parameters such as temperature could not have correct results.

In another study, the maps of exposure to job heat stress in the past, present and future for different regions of the world were drew (14). The drawn maps showed that the value of WBGT index in most regions during hot seasons between 1975 and 2000 has risen about 0.5 to 1 degree in conformity with global warming and the trend has been decreasing in some regions due to moisture loss. Assuming an increase of 3 degree in WBGT index due to climate change since 2000, their study concluded that the risk of heat stress in most regions would be moderate and high (14).

The number of days during which people will not be able to engage in physical activities in order to avoid the effects of heat stress increased with time, so that in 2070 about 15 to 26 days a year will be dangerous for physical activities, while the amount is currently one day a year (21).

Given the existing trend of climate change over time, the results of current study indicate that an increase in the risk of heat stresses for the workers in heavy, physical jobs in open environments will be seen over the hot month of the year.

Conclusion

Climate change in Tehran during the statistical period under review has had an effect on people exposure to heat stresses especially in the hot months of the year consistent with global warming. The continuation of these changes in future could have adverse effects on the health of people, especially vulnerable people such as the elderly, children and patients as well as health, safety and productivity of workers who are working physically and manually in the outdoor environments.

Ethical considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

Acknowledgment

The authors declare that there is no conflict of interest.

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