



Impact Assessment of Climate Change in Iran using LARS-WG Model

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ABSTRACT

Iran is situated in a very diverse environmental area. The climate of the region is varied and influenced by different patterns. In order to best describe the expected climate change impacts for the region, climate change scenarios and climate variables must be developed on a regional, or even site-specific, scale. The weather generator is one of the valid downscaling methods. In the current study, LARS-WG (a weather generator) and the outputs from ECHO-G for present climate, as well as future time slice of 2010-2039 based on A1 scenario, were used to evaluate LARS-WG as a tool at 13 synoptic stations located in the north and northeast parts of Iran. The results obtained in this study illustrate that LARS-WG has a reasonable capability of simulating the minimum and maximum temperatures and precipitation. In addition, the results showed that the mean precipitation decreased in Semnan, the south of Khorasan and Golestan. Meanwhile, the mean temperature during 2010-2039 would increase by 0.5°C, especially in the cold season.

Keywords: Climate change, weather generator, LARS-WG, GCM

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INTRODUCTION

Excessive use of fossil fuels, change of land use, increase in human activities and rise in the world population, especially after the industrial revolution, affect climate change. The summary of the Fourth Assessment Report (AR4) released in February of 2007 by the Intergovernmental Panel on Climate Change (IPCC) confirmed that the warming of the climate system is unequivocal, as is now

evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level (IPCC, 2007; Stathopoulou & Cartalis, 2009). Based on the IPCC report, the earth's average surface temperature has risen by 0.76°C since 1850. Most of the warming over the past 50 years is very likely to have been caused by emissions of carbon dioxide (CO₂) and other 'greenhouse gases' as a result of human activities (IPCC, 2007; Ragab & Prudhomme, 2002; Freiwan & Kadioglu, 2008).

In order for policymakers and resource managers to understand the magnitude and timing of the impacts of the climate change and their effects on the local and regional resources, they must be able to study the climate scenarios of key climate variables for future periods. There are three main classes of climate change scenarios which are used to develop climate scenarios: synthetic scenarios, analogue scenarios, and scenarios, based on the outputs from general circulation models that are also known as global climate models (GCMs) (Wilby & Dawson, 2002; Dibike & Coulibaly, 2005; Solomon *et al.*, 2007; Koenig, 2008). The complex computer models of GCMs describe the climatological conditions of the earth at a finite number of grid points (a grid point model) or by a finite number of mathematical functions (a spectral model). In this study, the output from two GCM experiments was combined with a stochastic weather generator, LARS-WG (Long Ashton Research Station Weather Generator), to produce a climate change scenario.

The objectives were to assess the performance of the model in simulating climate of specific site and suitability of model application.

MATERIALS AND METHODS

Description of LARS-WG Stochastic Weather Generator

LARS-WG (Long Ashton Research Station Weather Generator) is a stochastic weather generator which can be used for the simulation of weather data at a single site (Racsko *et al.*, 1991; Semenov *et al.*, 1998; Semenov & Brooks, 1999; Semenov & Barrow, 2002) under both current and future climate conditions. LARS-WG produces synthetic daily time series of maximum and minimum temperatures, precipitation and solar radiation (Semenov & Stratonovitch, 2010). The weather generator distinguishes dry and wet days, depending on whether the precipitation is greater than zero. Precipitation is modelled using semi-empirical probability distributions for the lengths of wet and dry series and for the amount of precipitation on a wet day. A semi-empirical distribution is a histogram with a fixed number of intervals (10 in the case of LARS-WG).

$$Emp = \{a_0, a_i ; h_i, i=1, \dots, 10\}$$

A semi-empirical distribution is sufficiently flexible and allows for the accurate simulation of various weather statistics (Semenov *et al.*, 1998). Minimum temperature, maximum temperature and radiation are related to the amount of cloud cover; therefore, LARS-WG uses separate distributions for wet and dry days for each of these variables. Meanwhile, the pattern of the daily temperature distributions is approximated by the normal distribution, with the values of mean and standard deviation changing daily and calculated by a Fourier series.

Time auto-correlations for the minimum and maximum temperatures are site specific, but constant throughout the year (Semenov *et al.*, 1998; Hansen, 1999; Parlange & Katz, 2000).

Two important reasons for using LARS-WG model include the provision of a means of simulating synthetic weather time-series with certain statistical properties which are long enough to be used in an assessment of risk in hydrological or agricultural applications and providing the means of extending the simulation of weather time-series to unobserved locations.

In fact, LARS-WG has been used in various studies, including the assessment of the impacts of climate change (Barrow & Semenov, 1995; Semenov & Barrow, 1996; Weiss *et al.*, 2003; Lawless & Semenov, 2005; Khan *et al.*, 2006; Scibek & Allen, 2006; Semenov, 2007; Semenov & Doblus, 2007; Dubrovsky, 1996). The process of generating synthetic weather data can be divided into three distinct steps; Model Calibration, Model Validation, and Generation of Synthetic Weather Data (Zhang & Garbrecht, 2003; Nakicenovic & Swart, 2000).

Study Area

The study area encompasses the north, northeast and a part of central Iran (defined as 38°N to 30°N and 48°E to 59°E), as shown in Fig.1. These areas were selected to enable the researchers to collect data from a variety of climatic zones. In the north of Iran (Near the Caspian Sea), there are two provinces called Gilan and Mazandaran which are covered by forest. The North of Iran has the best type of weather in Iran with a moderate and humid climate that is known as the moderate Caspian climate. The effective factors behind such a climate include the Alborz mountain range, direction of the mountains, the height of the area, and the Caspian Sea, vegetation surface, local winds, as well as the altitude and weather fronts. As a result of the above factors, three different climates exist in the region:

1. Plain moderate climate with an average annual rainfall amounts to 1200 or 1300 mm, decreasing to the east.
2. Mountainous climate which covers the high mountains and northern parts of the Alborz range. In the heights, the weather is cold mountainous and most of the precipitation is in the form of snow.
3. Semi-arid climate with the average annual rainfall stands at 500 mm and the average annual temperature is 18.2°C.

Semnan is in the north of the country and the southeast of Mazandaran. The Semnan province covers an area of 96.816 Km², stretches along the Alborz mountain range and borders the Dasht-e Kavir desert in its southern parts. The average annual rainfall in this area is 140 mm and the average annual temperature is 11.4°C.

Golestan is located in the north-east of the country, and the south of the Caspian Sea. Most of the year, Golestan enjoys mild weather and a temperate climate. The centre of this area has a semi-arid climate because of its especial topography. The average annual rainfall stands at 500 mm and the average annual temperature is 18.2°C. Khorasan is a region in the north-east of Iran. With a surface area of 313.335 Km², it is the largest province of the country. Khorasan is bounded on the north by Turkmenistan and on the east by Afghanistan.

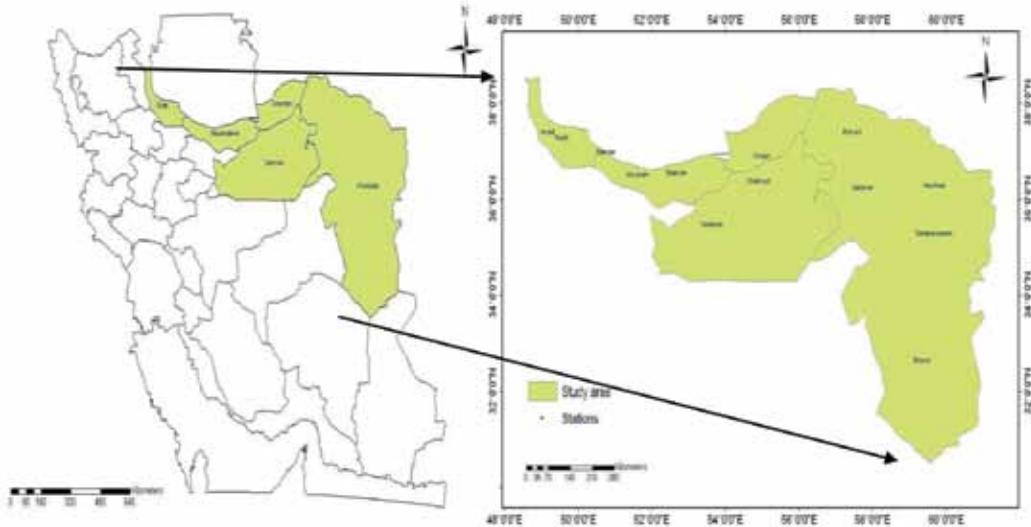


Fig.1: Study area

The climate of this part of Iran varies from semi-dry and locally humid in the north to dry in the south. The annual rainfall in the north of Khorasan Province is about 250 mm and this is 110 mm in the south. The annual mean temperature in the north of the province is about 13°C and this is 18°C in the southern part. In the recent years, some natural disasters have happened in the Khorasan province. During the last decade, there was a severe drought in this location, especially in the central and southern parts. Drought is the most common type of disaster that occurs in this part of country. Following this drought, two heavy floods occurred in the north of Khorasan in 2001 and 2002.

The observed data, GCM output in the same period with observed data, GCM output for the future period and a WG scenario are necessary to generating synthetic data and evaluating the model. A WG scenario can be produced using the GCM outputs in the observed and synthetic period. A scenario, which is needed in WG, consists of relative changes of mean temperature, standard deviation of temperature. Meanwhile, changes in precipitation and mean temperature are at the monthly time scale. The processes that are needed for generating synthetic data using LARS-WG model consist of three main steps, namely, model calibration, performance of the model and generating synthetic data.

In this study, the performance of the LARS-WG stochastic weather generator model was statistically evaluated by comparing the synthesized data with climatology period at 13 selected synoptic stations, based on ECHO-G and A1 scenario. Name, latitude and longitude coordinates, as well as the elevation of the synoptic stations are shown in Table 1.

The period of base data covered a period expanding from 1976 to 2005. Historical daily data contained precipitation, minimum and maximum temperatures. Such site parameters, which are also known as baseline, are commonly employed by LARS-WG in order to create a synthetic and local scale of weather time series on a daily basis. These time periods have arbitrary lengths and are statistically equal to the data collected for 1976-2005. Achieved

Table 1: Location and synoptic stations utilized in the study

Stations	Latitude (°N)	Longitude (°E)	Elevation (m)	Annual total rain (mm)	Annual mean temperature (°C)
Anzali	37.28	49.28	-26.2	1773	6.0
Babolsar	36.43	52.39	-21	943.1	7.5
Birjand	32.52	59.12	1491	169.8	16.2
Bojnurd	37.46	57.31	1091	269.3	12.9
Gorgan	36.51	54.16	13.3	546.1	10.1
Mashhad	36.28	59.6	999.2	254.7	13.0
Noushahr	36.39	51.3	-20.9	1293.5	6.8
Ramsar	36.54	50.4	-20	1216.3	6.5
Rasht	37.15	49.36	-6.9	1363.3	8.5
Sabzevar	36.2	57.66	977.6	188.6	17.4
Semnan	35.35	53.33	1130.8	142.8	11.4
Shahrud	36.25	54.57	1345.3	162.6	12.6
TorbatHeydarieh	35.27	59.22	1450.8	277.5	13.7

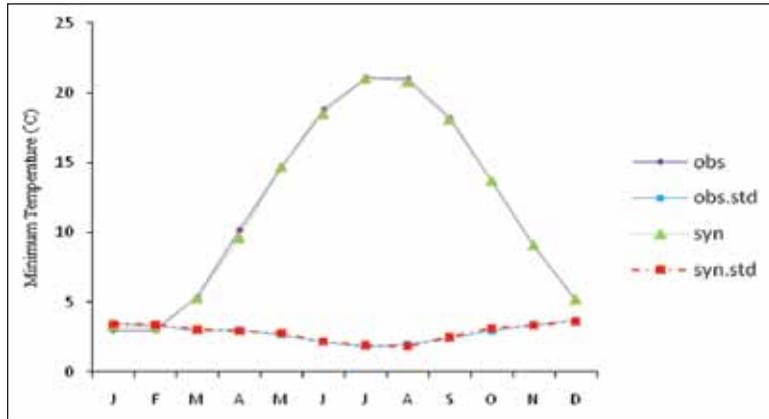
from a climate model, the predicted variations in the mean and variability of climate were applied to cause perturbation in the site parameters for the baseline climate. This section aims at examining the performance of LARS-WG for the ECHO-G dataset through a comparison of the observed and simulated weather time series on a daily basis. To this end, students' *t*-test was used to compare the means of climatic changes.

RESULTS AND DISCUSSION

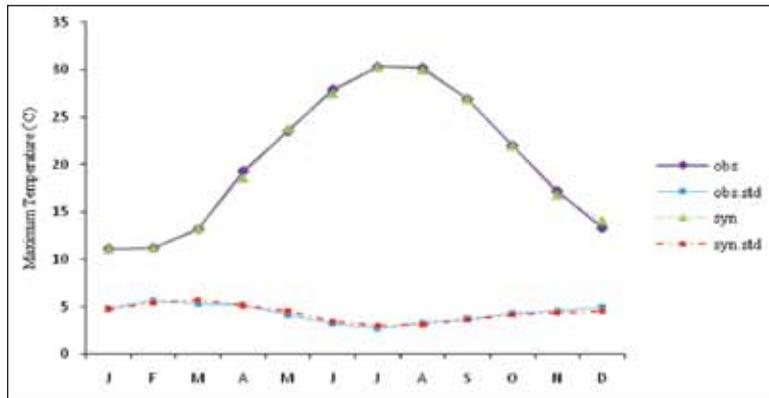
Model validation is one of the most important steps of the entire process. The objective was to assess the performance of the model in simulating climate at the chosen site to determinate whether or not it is suitable for use.

Firstly, LARS-WG model was performed based on the historical climate data obtained from 1976-2005 for verification of the model. For this purpose, a large number of years of simulated daily weather data were generated and the probability distribution for synthetic and the observed data were carried out using the Chi-square goodness-of-fit test and the means and standard deviations using the *t* test, respectively. In addition, population properties, correlation, RMS and relative errors were computed as well. The skill of the model for generating synthetic data is graphically shown in Fig.2, Fig.3, and Fig.4, which typically represents the comparison between synthetic and observed data. For this aim, the climate stations in the north of Iran, northeast and central of study area were combined. The model shows a better performance for the maximum and minimum temperatures than rainfall. The mean monthly correlation of the precipitation, minimum and maximum temperature is 0.95, which is acceptable in 0.05 level of confidence. The results show that the skill of the model in synthesizing the standard deviation of precipitation is different from that of the observed, except for dry months with lower rain.

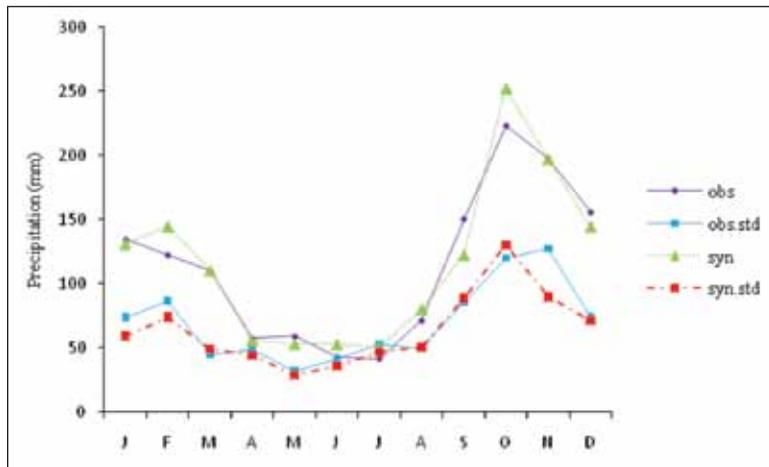
At this stage, the precipitation levels, as well as the minimum and maximum temperatures in the period of 2010-2039, were produced for the 13 selected ground-based synoptic stations based on the ECHO-G data. The results showed that except for June, the monthly precipitations



(a)

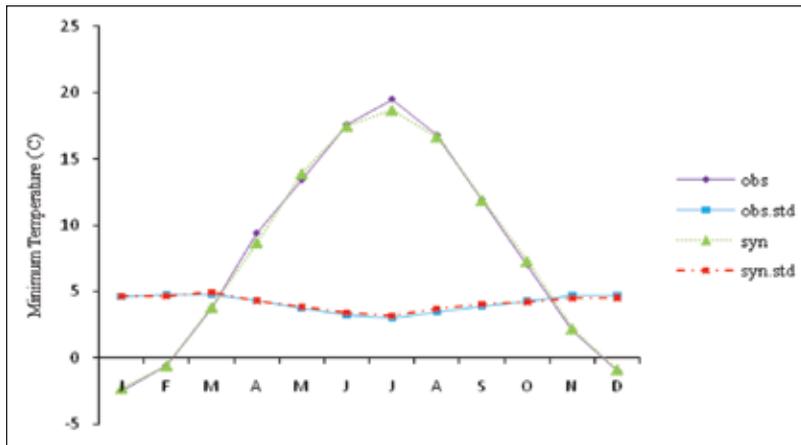


(b)

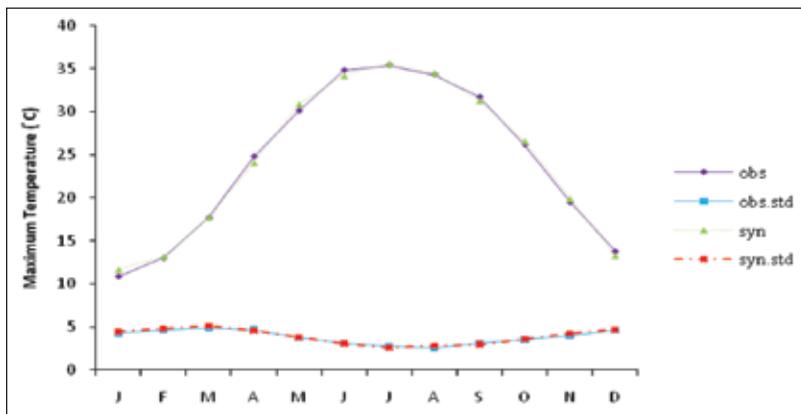


(c)

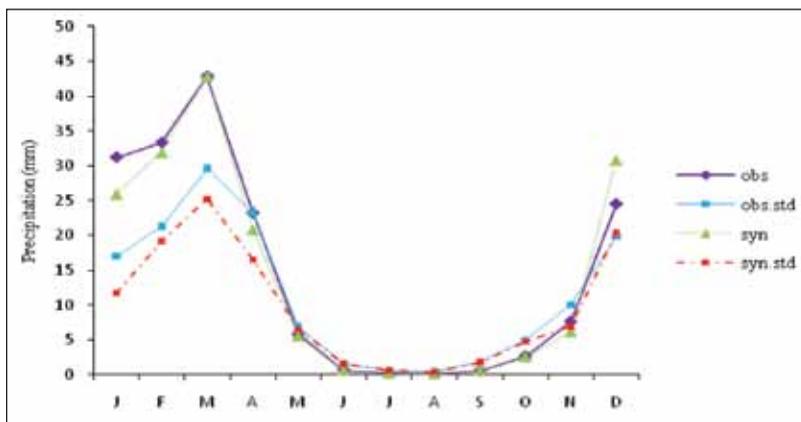
Fig 2: Comparison of the observed and synthetic data during 1976-2005 in the north of Iran; (a) Minimum temperature; (b) Maximum temperature, and (c) Precipitation



(a)

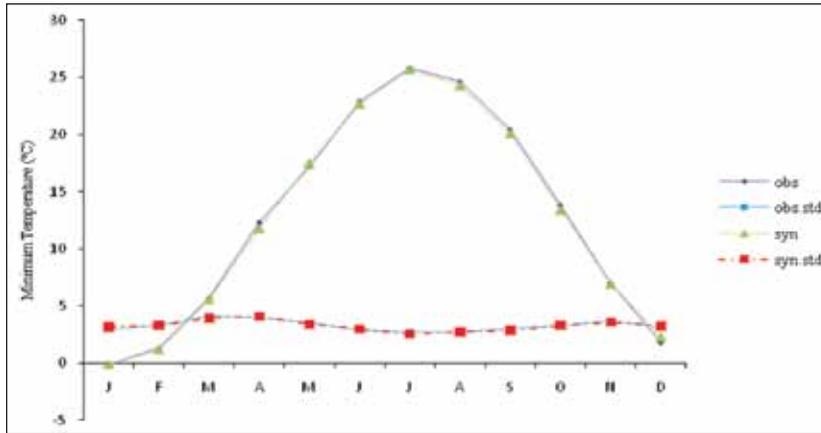


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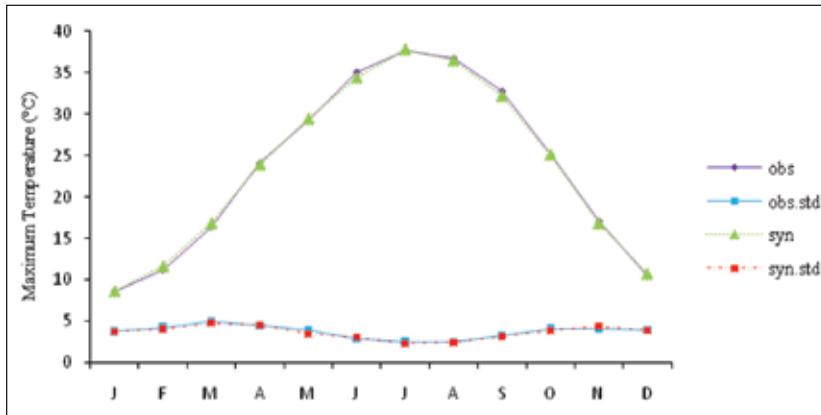


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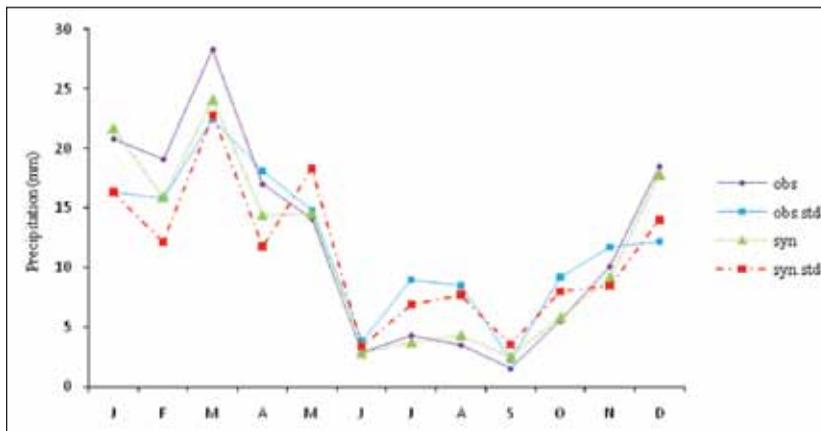
Fig.3: Comparison of the observed and synthetic data during 1976-2005 in the northeast of Iran; (a) Minimum temperature; (b) Maximum temperature, and (c) Precipitation.



(a)



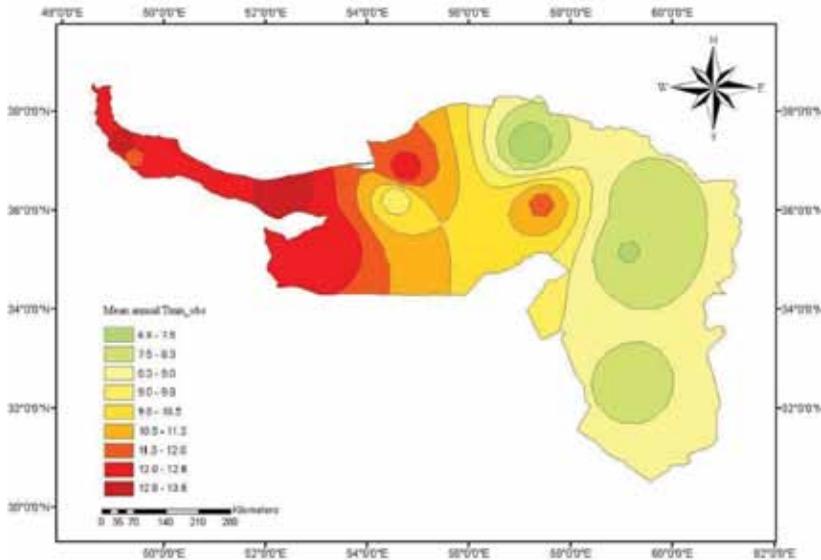
(b)



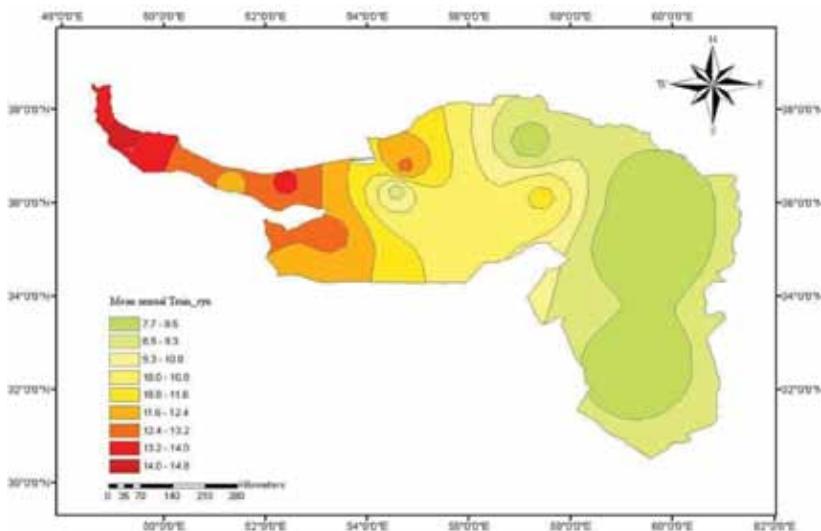
(c)

Fig.4: Comparison of the observed and synthetic data during 1976-2005 in the central Iran; (a) Minimum temperature; (b) Maximum temperature and (c) Precipitation.

would decrease in other months. The decrease in the rainfall during warm season is lower than during cold season. Statistical analysis indicates a decrease of rainfall in Yazd, Golestan and the south of Khorasan, but an increase of rainfall in Gilan and the north of Khorasan. The analysis showed that except for August and June, the mean monthly temperature would increase by 0.5°C in the cold season. The mean monthly increase in temperature was detected to be 1.7°C and 1.4°C in Rasht and Bojnurd, respectively. A stochastic weather generator was used in this study as a computationally cost-effective tool to construct site-specific climate change scenarios which incorporated changes in the climate means and



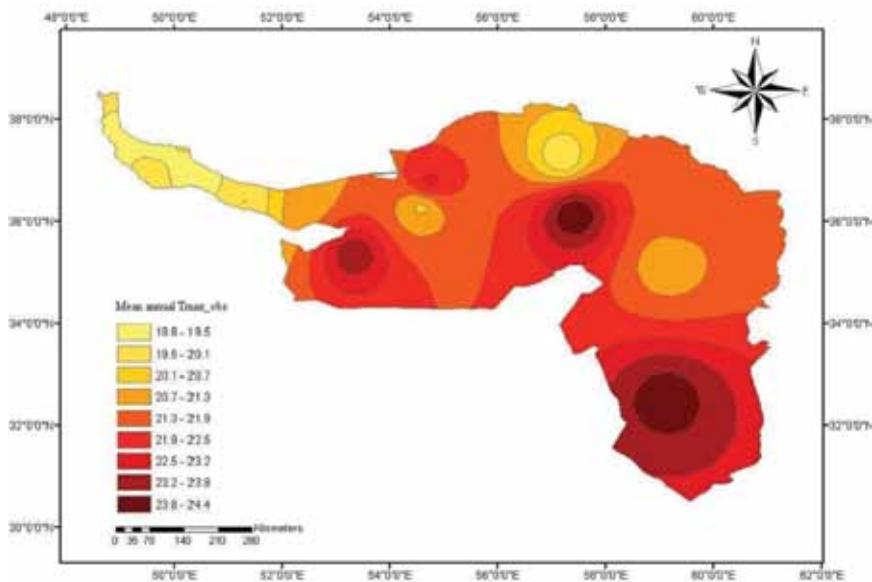
(a)



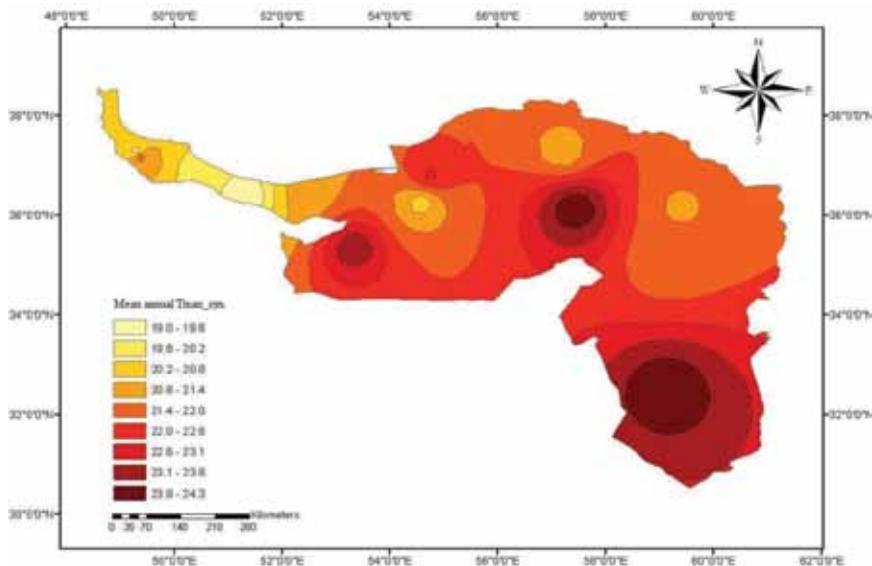
(b)

Fig.5: The mean annual minimum temperature; (a) 1976-2005 and (b) 2010-2039

climate variability. As the first step, the capability of the LARS-WG model was investigated. To obtain this aim, the base data were expanded from 1976 to 2005. The climate parameters contained precipitation, as well as the minimum and maximum temperatures. After validation of the LARS-WG model, this model was based on ECHO-G data for 2010-2039 for the selected stations. The results revealed that the mean precipitation would decrease in Yazd, and the south of Khorasan and Golestan. On the contrary, the mean temperature during 2010-2039 would increase by 0.5°C, especially in the cold season. Fig.5, Fig.6 and Fig.7 indicate the



(a)



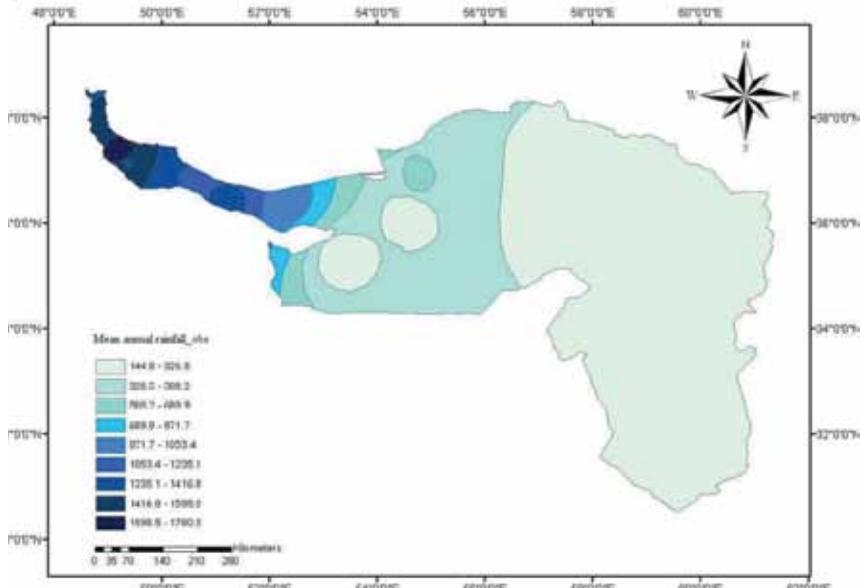
(b)

Fig.6: The mean annual maximum temperature; (a) 1976-2005 and (b) 2010-2039

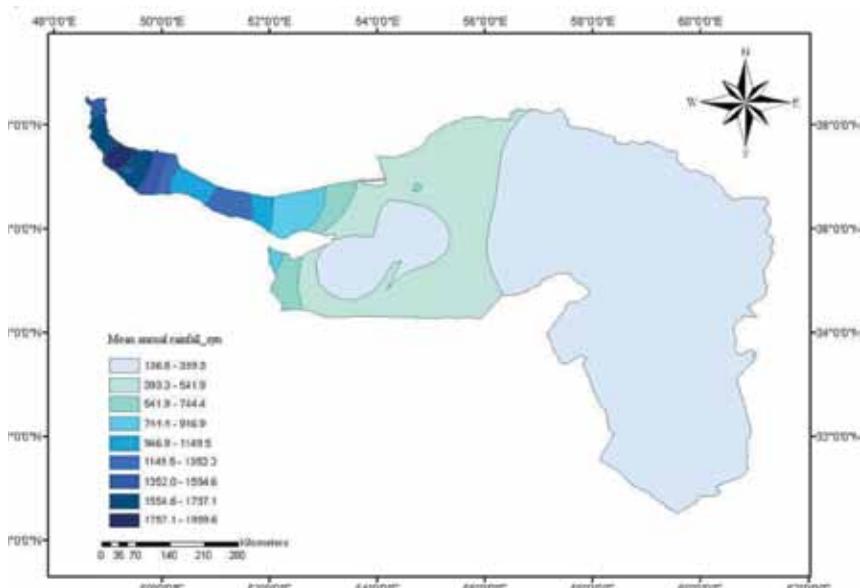
annual mean minimum and maximum temperatures, as well as the precipitation of the past and future, respectively.

CONCLUSION

The performance of the weather generator model LARS-WG was examined at 13 synoptic stations in the study area. The results of the current study indicated that the model has



(a)



(b)

Fig.7: The mean annual precipitation; (a) 1976-2005 and (b) 2010-2039

different performances in diverse climates and also at different stations in a similar climate. Nonetheless, the model has a better performance in the monthly minimum temperature and also the monthly maximum temperature in comparison with the mean monthly precipitation. This study has demonstrated that the mean monthly precipitation will decrease in the south of the study area (semi-arid regions) and Golestan, whereas it will increase in the northwest of Iran. Meanwhile, the mean temperature will increase by 0.5°C during 2010-2039 in all the climate regions. Hence, it can be strongly recommended that the model be evaluated for each station in which the model is utilized.

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