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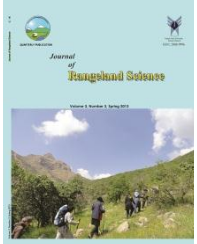

Full Length Article:

Statistical Downscaling HadCM3 Model for Detection and Perdiction of Seasonal Climatic Variations (Case Study: Khabr Rangeland, Kerman, Iran)

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Abstract. Rangelands are one of the most vulnerable parts concerning the climate changes' impacts. These impacts are even stronger in the arid and semi-arid areas where rangeland ecosystems are in critical conditions. Therefore, it is crucial to figure out the actual dynamics of climate variations on the rangelands. The aim of this research was to determine climate changes in Khabr rangeland, Kerman, Iran. So, four meteorological data sets of HadCM3 model including minimum and maximum temperature, precipitation and radiation rates were used to assess climate changes in the region. In this regard, climate changes during 2011-2039 were assessed by downscaling HadCM3 data using LARS-WG model under three scenarios of B1, A2 and A1B. The results have showed that the rainfall rates of spring and summer would have declining trends under all three scenarios. Minimum and maximum temperature rates would increase in all seasons, and just radiation one showed a decreasing trend for winter. Based on A1B scenario, minimum and maximum temperature rates had the highest increasing trend. Radiation and precipitation had the highest increasing and declining trends in the A2 scenario, respectively. Moreover, the increase in maximum and minimum temperature rates was averagely greater than the past and consequently despite the increasing trend in minimum and maximum temperature rates, the increase in the mean temperature rate during this period would be expected. According to the results, Khabr rangeland's climatic conditions will be significantly different in the next 30 years and long-term and strategic planning is necessary in consistent with the management policies with these conditions.

Key words: Climatic-Parameters, HadCM3, LARS-WG, Khabr rangelands

1. Introduction

Climatic changes are ascribed to human activities that change the structure of the global atmosphere and to natural climate variability observed over comparable time periods (IPCC, 2007). Human activities, particularly the burning of fossil fuels and changes in land uses are today believed to increase the atmospheric accumulation of greenhouse gases. This change of energy balance has led to make the atmosphere warm and consequently, climatic changes. Some researches show that climatic parameters such as mean annual global surface temperature have increased by about 0.3 - 0.6^{o}C since the late 19th century, and it is anticipated to increase by 1-3.5 $^{\circ}$C over the next 100 years (Solomon *et al.*, 2007). The most important impacts of climatic changes on rangelands will probably change both pasture productivity and forage quality. However, there are other impacts on rangelands that managers will confront including botanical changes in vegetation composition, pests, diseases, soil erosion, animal husbandry and health (Hall *et al.*, 1998). Currently, global climate models are the only reliable tools available for simulating the response of the universal climate system to the increase of greenhouse-gas concentrations (IPCC-TGCIA, 2007). Therefore, the fourth assessment report of AR4 was constructed according to a huge dataset about forthcoming climate-change projects by 18 worldwide groups, and climate experiences were run in several Global Climate Models (GCMs), and different scenarios (Semenov, 2008; Semenov and Stratonovitch, 2010). Scientists emphasize the needs for appropriate model testing against the observed data and the evaluation of uncertainty in future projections. Furthermore, climate models functions at spatial scales are considerably larger than those in which managerial decisions are made on the desired ecosystems. Downscaling allows data obtained from global and regional models to be estimated for finer spatial scales. There is therefore a need to utilize the existing methods or develop new ones as appropriate ones from downscale climate model estimates to scales that are more relevant for site-specific decision-making. By the help of downscaling method, the GCM outputs can be correctly changed into surface variables in the scale of the basin under study. This method is based on the statistical model linking the climate simulated by the GCM, and the current climate characterized by instrumental data. This method has been widely applied to derive the daily and monthly precipitation rates at higher spatial resolutions for the impact assessments (Semenov and Barrow, 2002; Wilby *et al.*, 2002).

LARS-WG stochastic weather generator simulates high-resolution temporal (daily) and spatial (site) climatic changes’ scenarios for a number of climate variables (e.g. precipitation, maximum/minimum temperature, and solar radiation rates). Scenarios have combined the changes with climatic variables such as duration of dry and wet spells or temperature variability derived from the daily output from GCMs (Semenov and Barrow, 2002). Future climate scenarios are stochastically generated by adjusting the parameters with respect to the directions proportion to the changes projected by a GCM. Further details of the LARS-WG can be found in the user manual (Semenov and Barrow, 2002). The main advantage of weather generators is their ability to generate multiple climate scenarios of daily climatic variables at a local station while making them very useful for the risk assessment studies. Therefore, they will be used within this study for the manufacturing of future climatic scenarios. The aim of this research was to determine climatic change in Khabr rangeland, Kerman, Iran. So, four meteorological datasets of HadCM3 model including minimum and maximum temperature, precipitation and radiation rates were used to assess climatic change in the region.

2. Materials and Methods

The field research is a part of Khabr National Park's rangelands located in Kerman Province in the south-east of Iran (29º 14' N, 56º 35' W, see Fig. 1). According to Emberger method, the region climate is arid frigid. The study site receives about 261 mm of annual precipitation that mostly occurs during November and May. The annual mean temperature is 17.6 ºC. According to gaussen ambrothermic diagram, the region aridity period is 7 months. Low precipitation and high vapour-transpiration in this area have led to a severe drought in the recent decades.

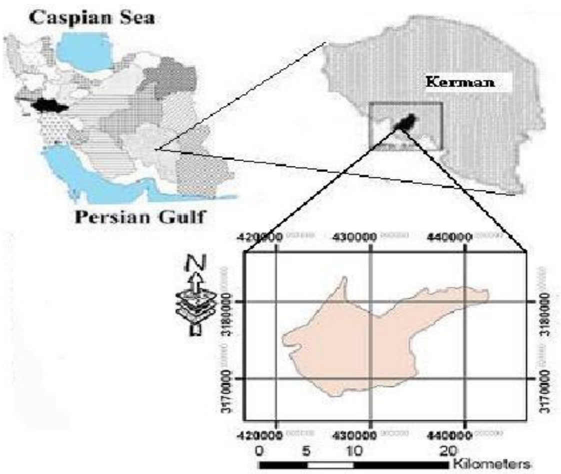

Fig. 1. Location of case study, Khabr- Baft

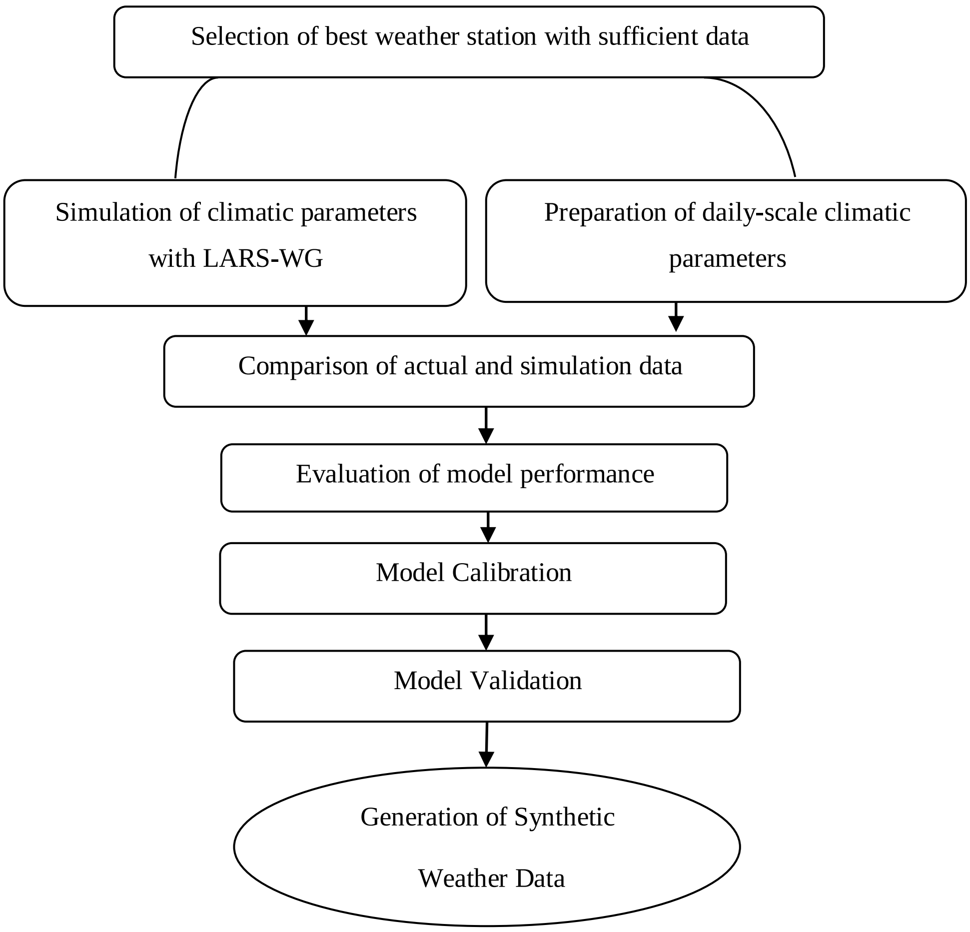

Fig. 2. Research method diagram

2.1. Case study

In this study, four main sources of data were used which are as follow:

1- Daily historical temperature and precipitation data of Baft meteorological station during 1898-2011 (minimum temperature (T-min), maximum temperature (T-max), precipitation (P) and sunshine hours).

2- Daily projected data of HadCM3 during 2011-2039 (T-min, T-max and P and sunshiny hours) that were resulted from GCM-runs for the Third Assessment Report (TAR) based on the IPCC-SRES scenario of A2.

3- Monthly projected data of HadCM3 during 2011-2039 (T-min, T-max, P and sunny hours) based on the scenario of B1.

4- Monthly projected data of HadCM3 during 2011-2039 (T-min, T-max, P and sunny hours) based on the scenario of A1B.

As it has been shown in the research method diagram (see Fig. 2), LARS-WG model was applied to simulate climatic parameters. This model is one of the weather generators which can be utilized for the simulation of weather data at a single site (Rasco *et al.*, 1991) under current and future climatic conditions. These data are in the shape of daily time-series for a set of climatic variables namely, precipitation (mm), maximum and minimum temperature and solar radiation rates (MJm-2day-1).

LARS-WG is based on the series weather generator described by Rasco *et al.* (1991). It used semi-empirical distributions for the lengths of wet and dry day series, daily precipitation and daily solar radiation. Suitable large-scale predictors are selected using correlation analyses and partial correlations between predictors (large-scale atmospheric variables) and predictants (local surface variables) in the area under study.

The simulation of a precipitation event is modelled as an alternate wet and dry series where a wet day is defined to be a day with the precipitation rate of > 0.0 mm. The length of each series is randomly selected from the wet or dry semi-empirical distributions for the month when the series starts. In determining the distributions, the observed series are also allocated to the month when they start. For a wet day, the precipitation value is generated from the semi-empirical precipitation distribution for the particular month independent from the length of the wet series or the amount of precipitation in previous days.

Daily minimum and maximum temperature rates are considered as stochastic processes with daily means and daily standard deviations in the wet or dry status of the day. The technique used to simulate the process is very similar to that one presented by Rasco *et al.* (1991).

LARS-WG performs the process of generating synthetic weather data with three distinct steps:

1. Model Calibration - SITE ANALYSIS – the observed weather data are analysed to determine their statistical characteristics. This information is stored in two parameter files.

2. Model Validation - QTEST - the statistical characteristics of the observed and synthetic weather data are analysed to determine whether there are any significant differences statistically.

3. Generation of Synthetic Weather Data - GENERATOR - the parameter files derived from the observed weather data during the model calibration process are used to generate synthetic weather data having the same statistical characteristics as the original observed data, but they are different on a day-to-day basis. Synthetic data corresponding to a particular climatic change scenario may also be generated by applying global climate model derived from the changes in precipitation, temperature and solar radiation rates for the LARS-WG parameter files.

At the beginning, the processing and sorting of climatic parameters were performed. Then, the model was run for the base period and model calibration was completed. The next step was evaluated using statistical methods such as NASH (Eq. 1), Root mean square error (Eq. 2), Mean absolute error (Eq. 3) and Bias model performance (Eq. 4).

$$(1)\quad NA = 1 - \frac{\sum_{i=1}^{n}(Yi - Xi)2}{\sum_{i=1}^{n}(Xi - \bar{X}i)2}$$

$$(2)\quad RSME = \sqrt{\frac{\sum_{i=1}^{n}(Xi - Yi)2}{n}}$$

$$(3)\quad MAE = \frac{\sum_{i=1}^{n}|Xi - Yi|2}{n}$$

$$(4)\quad Bias = \frac{1}{n}\sum_{i=1}^{n}(Xi - Yi)2$$

Where

X_i = observed data

Y_i= Simulated data

n= Total number of samples

After reviewing the results of the statistical methods, high performance of Lars-WG Model was demonstrated. With this model, daily value of meteorological parameters during 2011-2039 was simulated. The simulation was done under A2, A1B and B1 scenarios. Monthly normal climatic parameters were calculated for 2011-2039 based on three scenarios. Then, monthly and seasonal variations of these parameters were obtained under the scenarios of A2, A1B and B1.

3. Results

Comparison of results showed no significant difference between the modelled values and the actual values (P<0.05). (Table 1), shows Pearson correlation coefficient of all parameters. These values represent the accuracy of LARS-WG to simulate the climatic parameters. In (Table 2), NASH (NA), Root Means Square Error (RMSE), Mean Absolute Error (MAE) and Bias show high accuracy (when the value of NA is closer to one, Bias is closer to zero, RMSE and MAE have the minimum values whereas the observed and simulated values have more similarities). Based on these results during 1989-2010, the observed and simulated values have high similarities. Observation and modelling values of parameters such as the absolute minimum temperature, absolute maximum temperature, precipitation and sunshine hours with a standard deviation coefficient show that this model can simulate the trends within the data very well.

Table 1. Pearson correlation coefficients of the observed and simulated values in the model during 1989-2010

BAFT station	Rainfall	Min Tem	Max Tem	Sunshine Hours
Correlation	**0.98	**0.99	**0.99	**0.98
Weighted correlation	0.87	0.98	0.98	0.96

**=Significant at 1% probability level

Table 2. Evaluation indicators

BAFT Station	Rainfall	Min Tem	Max Tem	Sunshine Hours
MAE	4.14	0.15	-0.02	-0.1
RSME	5.26	0.29	0.22	0.2
Bias	2.41	0.007	-0.07	-0.08
NA	0.95	0.99	0.99	0.96

The observed and simulated climatic parameters during 1989-2010 by LARS-WG model are shown in (Figs. 3-6). It represents the ability of the model to generate daily data on climate parameters which may be consistent with the research conducted by Semenov (2007).

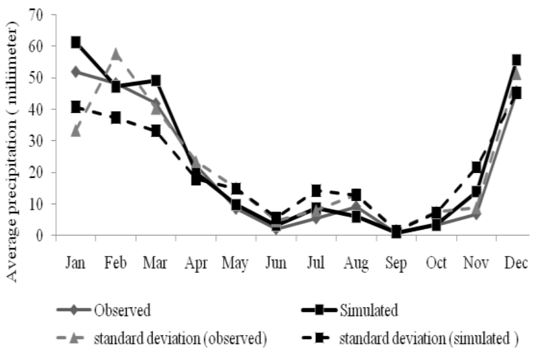

Fig. 3. Mean monthly precipitation (1989-2010)

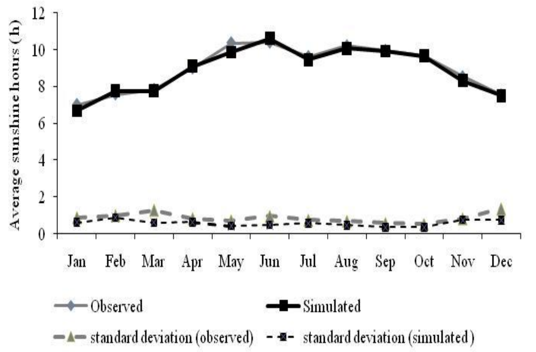

Fig. 4. Mean monthly sunshine hours (1989-2010)

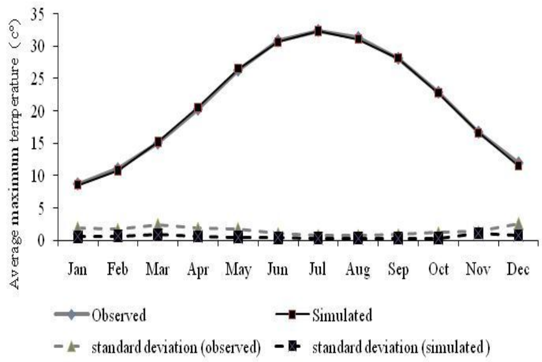

Fig. 5. Mean monthly maximum temperature rates (1989- 2010)

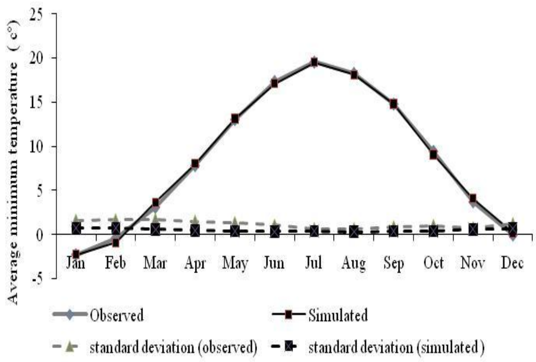

Fig. 6. Mean monthly minimum temperature rates (1989- 2010)

Mean monthly values of climatic parameters and their changes under the baseline period and future scenarios (HadCM3 model scenarios) are given in (Table 3).

Table 3. Mean monthly values of climatic parameters and their changes under the baseline period and future scenarios

Parameters	Scenarios	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Des
Normal Rainfall	Baseline	55	48.3	41.9	22.2	8.5	2	5.5	9.2	0.9	3.3	6.8	54.7
	A1B	66.8	45	38.2	18.5	9.3	1.5	5.6	11	0.9	3.4	6.8	39.7
	A2	66.6	45	38.2	18.7	9.6	1.4	5.1	10.1	0.9	3.38	6.5	39.2
	B1	65.7	45.2	39.6	19.6	10	1.5	5.5	11	0.9	3.5	6.7	39
Variations	A1B	14.8	-3.3	-3.7	-3.7	0.8	-0.6	0.1	1.9	0	0.1	0	-6
	A2	14.6	-2.8	-3.7	-3.6	1.1	-0.6	-0.3	0.9	0	0.08	-0.31	-6.6
	B1	13.7	-3.1	-2.4	-2.6	1.5	-0.6	0	1.8	0	0.2	-0.1	-6.7
Minimum temperatures	Baseline	-2.3	-0.4	3.0	7.8	13	17.3	19.5	18.2	14.8	9.5	3.7	-0/04
	A1B	-1.0	0.2	4.5	8.5	13.8	17.6	19.9	18.8	15.5	10	5	1.3
	A2	-1.2	-0.2	4.0	8.1	13.6	17.7	19.9	18.7	15.6	9.9	4.6	0.9
	B1	-1.2	0.2	4.8	8.6	13.8	17.6	19.8	18.5	15.3	10	5	1.2
Variations	A1B	1.3	0.6	1.4	0.7	0.8	0.3	0.4	0.5	0.7	0.6	1.3	1.3
	A2	1.1	0.2	1.0	0.3	0.6	0.4	0.4	0.5	0.8	0.4	0.9	0.95
	B1	1.1	0.6	1.7	0.8	0.8	0.3	0.3	0.3	0.6	0.6	1.3	1.2
Maximum temperatures	Baseline	8.7	11.1	15	20.3	26.3	30.8	32.4	31.3	28.1	22.9	16.7	12
	A1B	9.7	11.5	16.1	20.9	27.2	31.1	32.8	31.8	28.9	23.6	17.8	13
	A2	9.5	11.1	15.6	20.5	27	31.1	32.8	31.8	28.9	23.5	17.5	12.7
	B1	9.6	11.6	16.3	21	27.1	31	32.7	31.6	28.7	23.7	17.9	12.9
Variations	A1B	1.0	0.5	1.0	0.6	0.9	0.3	0.4	0.5	0.7	0.8	1.1	1
	A2	0.8	0	0.6	0.2	0.7	0.3	0.4	0.5	0.8	0.6	0.8	0.7
	B1	0.8	0.5	1.3	0.7	0.9	0.3	0.3	0.3	0.6	0.8	1.1	0.9

The results from the analysis of climatic parameters showed that in the study area, the most significant changes of precipitation during 2011-2039 computed as 6.7% reduction will occur under the A2 scenario. After that, A1B and B1 scenarios with the decrease rates of precipitation as 5.8% and 5.1% have the highest percentage of variations, respectively (Fig. 7). Mean changes in sunshine hours on an average of 0.04 hours will decrease under the B1 scenario and this parameter will increase under the A1B and A2 scenarios (Fig. 8).

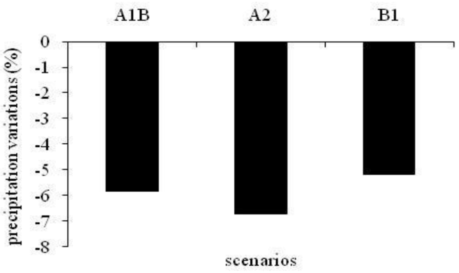

Fig. 7. Precipitation variations during 2011-2039

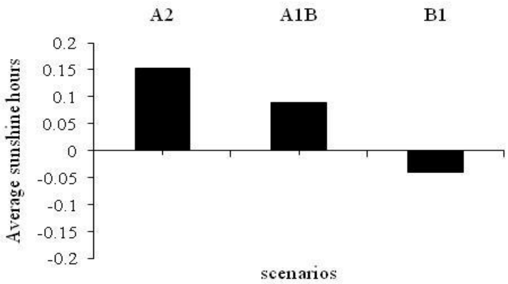

Fig. 8. Sunshine variations during 2011-2039

The mean minimum and maximum temperature variations during 2011-2039 are increased under all three scenarios. The highest variation rate in these parameters will occur under the A1B scenario with an average of 0.82 and 0.73 °C (Figs. 9 and 10).

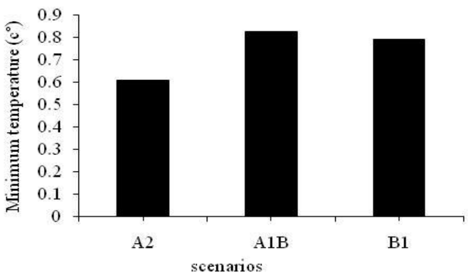

Fig. 9. Minimum temperature variation during 2011-2039

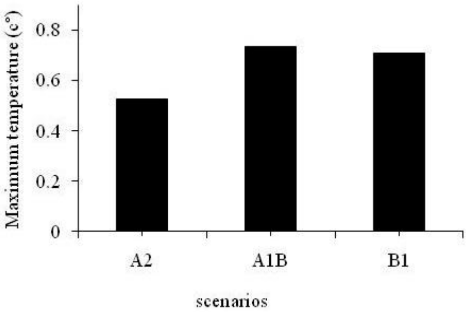

Fig. 10. Maximum temperature variation during 2011-2039

Analysis of seasonal parameters under climate scenarios for 2011-2039 showed that spring and summer rainfall variations under all three scenarios will decrease and the increase of them will occur only in winter (Fig. 11).

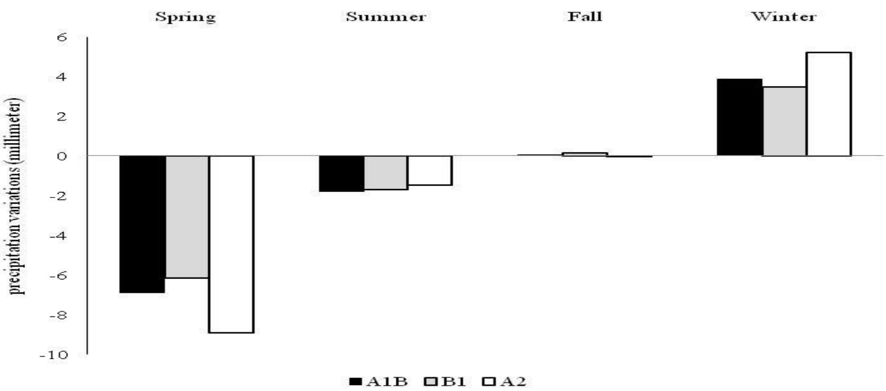

Fig. 11. Seasonal precipitation variation

Generally, the minimum and maximum temperature rates will increase in all seasons regarding three scenarios. The A1B and A2 scenarios have the highest and lowest variations concerning the three scenarios, respectively (Figs. 12 and 13).

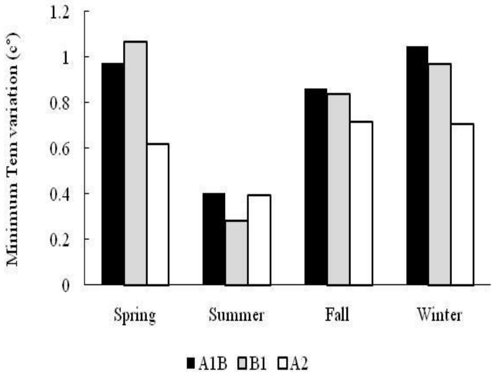

Fig. 12. Seasonal maximum temperature variation

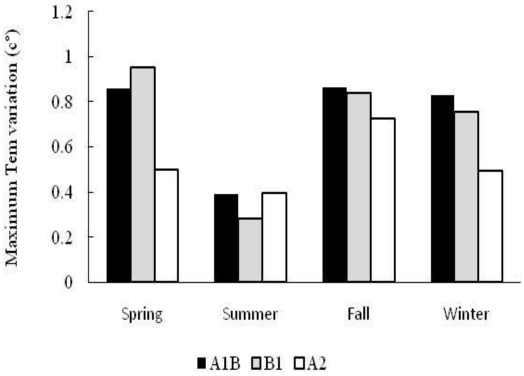

Fig. 13. Seasonal minimum temperature variation

Data analysis showed that sunshine hours will have a decreasing trend in winter under all three scenarios and an increasing trend in the sunshine hours in the other seasons is shown in Fig. 14.

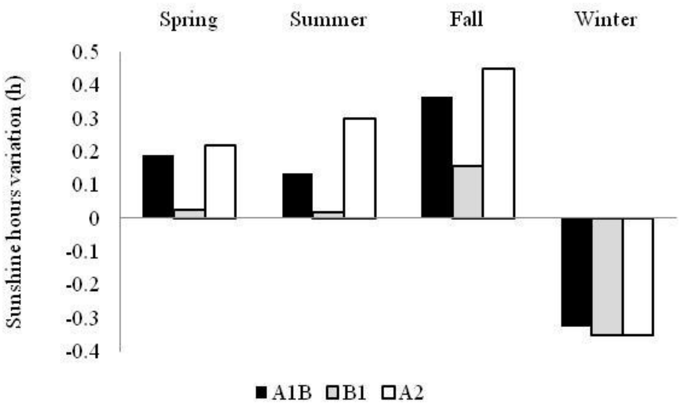

Fig. 14. Seasonal Sunshine hours' variations

4. Discussion

In this paper, for evaluating and understanding the climatic changes in the Khabr rangeland in Kerman province during 2011-2039, long-term predictions of an atmospheric general circulation model (HadCM3) were downscaled by LARS-WG model. The results showed that this model has a high efficiency in the simulation of daily climatic parameters which confirms the results of research conducted by Elashmay *et al.* (2005) and Semenov and Barrow (2002).

Downscaled data by HadCM3 model based on three scenarios of A1B, A2 and B1 for 2011-2039 have indicated that maximum and minimum temperature rates will increase with the average values of 0.61-0.82 and 0.53-0.73 (°C), respectively. Thus, the average temperature rate will be increased. Furthermore, an increasing trend will be observed in the number of sunshine hours. On the other hand, precipitation rate will be decreased to 12-14 (mm) under all three scenarios.

These results are in agreement with the results of Kousari *et al.* (2010) and Ragab and Prudhomme (2002).

Based on the results, the climate in the Khabr region for the next 30 years will markedly be different from the current situation as the largest decrease of precipitation rate (4-6%) will occur in spring and autumn as compared to the baseline precipitation in each scenario.

Minimum and maximum temperature rates also showed an increasing trend in spring and autumn in all three scenarios. This is consistent with the findings reported by Abasi *et al.* (2010). They stated that temperature rates would increase to 0.3°C, and most of it will be in winter. The observed trends in precipitation and temperature may cause snowfall to be reduced. In contrast, heavy rains will be increased. The consequence of that will be a reduction in the storage and supply of water through the gradual melting of snow in the mountainous areas. This heavy rainfall leads to increase the damage to natural ecosystem and people; on the other hand, fertile soils will be lost.

Undoubtedly, climatic changes are affecting dry lands and pastoral livelihoods. As a result, these areas will tend to become drier, and the existing water shortages will be worsened. In addition, climatic changes are likely to bring about even more erratic and unpredictable rainfalls and most extreme weather conditions such as longer and more frequent droughts. Where this happens, the delicate balance on which pastoral systems depend is undermined.

Saadatfar *et al.* (2010) reported that changes in climatic parameters may cause to influence the growth behaviour of plants and rangeland exploitations. The changes in the number of freezing days may cause to alter the plant regeneration. Moreover, the earliest start of growing period leads to the changes of exploitation times as well as pastorals' calendar. Apart from temporal changes, there are some impacts on spatial aspects in the mountainous ecosystems due to the mentioned thermal increase, i.e. changes in the existence boundaries of plant species and communities, their expansion to higher altitudes and shrinkage of meadows. Munanga *et al.* (2010) suggested that it is essential to amalgamate across information types (i.e. weather, climate, socio-economy, policy and ecology) to admonish those involved in decision-making better for the ecosystem management. The preparation of climate information and an understanding of ecosystem responses to climate changes and variability need to support all the planning and decision-making processes for the future.

With assessing the rangeland climate concerning the climatic changes' scenarios, it is possible to realize the rates of changes in rainfall seasons and periods, severe droughts, floods, pest outbreaks, river flow decline, wetlands drying and expansion and intensification of dust storms in the future and based on them, risk in the rangelands should be effectively managed. This management approach can reduce the rangeland vulnerability and empower the rangeland beneficiaries in coping and adapting the critical situations.

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پیش‌بینی تغییرات فصلی پارامترهای اقلیمی مراتع با استفاده از ریز مقیاس‌نمایی داده‌های مدل HadCM3 (مطالعه موردی: مراتع خبر کرمان)

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چکیده

مراتع یکی از آسیب‌پذیرترین بخش‌ها، ناشی از اثرات تغییر اقلیم می‌باشند. این تأثیر، در مناطق خشک و نیمه‌خشک، در جایی که مراتع در شرایط بحرانی قرار دارند، بیشتر است. بنابراین شناخت پویایی واقعی، تغییر اقلیم بر مراتع، بسیار مهم است. هدف از این تحقیق، تعیین تغییر اقلیم در منطقه خبر کرمان می‌باشد. در این راستا، چهار مجموعه از داده‌های هواشناسی مدل HadCM3 شامل حداکثر دما، حداقل دما، بارش و ساعات آفتابی تحت سه سناریوی B1، A2 و A1B برای تعیین تغییر اقلیم در منطقه خبر مورد استفاده قرار گرفت. در این تحقیق به منظور ارزیابی تغییر اقلیم در دوره ۲۰۳۹-۲۰۱۱ از داده‌های مدل HadCM3 که با استفاده از مدل LARS-WG تحت سناریوهای B1، A2 و A1B ریز مقیاس گردیدند، استفاده شد. نتایج نشان داد که میزان بارش در دو فصل بهار و تابستان طبق هر سه سناریو دارای روند کاهشی است. دمای کمینه و بیشینه در همه فصول روند افزایشی خواهند داشت و تنها ساعات آفتابی در فصل زمستان روند کاهشی از خود نشان داد. بر اساس سناریو A1B دمای کمینه و بیشینه بیشترین روند افزایشی را داشتند. ساعات آفتابی و مقدار بارش نیز به ترتیب بیشترین روند افزایشی و کاهشی را در سناریو A2 دارا بودند. علاوه بر این، افزایش در حداکثر و حداقل درجه حرارت به طور متوسط بیشتر از گذشته بوده است و در نتیجه با وجود روند افزایشی دمای کمینه و بیشینه، افزایش دمای متوسط هوا در این دوره قابل انتظار خواهد بود. طبق این نتایج، شرایط اقلیمی مراتع خبر در ۳۰ سال آتی تفاوت محسوسی با شرایط فعلی خواهد داشت و برنامه‌ریزی‌های بلندمدت و استراتژیک برای مدیریت سازگار با این شرایط، ضروری به نظر می‌رسد.

کلمات کلیدی: پارامترهای اقلیمی، HadCM3، LARS-WG، مراتع خبر