Natural Environment Change, Vol. 2, No. 2, Summer & Autumn 2016, pp. 89- 98

Comparative assessment between historical and future trends in the daily maximum temperature parameter over selected stations of Iran

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Recieved: July 11, 2016 Accepted: November 13, 2016

Abstract
Objective of this study is to determine whether there are significant changes in maximum temperature trends between the current (1981-2010) and future (2011-2099) periods. To this end, statistical downscaling is used to project future changes in the maximum temperatures according to A2 and B2 scenarios of HADCM3 in the 7 selected stations of Iran. The possibilities of an accelerating trend are detected in the maximum temperature at 95% confidence level using of Mann–Kendall and Sen's slope methods. The results showed that there is an increasing tendency in the maximum temperature trends over Iran, especially in the northern highlands for the future decades of the 21st century than the last three decades. The highest trend slopes in annual maximum temperatures are found by 0.69, 0.68, and 0.62°C per decade at Isfahan, Tabriz, and Tehran stations based on A2 scenario for the future decades (2011-2099), respectively, while the lowest trend slope is found at B-Abbas station that is equivalent to 0.14°C per decade based on B2 scenario. It is important to mention that the rate of warming trend will be accelerating based on temperature-time relations in coming decades. In this point, the future occurrences of desirable daily temperatures could be exposure in the southern coasts of Iran where it will be affected by more capacity of atmospheric humidity.

Keywords
current decades, future decades, temperature trends, warming rate.

1. Introduction
Global warming continues to affect the whole world by causing numerous adverse social and economic consequences. The signal of climate change is often described by changes in temperature. This has affected the overall health of people, especially those living in third world countries. Also, the temperature variations in arid and humid climates have been observed in

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most regions of the world. Therefore, temperature changes in dry lands will accelerate the process of desertification. According to the assessment report of Intergovernmental Panel on Climate Change (IPCC), the global average of combined land and ocean in the surface temperature data shows a warming linear trend of 0.85 [0.65 to 1.06]°C over the period of 1880 to 2012 (IPCC, 2013). As noted, the temperature trends around the world show that global warming is taking place. Therefore, the main purpose of this study is to improve the understanding of warming trends for future decades.

Although, there are a number of studies about temperature trends for last decades (e.g. Jones and Moberg, 2003; European Environment Agency reports, 2008; Toros, 2012; Croitoru and Piticar, 2013; Insaf et al., 2013; Whan et al., 2014; Kim et al., 2015; Kumar et al., 2016; Gray et al., 2016) but no one has performed the statistical downscaling methods on General Circulation Model (GCM) outputs for comparing the future trends rather than observation periods.

A number of researchers have studied the past temperature trends in some parts of Iran (Smadi, 2006; Hamdi et al., 2009; Tabari and Hosseinzadeh Talaee, 2011; Abbasnia et al., 2016). In a regional scale of temperature studies, Masoodian (2007) showed an increase in the maximum temperature of Iran for about 0.5°C during the whole period of 1951-2000. Also, Saboohi et al. (2012), analyzing the annual maximum temperature in 35 weather stations of Iran, found that 71% of the studied stations had significant positive trend during the observation period of 1951-2007. In this case, the research results of Mojarrad and Basati (2014) showed an increase in the maximum temperature for about 0.62°C during a period of 45 years (1964-2008). Overall, the results of these studies showed that there are warming trends in the majority of the status quo of Iran’s temperature time series, while it is really hard to find any researchers who have analyzed the impacts of climate change in the temperature trends for future decades.

However, GCMs outputs could be used in order to understand the global warming effects and climate change impacts in the future periods. Forasmuch as temporal and spatial resolution of the GCM outputs is coarse, downscaling methods are necessary for converting the GCM outputs in local scale of study stations (Salon et al., 2008). To this end, researchers could use the dynamical or statistical downscaling methods. In this regard, ‘SDSM’ model by Wilby et al. (2002) has been developed as an appropriate tool for statistical downscaling method. So far, many studies in the field of climate change have used the SDSM model for downscaling process (e.g. Huang et al., 2011; Mahmood and Babel, 2014). Thus, with regards to the increase of temperature extremes over Iran (IRIMO, 2012; Darand et al., 2015), the present study focuses on analyzing and comparing the maximum temperature trend for behaving more rationally with the rising temperature situations in the coming decades. Therefore, in the first step of this study, it has been tried to detect the future projection of maximum temperature changes over Iran. Then, the annual trends in maximum temperature series has been evaluated at 7 selected stations of Iran during the whole current and future periods.

2. Study area

Iran lies between 25°3′N and 39°47′N in latitude and between 44°5′E and 63°18′E in longitude. Iran contains two mountain ranges: Elburz in the north and Zagros in the west (Saboohi et al., 2012). Topography diversity of Iran has caused the spatial distribution of temperature that is not followed by the regular pattern. Generally, Iran’s temperature is increasing from Northern mountain regions to Southern lowland regions and from Western mountain regions to Eastern lowland regions due to the temperature patterns that are followed by the elevation distributions. Figure 1 shows the geographical distribution of 7 synoptic stations which have been chosen as representatives of climatic regions in Iran (Abbasnia and Toros, 2016).

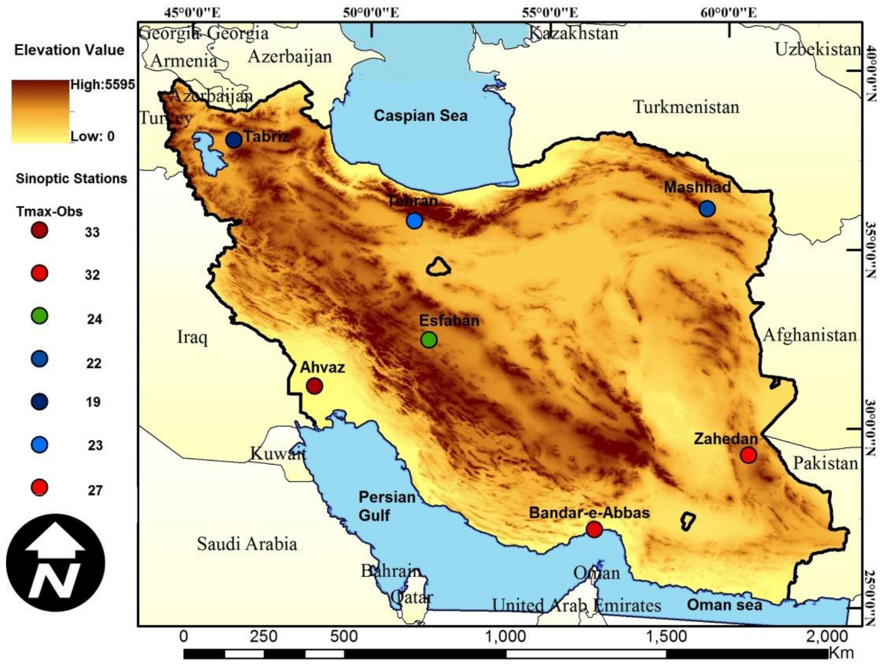

Fig. 1. Topography map and spatial distribution of the studied stations in Iran

3. Materials and Methods

3.1. Data analysis

To assess the maximum temperature changes in coming decades, the SDSM model is used to handle the statistical downscaling process on GCM outputs. The main method in SDSM software is combination of Stochastic Weather Generator (SWG) and Multiple Linear Regression (MLR) to find the relation between climate variables in local scale as predicted variables and large-scale atmospheric variables as predictor variables (Wilby and Dawson, 2013). In this study, two data sets are needed to project the daily maximum temperature in station scales:

1. Daily maximum temperatures during the observation period (1981 to 2010) prepared from Islamic Republic of Iran Meteorological Organization (IRIMO) at 7 synoptic stations as climatic representatives in the vast range of Iran. The accuracy of these data at the confidence level of 95% is approved based on the adequacy test of data, the homogeneity of Run test, and the normality test of Kolmogorov-Smirnov.

2. Daily large-scale atmospheric variables that are prepared from The National Center for Environmental Prediction (NCEP) for the observation period (1981-2010) and also outputs of HADCM3 model under existing scenarios that are extracted from the Canadian Climate Change Scenarios Network (CCCSN) for the observation period (1981-2010) and future period (2011-99) (Table 1).

Also, Table 2 indicates the number of nearest grid box than the geographical location of each studied station for extracting the HADCM3 data regarding the longitude and latitude of the study area.

Table 1. Characteristics of HADCM3 model as input of SDSM software

GCM	IPCC	SRES	Resolution	Reference
HADCM3	IPCC4	A2, B2	2.5° × 3.75°	AR4, Met Office, Hadley Center for Climate Prediction & Research (HCCPR), United Kingdom

Table 2. The box numbers of latitude and longitude in station scale for HADCM3 model

GCM	Station	Mashhad	Zahedan	Tehran	Isfahan	B-Abbas	Ahvaz	Tabriz
HADCM3	X	17	17	15	15	16	14	13
	Y	21	23	21	22	24	23	20

3.2. Climatic scenarios generation

After preparing the database, correlation analyses in the SDSM software are used to identify the strongest significant correlations between the large-scale atmospheric variables as predictors and observational maximum temperature as predicted at each study station, which include: correlation matrix analysis, partial correlation, scatter plot, and proportion of explained variance between all variable groups (Mahmood and Babel, 2014; Liu and Xu, 2015). So, in this study, the best predictors are selected to develop the best multivariate regression model based on the results of correlation analyses at each studied station (Table 3).

In validation step, there are some measurement errors for calibration of prediction outputs due to the final developed multivariate regression models in the SDSM software. In this study, we have used the measurement errors such as Standard Error (SE), R Square (R2), Mean Absolute Error (MAE), and Mean Bias Error (MBE) for comparative analysis between the results of simulations and observational values in the base period (2010-1981). Overall, the results of all statistical measurement errors showed that the final multivariate regression models have acceptable accuracy for simulation of the daily maximum temperature in future decades (Table 4). Thus, after calibration step, the daily maximum temperature series are simulated and produced in the selected stations scale for the future period (2011-99).

Table 3. Partial correlations between the selected predictors of HADCM3 model and maximum temperature of studied stations during the observation period

Predictor	Description Station➔	Tehran	Tabriz	Isfahan	Ahvaz	Zahedan	Mashhad	B-Abbas
Mslp	Mean sea level pressure	-0.29	-0.31	0.07	-0.21	-0.34	-0.64	-0.76
P500	Geopotential height (500 hPa)	0.41	0.49	0.10	0.10	0.56	0.73	__
P850	Geopotential height (850 hPa)	__	__	__	0.15	__	__	0.67
P8_u	U Wind (850 hPa)	-0.25	__	__	-0.32	__	0.12	0.67
R850	Relative humidity (850 hPa)	0.12	__	__	-0.11	-0.29	__	__
Shum	Near surface specific humidity	0.07	0.08	0.04	0.05	__	__	-0.13
Temp	Mean temperature at 2m	0.15	0.17	0.70	0.17	0.18	__	__
p8_v	V Wind (850 hPa)	__	__	__	-0.26	__	__	-0.09
p5zh	Divergence (500 hPa)	__	__	__	0.07	__	__	__
p_z	Near surface Vorticity	__	__	__	-0.20	__	-0.37	-0.21
r500	Relative humidity (500 hPa)	__	__	-0.36	-0.17	__	__	__
Rhum	Near surface relative humidity	-0.20	-0.06	-0.21	-0.21	__	__	__

Table 4. The calibration results of the SDSM model during the base period (1981-2010)

Station	SE	R^2	MAE	MBE
Tehran	2.25	0.62	1.84	0.04
Tabriz	2.53	0.61	2	0
Isfahan	2.20	0.55	2.45	0
Ahvaz	2.01	0.59	2.2	-0.002
Zahedan	2.20	0.61	1.7	-0.23
Mashhad	3.42	0.48	2.8	-0.004
B-Abbas	1.80	0.45	2	0.01

In all the studies about climate change, various uncertainties resulting from modeling process should be considered to achieve more reliable results (Semenov and Stratonovitch, 2010). So, in this study, the Mean Observed Temperature method is used to evaluate the uncertainty arising from various used scenarios (Eq. 1).

$$W_{i,j} = \frac{\frac{1}{\Delta T_{i,j}}}{\sum_{j=1}^{n} (1/\Delta T_{i,j})} \quad (1)$$

In this equation, ($W_{i,j}$) is the weight that is given to each scenario (j), ($\Delta T_{i,j}$) is the difference between the simulation of mean maximum temperature in the future period from the observational mean of maximum temperature in the base period at per day (i), and (n) is total number of used scenarios.

Thus, in this study, the probability weights are calculated to show the ability of used scenarios in simulation process of the maximum temperature. According to Table 5, it is clear that the scenario B2 has allocated the highest probability of simulation among all scenario outputs of HADCM3 model.

Table 5. The percentage of simulation occurrence in the maximum temperatures under studied scenarios for the future period (2011-99)

Model/SRES	HADCM3	
Station	A2	B2
Tehran	0.15	0.22
Tabriz	0.13	0.19
Isfahan	0.13	0.29
Ahvaz	0.11	0.18
Zahedan	0.14	0.20
Mashhad	0.08	0.12
B-Abbas	0.09	0.14

3.3. Trend analysis

After preparing the data for current and future periods, the MAKESENS method, developed by the Finnish Meteorological Institute (Salmi et al., 2002), is used to estimate the annual trends of maximum temperature series. This procedure is based on the non-parametric method of Mann-Kendall for the monotonic trend and the non-parametric method of Sen's slop for the magnitude trend (Mann, 1945; Kendall, 1975). The Mann-Kendall test analyzes whether to reject the null hypothesis H0 (no monotonic trend) and/or accept the alternative hypothesis H1 (monotonic trend is present). As Equation (2) shows, the Mann-Kendall test is applicable in all cases when the data values xi of a time series can be assumed to obey the model (Piticar and Ristoiu, 2012).

$$Xi = f(ti) + \varepsilon i \tag{2}$$

where f(t) is a continuous monotonic increasing or decreasing function of time, the residuals (εi) can be assumed to be from the same distribution with zero mean.

Then, an upward or downward trend is given by a positive or negative value of Z. To this end, at first, the variance of S is computed using Equation (3).

$$VAR(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t(t-1)(2t+5)}{18} \tag{3}$$

where (m) is the number of tied groups and (t) is the number of data values in the (i) group. Then, the values of (S) and VAR(S) are used to compute the Mann-Kendall test statistic of (Z), as is present in Equation (4) (Z: a, b, c):

$$\begin{aligned} Z_a &= \frac{S-1}{\sqrt{VAR(s)}}, \text{if.} S > 0, \\ Z_b &= 0, \text{if.} S = 0, \\ Z_c &= \frac{S+1}{\sqrt{VAR(s)}}, \text{if.} S < 0. \end{aligned} \tag{4}$$

Then, non-parametric method of Sen's slop was used to estimate the actual slope of (Q) in the existing trend. As Equation (5) shows, Sen's slop method can be used in all cases where trend is assumed to be linear, so that linear model (f(t)) is equal to (Refat Nasher and Uddin, 2013):

$$f(t) = Qt + B \tag{5}$$

where (Q) is the slope and (B) is a constant value.

To determine the (Q) value, the slope is calculated for all pair values, first (Eq. 6).

$$Q_i = \frac{x_j - x_k}{j - k} \tag{6}$$

where (j>k), the (Q) slope represents the median of all (Qi) values that are ranked in ascending order. The constant (B) is given by the median of n values of (xi– Q(ti))

4. Results and Discussion

In this study, after assessing the ability of SDSM model for statistical downscaling of HADCM3 outputs and uncertainty analysis onto all scenario outputs of HADCM3 model at the station scale, it is worth noting that the obtained results based on each studied scenarios represent a more increasing rate of maximum temperature in all of studied stations for the future decades than the observation decades (Table 6). In future decades, the greatest increase of maximum temperature is observed based on A2 scenario of HADCM3 model. In this case, the greatest increase rate of maximum temperature based on all emission scenarios are observed at Tabriz and Tehran stations which are respectively located in the northwestern and northern parts of Iran, while the lowest is observed at Isfahan and B-Abbas stations which are respectively located in central and southern parts of Iran. It can be due to different climatic conditions such as existence of humidity in their atmospheric and latitude location and rate of urbanizing or other effective human activities as anthropogenic behavior that are related to global warming. In other words, analyzing the maximum temperature changes in the whole of 21th century (2011-99) has shown that average maximum temperatures will be increased about for 0.2 to 3°C based on all scenario outputs of HadCM3 model in Iran.

Table 6. Difference in the rising temperature between scenario outputs in future period (2011-99) and observational data during the base period (1981-2010)°C

Station	Elevation (m)	Base period	SRE/A2	SRE/B2
Ahvaz	23	33.2	1.5	1.0
B-Abbas	10	32.1	0.8	0.6
Isfahan	1550	23.7	0.7	0.2
Mashhad	999	21.9	1.9	1.4
Tabriz	1364	18.6	3.0	2.4
Tehran	1191	23.0	2.5	1.9
Zahedan	1370	27.0	1.7	1.3

The annual trend analysis reveals that the highest rising in the maximum temperature parameter will happen based on output of A2 scenario in future period. Also, the annual trend over the whole study time periods shows a significant positive trend in 100% of the studied stations at the 95% confidence level. Therefore, there are not any selected stations over Iran which has significant or non-significant negative trends and slope trends (Table 7). The results of Mann-Kendall test showed that the significant increasing trends in annual maximum temperature varied between observation and future periods. Therefore, according to the results of Z value during the base period, the highest positive trends were respectively obtained at Tabriz and Tehran stations. Also in the future periods, the analyzing results of Z value in maximum temperature series showed that the highest positive trend will respectively happen at Ahvaz, Tabriz, and Tehran stations based on A2 scenario and at Zahedan and Tehran stations based on B2 scenario, while the lowest positive trends have been found at B-Abbas station during the whole time period which is located in the southern coasts of Iran.

At the analyzed stations scales, the results of slope trend (Q) at significance level of 0.05 showed that the average values of slope trend in total amount of 7 maximum temperature series are varied for the positive slopes, while none of the total amount of 7 stations, maximum temperature series have negative slopes in the whole study area. So, the annual significant positive slope trends were compared statistically in order to see which number of stations has greater or lower values. Thus, the results of Q value during the base period indicated the highest positive slope trend for all stations that are situated in northern parts of Iran, especially at Tabriz Station, and, vice versa, the lowest slope trend has been found at B-Abbas station in the most southern part of study area. Also, in future periods, the analyzing results of slope trend in maximum temperature series showed that the highest positive slope trend will respectively happen at Isfahan and Tabriz stations based on A2 scenario and at Isfahan station based on B2 scenario, while, the lowest positive slope trend will happen at B-Abbas station in the southern coasts of Iran.

Table 7. The statistic results of Mann-Kendall (Z) and Sen's slope (Q) tests in the mean annual of maximum temperature series at significant level of 0.05 during the whole of studied time period (1981-2099)°C

Trend Statistics	Time period	Ahvaz	B-Abbas	Isfahan	Mashhad	Tehran	Tabriz	Zahedan
	Base	2.89	2.03	3.35	2.71	3.96	4.35	2.46
Test Z	SRE A2	9.07	7.63	7.94	8.05	8.38	8.42	8.29
	SRE B2	6.03	4.95	6.71	6.54	6.82	5.79	7.33
	Base	0.04	0.04	0.06	0.07	0.06	0.09	0.05
Q	SRE A2	0.05	0.02	0.07	0.05	0.05	0.07	0.05
	SRE B2	0.03	0.01	0.04	0.03	0.03	0.03	0.03
	Base	30.7	29.6	20.68	18.99	20.1	15.2	24.3
B	SRE A2	30.2	29.8	19.45	19.65	21	16.5	24.5
	SRE B2	30.9	30	20.17	19.85	21.4	17.4	24.8
	Base	0.07	0.06	0.09	0.11	0.09	0.13	0.08
Qmax 95	SRE A2	0.06	0.03	0.07	0.05	0.06	0.07	0.05
	SRE B2	0.03	0.02	0.04	0.04	0.04	0.04	0.04
	Base	0.01	0.01	0.03	0.02	0.03	0.06	0.01
Qmin 95	SRE A2	0.05	0.02	0.06	0.04	0.05	0.06	0.04
	SRE B2	0.02	0.01	0.03	0.03	0.03	0.03	0.03

Overall, there is a general tendency of warming trends at all of the study stations during the observation and future periods that can be affected from the local and regional air pollution and different urbanization characteristics and physical factors such as local physical geography, topography, exposure, etc. Also, atmospheric circulation features may influence the nature and magnitude of the annual maximum temperature trends in different ways over the study area. For better understanding, the graphs of annual trends in the maximum temperature at each station are respectively presented for the whole observation and future periods based on A2 and B2 future scenarios in Figures 2 and 3. In this case, the linear trends of annual maximum temperature will be increased respectively at Tabriz, Ahvaz, and Zahedan stations.

A stronger positive linear trend will be mostly observed at Tabriz station based on all scenarios of simulations during the future periods compared to observation period where it is rapidly urbanizing and situated in the highest northern mountains of the study area. Also, in the field of warming trends, the mega-cities of the study area, such as Tehran, Isfahan, Mashhad, and Tabriz, are different in many ways from other cities which are situated in the more southern latitudes. Therefore, in these cities, the population density is high and existence of high-rise buildings in these cities is able to absorb more solar radiation. These cities also consume huge resources, particularly fossil fuels due, to large vehicular population. All these activities would affect the climate of these cities. On the other hand, the lowest positive linear trend will happen specifically in B-Abbas station during the future period where it is situated in southern coast lowlands of Iran. It can be due to different climatic condition such as more humidity and lower latitude and rate of slower urbanizing compared to other study stations.

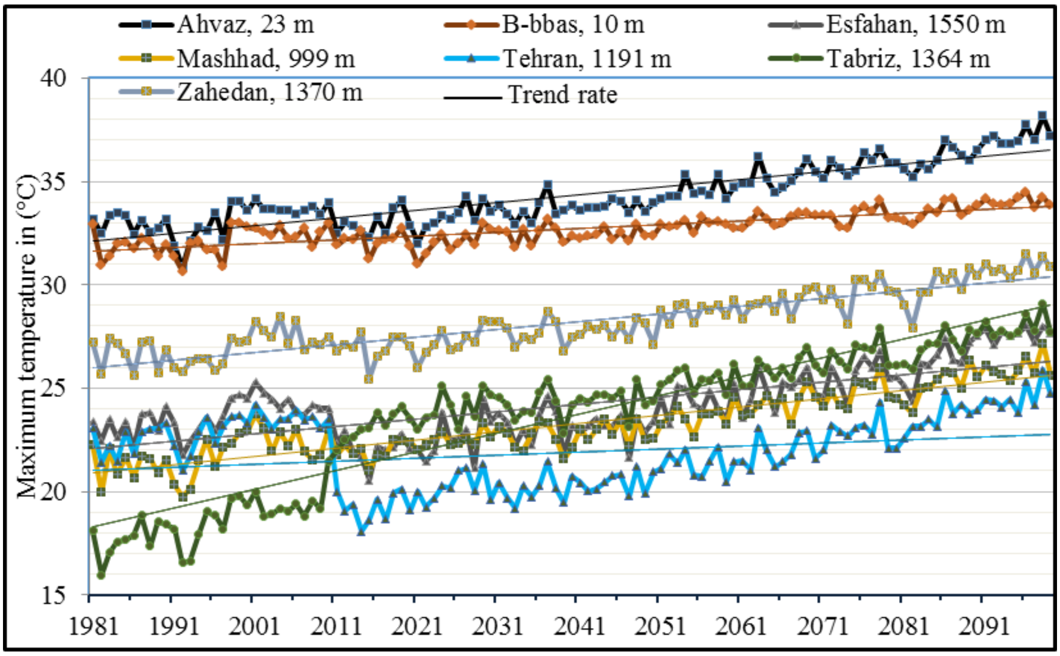

Fig. 2. The trend values in the mean annual of maximum temperature based on A2 SRE of HADCM3 Model during the whole of current and future periods (1981-2099)

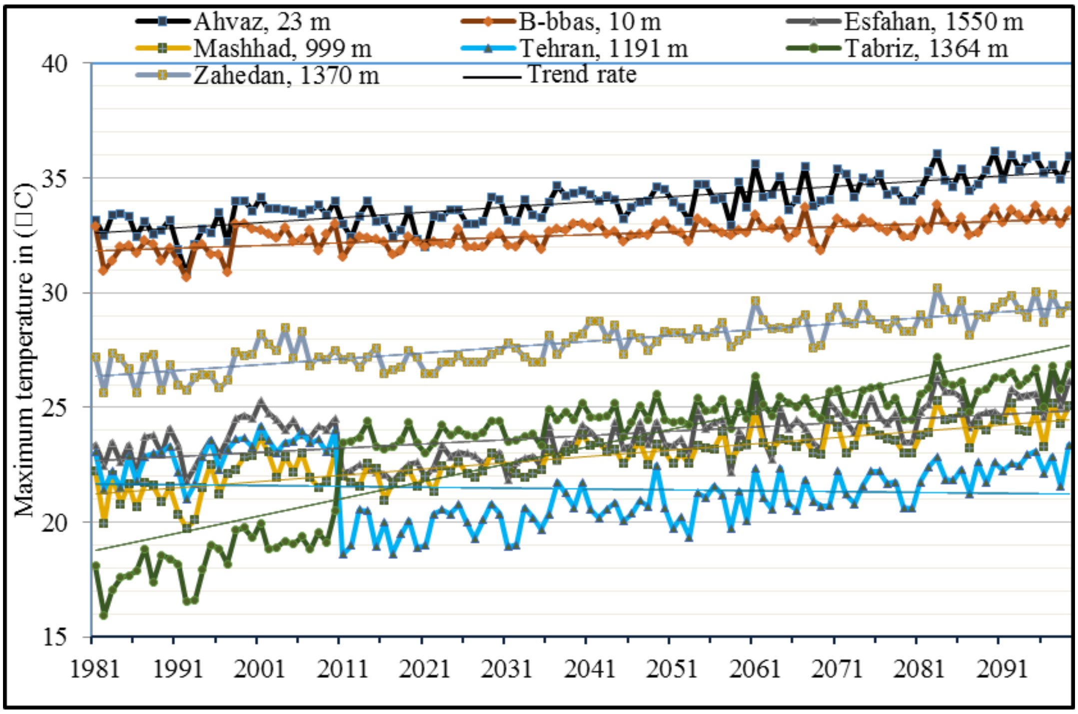

Fig. 3. The trend values in the mean annual of maximum temperature based on B2 SRE of HADCM3 Model during the whole of current and future periods (1981-2099)

4. Conclusion

Global warming and rising temperatures are one of the most important challenges for human society which affect the ecological, social, and economic systems. This study aimed to compare trend rate and trend slope in the maximum temperature series in 7 selected stations over vast territory of Iran between the current (1981-2010) and future (2011-2099) periods. The obtained results of observational trends are generally in agreement with the obtained results worldwide which have shown a trend of increasing temperature during the past decades. Meanwhile, the calculated rate of future trends in maximum temperature is generally severer than observation period, especially in arid and semi-arid regions of Iran.

Overall, the result of trend analysis showed that most of annual trends in maximum temperature series are positive at the 95% confidence level over both observation and future decades. The highest rate of trend slope in maximum temperature over observation period (1981-2010) is found by 0.25 and 0.22°C per decade at Tehran and Tabriz stations as well as its lowest is found by 0.06 and 0.05°C per decade at B-Abbas and Ahvaz stations, respectively, while the highest and lowest of mean trend slope in maximum temperature over future period (2011-2099) is found by 0.40 and 0.20°C per decade at Tabriz and B-Abbas stations based on all scenarios outputs.

At this point, the results of trend analysis showed that the highest positive trend and slope trend during the whole observation and future decades are happening at all stations that are situated in northern latitudes of Iran, especially at Tabriz station, while the lowest is happening at B-Abbas station that is situated in the southern coasts of Iran. Moreover, analyzing the maximum temperature changes in the whole of 21st century (2011-99) has shown that the average maximum temperatures of Iran will be expected to increase about for 1.5 °C based on all emission scenarios outputs of HADCM3 model. Meanwhile, increasing changes of maximum temperature will be expected to be more intensified based on A2 scenario of HADCM3 at all studied stations in Iran.

In general, what can be obtained from the survey results in the observation and future periods is that the maximum temperatures in the mountainous stations which are located in more northern latitudes with drier climate will be expected to be raising more in lowland stations which are located in the southern coasts with wetter climate. But the southern stations will be expected to encounter the risk of rising maximum temperatures more with regard to more capacity of humidity in their atmosphere that will probably combine with warmer climate. It is expected that the findings of this study will bring about more insights to understand the regional temperature change behaviors in coming decades.

Acknowledgement
The authors are grateful to the Islamic Republic of Iran Meteorological Organization (IRIMO) for their technical support.

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