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Evaluation of the Change-Factor and LARS-WG Methods of Downscaling for Simulation of Climatic Variables in the Future (Case study: Herat Azam Watershed, Yazd - Iran)

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ABSTRACT Prediction of climatic variables on a local scale by General Circulation Models of the atmosphere is impossible because the models have large-scale network of resolution. Therefore, downscaling methods are used to solve this problem. Since the climate change phenomenon can affect different systems such as, water resources, agriculture, environment, industry and economy as well, Selection of the most suitable downscaling method is very important. This study aims to evaluate performance of Change-Factor (CF) and LARS-WG downscaling methods in prediction of future climate variability of the Azam River Watershed, located in Yazd Province, Iran, for the period of 2010-2039. For this purpose, the CGCM3-AR4 model under the A2 emission scenario and also two methods of downscaling including statistical (LARS-WG) and proportional (CF) approaches were applied. The results showed increasing of temperature by both downscaling methods in the Azam River watershed in the future. Average temperature difference obtained from the two methods is about 3 to 4 percent. On the other hand, based on the climate condition, the amount of rainfall varied in the whole watershed, in a way that the future maximum precipitation difference calculated by two downscaling methods is about 30 percent.

Key words: *CGCM3-AR4, Change-factor, Climate Change, Downscaling, LARS-WG*

1 INTRODUCTION

Changes in air temperatures and precipitation have significant effects on the hydrological cycle. Such changes in climatic variables will also have significant impact on local hydrological regimes particularly in semi-arid catchments. Increasing of temperature due of rising greenhouse gases which have caused the imbalances of earth climate system in recent decades. Studies showed that the average global temperature has been increased for about 0.6 °C since the beginning of the twentieth century, which can lead to increase rates of evapotranspiration and further displacement of

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water vapor in the atmosphere, and consequently more water shortages. Rainfall variability in space and time is a main characteristic of semi-arid regions (Romero *et al.*, 1998). Therefore, climate change will cause more changes in these areas. The variability of rainfall makes it difficult to assess contemporary trends in rainfall distributions and potential impacts of climate change.

Tompkins (2005) reported that the frequencies of extreme events such as droughts and floods are likely to increase with climate change Rind *et al.*, (1989) exposed that climate change is likely to lead to modifications in climate variability and changes in average precipitation in time and space, including extreme events. Simulations performed in most parts of South Africa by Zhao *et al.* (2005) showed that by the end of 21^{st} century, the quantity of precipitation will be reduced about 2.8%. Additionally, Nnyaladzi and Brent (2010) found a decreased trend of rainfall which is associated with decreases in the number of rainy days throughout the Botswana. Both the drying trend and decrease in rainy days agree with climate change projections for southern Africa. Hu *et al.* (2011) mentioned that the source region of the Yellow River has become warmer and experienced some seasonally varying changes in rainfall over the past 40-45 years. Atmosphere-ocean coupled Global Climate Models (GCMs) are the main source to simulate the present and project the future climate of the earth under different climate change emission scenarios (IPCC, 2000). However, the existing GCMs have only limited ability to simulate the complex and local climate features, such as temperature and precipitation data. The outputs provided by (GCMs) are too coarse to be useful in hydrologic impact assessment models, as these models require information at much finer scales. Therefore, downscaling of GCM outputs is usually employed to provide fine-resolution information required for impact models. Massah Bavani and Morid (2006) by study on changes of rainfall and temperature using AOGCM models under all Special Report on Emissions Scenarios (SRES) for three periods viz. 2010-2039, 2040-2069 and 2070-2099 in Zayandehrood River (is the largest river begins on the central plateau of Iran) showed that until near the end of 21 century, the rate of temperature will be increased while rainfall changes didn’t show a clear trend. Furthermore, Abbasi *et al.* (2011) reported the assessment of climate change on Zagros area (West of Iran) for the time period of 2010-2039 by using statistical downscaling of ECHAM4 + HOPE-G model (ECHO-G) over 18 synoptic stations with emission scenario A1. Results showed that mean annual precipitation will be decreased by 2%, while increasing of mean annual temperature by 0.4°C during the future studied time period. In addition, a study in South Khorasan Province in Iran for the period of 2010-2039 illustrated that, climate change is likely to lead to modifications in climate variability and changes in average rainfall (rising of 4%), reducing the number of ice days and increasing the average annual temperature about 0.3°C (Abbasi *et al.*, 2010). Yang *et al.* (2011) by projection of climate change for daily precipitation in one of the- catchments in Taiwan, based on the outputs of GCMs as predictors and using statistical downscaling, revealed that the projected local precipitations under two emission scenarios tend to decrease. Regarding to this point that precipitation and temperature data are the most regularly used forcing terms in hydrological models, so choice of the most appropriate downscaling techniques is important. A number of researchers have reviewed different downscaling methods (Wilby and Wigley, 1997; Semenov *et al.*, 1998; Xu, 1999; Qain *et al.*, 2004; Wilby *et al.*, 2004; Fiseha *et al.,* 2012; King *et al.*, 2012; Muluye, 2012; Hu *et al.*, 2013). The research of Semenov *et al. (*1998), in comparison of the downscaling methods, indicated the LARS-WG generator used more complex distributions for weather variables and tended to match the observed data more closely than Weather Generators (WGEN), although there are certain characteristics of the data that neither generator reproduced accurately.

The objective of this study is to assess the performance of change-factor (CF) and LARS-WG downscaling techniques in prediction of future climate variability of the Azam Watershed of Herat, located in Yazd Province, Iran, for the period of 2010-2039. In addition, the temperature and precipitation variability and trends in semi-arid environment have been investigated by examining the impacts of climatic phenomenon in Yazd Province in Iran. In this regards, we were used from variation CGCM3 model outputs, one of the subset of AR4 – IPCC, under emission scenario A2.

2 MATERIALS AND METHODS

2.1 Case study and data

The study area in this research is Azam Watershed of Herat in Yazd Province, Iran. The watershed expanded about 1017 km^2 and located between 53° 37′ 21″ to 54° 06′ 11″ E and 29° 47′ 59″ to 30° 11′ 58″ N. This river is one of the two main rivers of Yazd Province which comes from Sarsefid and Chokan mountains. Reliable data and adequate record length are the prerequisite to climate research and increased validity of the results. The base data used in this study includes daily observation data of temperature and precipitation for the period of 1982 to 2008 from selected stations in the study area. However, due to lack of sufficient recorded data in the stations within the area, the temperature and precipitation data of the rain gauge, climatology and synoptic stations located nearby the study area were used. After proving the correctness and homogeneousness of the data using RUN-TEST method, the climate data of the stations within the study area was prolonged and completed for a statistical period of twenty years. In this regards, monthly gradient of elevation-precipitation and elevation-temperature were prepared, and the average monthly temperature and precipitation for the study area were calculated. To generate daily precipitation and temperature data for the study area, daily data of rain gauge station of “Bande Paeen” and synoptic station of “Marvast” which have the elevation close to the average elevation of the study area were used as the base stations for precipitation and temperature, respectively. Then, daily data of the station were generated by corresponding elevation of each station to the average elevation of the watershed. Figure 1 shows distribution of stations around the Azam Watershed of Herat in the Yazd Province. Table 1 shows geographical position and period of the study stations.

2.2 Climate models and emissions scenarios

Currently, three-dimensional coupled Atmosphere-Ocean General Circulation Model (AOGCM) is the most reliable tool for generating climate scenarios (Mitchell, 2003; Wilby and Harris, 2006; Zhang *et al.,* 2011). AOGCM model that is used in this study is a subset of AR4 of IPCC, namely CGCM3. The output of CGCM3 model is available from the Data Distribution Center (DDC) which was formed by the IPCC in 1998. Table 2 shows the characteristics of this model (Kim *et al.,* 2003).

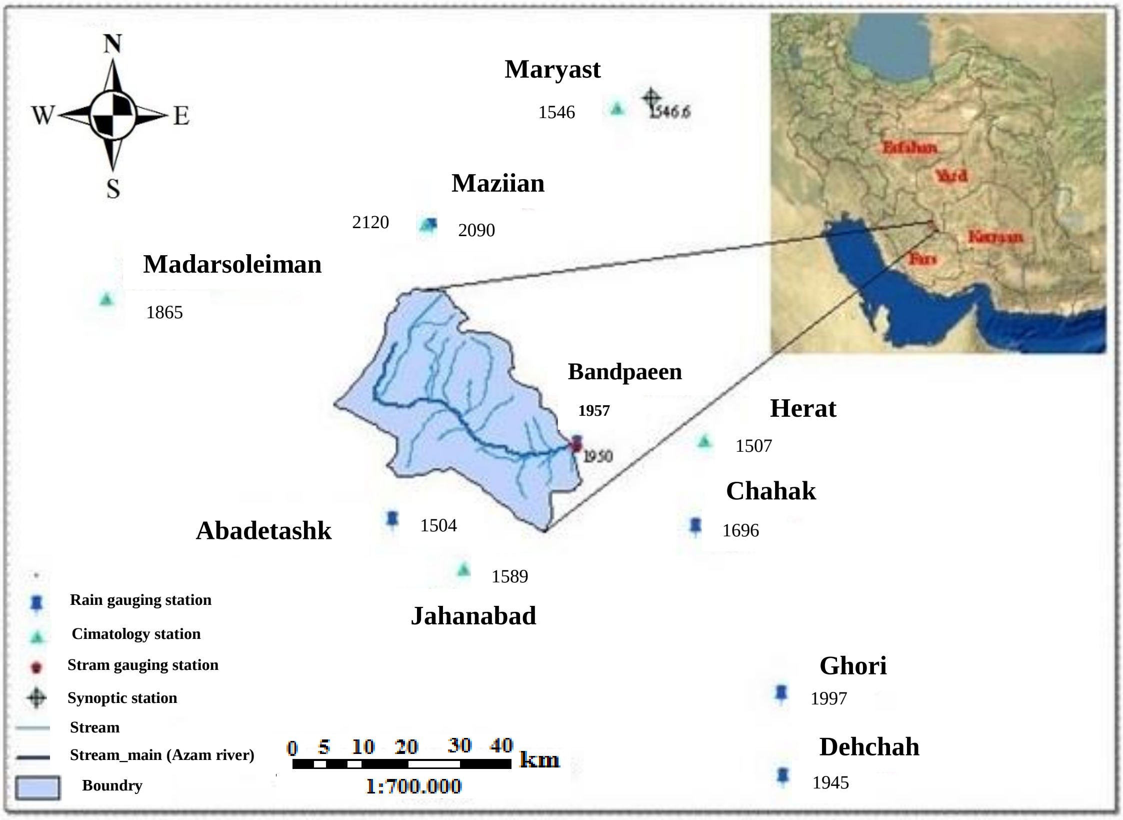


Figure 1 Geographical location of Azam River Watershed of Herat in Iran and distribution of the stations

Table 1 Details of stations of Azam Watershed of Herat, Yazd Province, Iran

Station	Latitude	Longitude	Elevation (m)	Type of station	The period of study
Bande paeen	29° 55'	54° 05'	1830	Rain gauge	1982-2008
Mazijan	30° 18'	53° 49'	2090	Rain gauge	1982-2008
Chahak	29° 47.2'	54° 18.7'	1696	Rain gauge	1982-2008
Ghoori	29° 30.4'	54° 28.2'	1897	Rain gauge	1982-2008
Dehchah	29° 22.2'	54° 28'	1945	Rain gauge	1982-2008
Abadeh tashk	29° 48.7'	53° 43.6'	1604	Rain gauge	1982-2008
Marvast	30° 29'	54° 11'	1545	Climatology	1982-2008
Herat	29° 56'	54° 20'	1607	Climatology	1982-2008
Madarsoliman	30° 11'	53° 10'	1865	Climatology	1982-2008
Jahanabad	29° 43.1'	53° 51.7'	1589	Climatology	1982-2008
Mazijan	30° 18'	53° 48.20'	2120	Climatology	1982-2008
Marvast	30° 29'	54° 15'	1546.6	Synoptic	1982-2008
Bande paeen	29° 55'	54° 5'	1950	Synoptic	1982-2008

Table 2 Characteristics of the CGCM3 model

Model	Organization	Emission Scenario	Resolution		Reference
			Atmosphere	Ocean	
CGCM3	CCCMA (Canada)	A2 , B1,A1B	3.75˚*3.75˚	1.875˚*1.875˚	Kim *et al.* (2003)

CGCM3: Coupled Global Climate Model
CCCMA: Canadian Centre for Climate Modelling and Analysis

Non-climate scenarios reflect the social-economic situation and its impact on the greenhouse gas emissions in the atmosphere, which is called emission scenarios. New series of emission scenarios called SRES was presented in 1996 and 40 subfamily of scenarios have been presented up to now. Each of the sub scenarios related to one of the families; A1, A2, B1 and B2. A2 emission scenario was used in this study. This scenario is a representative of a very heterogeneous world and its original concept is self-sufficiency and relying on local identity. Fertility patterns across regions have very little turnover, which results in continuously increasing population. The economic development initially emphasis is on regional development (IPCC-TGCIA, 2007). Since the A2 scenario features closer to the prevailing conditions in Iran, this scenario were chosen in this research.

2.3 Downscaling

The computational grid of the GCMs is very coarse and thus they are unable to skillfully model the sub-grid scale climate features like topography or clouds of the area in question (Wilby and Dawson, 2002). Consequently, GCMs to date are unable to provide reliable information of temperature and precipitation data for hydrological modeling. Thus, there is a need for downscaling, from coarse resolution of the GCM to a very fine resolution or even at a station scale. Downscaling is one of the techniques that used to convert large networked global climate models to local and regional levels. In this study in order to assess the effect of different downscaling methods on variation of climatic variables of the watershed, we have been used from two downscaling methods, CF and a statistical downscaling method.

2.4 Change Factor method (CF)

In Change Factor method (CF), typically, monthly ratios is constructed for the historical series and the climate change scenarios for temperature and precipitation are produced. For constructing climate change scenario of each GCM, the “difference” and “ratio” for the temperature and precipitation (equations 1 and 2), respectively, are calculated based on the long-term monthly average of future period (2010-2039 period) and baseline period (1982-2008) simulated by the same GCM model in each cell of computational grid (Jones and Hulme, 1996; IPCC-TGCIA, 2007).

$$\Delta T_i = \left(\overline{T}_{GCM,FUT,i} - \overline{T}_{GCM.Base,i}\right) \quad (1)$$

$$\Delta P_i = \left(\overline{P}_{GCM,FUT,i} / \overline{P}_{GCM,Base,i}\right) \quad (2)$$

In above equations, ΔTi and ΔPi are climate change scenarios of the temperature and precipitation, respectively, for long-term 30-year average for each month ($1 \leq i \leq 12$); $\overline{T}_{GCM,FUT,i}$ the average 30-year temperature simulated by the AOGCM in the future periods per month (in this study 2010-2039); $\bar{T}_{GCM,base,i}$ the average 27- years temperature simulated by the AOGCM in the period similar to observation period (in this study 1982-2008) for each month. The above calculations are true for precipitation as well. After calculating climate change scenarios, the CF method is used for downscaling data (Diaz-Nieto and Wilby, 2005; Minvile *et al.*, 2008; Tabor and Williams, 2010). For obtaining time series of future climate scenarios, climate change scenarios are added to the observations values (equations 3 and 4) (in this study 1982-2008):

$$T = T_{obs} * \Delta T \quad (3)$$

$$P = P_{obs} * \Delta P \quad (4)$$

T; time series of the future climate scenarios of temperature (2010-2039) and ΔT; downscaled climate change scenarios. Equation (4) is for precipitation. It should be noted that the time series produced for the future by CF has similar variance and different average with the observational data. It means that the daily amounts of future data are similar to the observational data, but with an increase in temperature (ΔT) and a certain percentage change for precipitation (ΔP).

2.5 Long Ashton Research Station Weather Generator Model (LARS-WG)

LARS-WG model is one of the most popular stochastic weather generators, which is useful for producing daily precipitation, radiation, and maximum and minimum daily temperatures at a station under the present and future climate conditions. The first version of LARS-WG was created as a tool for statistical downscaling method in Budapest in 1990 (Semenov and Barrow, 2002; Rasko *et al.,* 1991). A study by Semenov (2008) has tested LARS-WG for different sites across the world, including one site in South Island of New Zealand, and has shown its ability to model rainfall extremes with reasonable skill. (LARS-WG model employs complex statistical distribution model for the purpose of modeling meteorological variables. The basis for modeling is the duration of dry and wet periods, daily precipitation, and semi-empirical radiation distribution series. The output includes the minimum temperature, maximum temperature, precipitation and radiation. This model is composed of three main parts; calibration of the model, assessment of model, and production of meteorological data. In order to run the LARS-WG model and downscaling GCM data for future periods, two files have to be created, one file defines the behavior of the climate in the past (*.WG) and the other is climate change scenario file (*.Sta). For generating file of climate change scenario for LARS-WG, climate change scenarios for three climate variables have to be calculated from AOGCM; changes in long-term average monthly precipitation of future period related to baseline period (equation 1), changes in long-term average monthly for the duration of wet and dry spells of future period related to baseline period, absolute change of long-term monthly average minimum and maximum temperature of future period related to baseline period (equation 2), change of fluctuations of daily temperature of future period relative to baseline period, and absolute changes of long-term monthly radiation of future period relative to baseline period and are introduced under (*.sce) files to the LARS-WG model. It should be mentioned that daily data of AOGCM are needed for dry and wet period calculation and fluctuations of daily temperature and for the remaining variables monthly data are satisfactory.

In this study two different modes of statistical downscaling by LARS-WG model were used. For the first scenario, changes of variables of dry and wet periods and fluctuations in daily temperature for the future periods are supposed to be constant and other variables change. hence, standard deviation of daily time series of projected variables are close to observation data with differences in mean and corresponded data of future and observation data. If all scenarios of climate variables change (second scenario), not only corresponded daily variables of future parameters are different with observation ones but also statistical parameters (mean and standard deviation) are different from the observation ones. Generally, in this study two different methods including CF and LARS-WG have been used for downscaling of CGCM3 climate model data. In statistical method (LARS_WG), two different modes of climate change scenarios is considered which are named here as scenario I and scenario II.

3 RESULTS AND DISCUSSION

3.1 Temperature changes

Figure 2 shows results of downscaled temperature by CF and two modes of LARS-WG methods in form of long-term monthly average different between observed and future period. According to Figure 2, both scenarios of LARS-WG showed increasing temperature more than CF in all months except January and December. In the scenario I of LARS-WG model, the greatest difference is in November ($1^{℃}$) and the lowest is in July ($0.1^{℃}$). Scenario II of the LARS-WG shows the highest difference of temperature in February which is about $0.8^{℃}$ and the lowest in March. CF method showed increase of temperature more than LARS-WG in January and December in the future period in comparison to observation period. Generally, the highest temperature increase for the future period in comparison to observation period is in August and under scenario II of LARS-WG.

3.2 Precipitation changes

Future changes in precipitation for the future periods in comparison to observation period by two scenarios of LARS-WG and CF do not follow a uniform process. In other words, in some months the amount of precipitation of future is more than observation period and in some months are less than the observation period. As shown in Figure 3, the highest future decrease precipitation by the CF in comparison to observation period will occur in March. The LARS-WG scenario I (with respect to the point that change in the variance remain constant in future), indicates that precipitation increases in all months except May and November in which amount of rainfall of future period is less than observations period for these two months. Scenario II, by applying changes of variance in future, shows monthly increase of changes of precipitation, except on March, November and May, and annual increase of precipitation in comparison to observation period. On the other hand, values of the long-term average precipitation projected by the two scenarios of LARS-WG are higher than those of CF in almost all the months. Moreover, the maximum difference is between scenarios II (coupled changes of average and the fluctuations in the future) and scenario I (changes in mean and stabilize fluctuations in the future) of LARS-WG in February about 56 mm. This difference is remarkable in October in Scenario I compared to Scenario II. The CF and scenario II of the LARS-WG show reduced precipitation while scenario I, show increased precipitation in March to observation period. The scenario II of LARS-WG projects larger reduction of precipitation on May and November than Scenario I and the CF method.

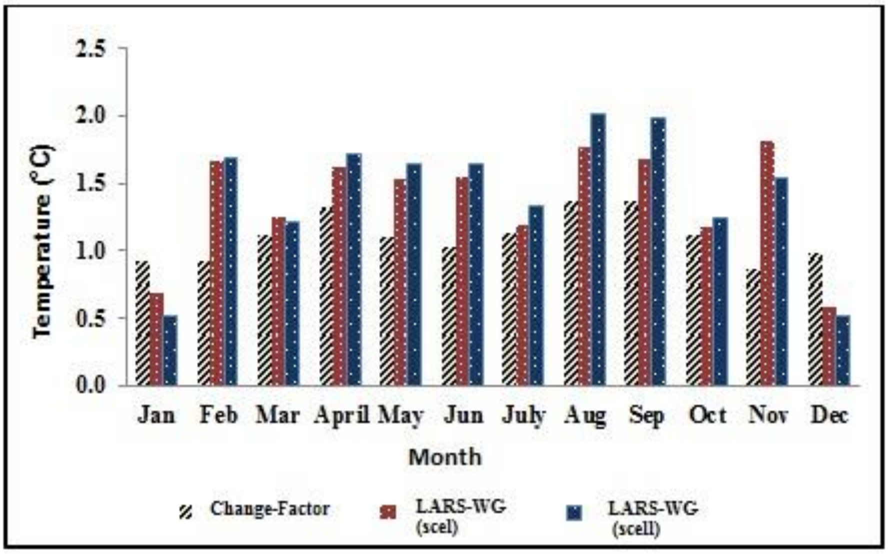


Figure 2 Changes of long-term average monthly temperature of future period relative to observation period by three downscaling methods (CF and two scenarios of LARS-WG)

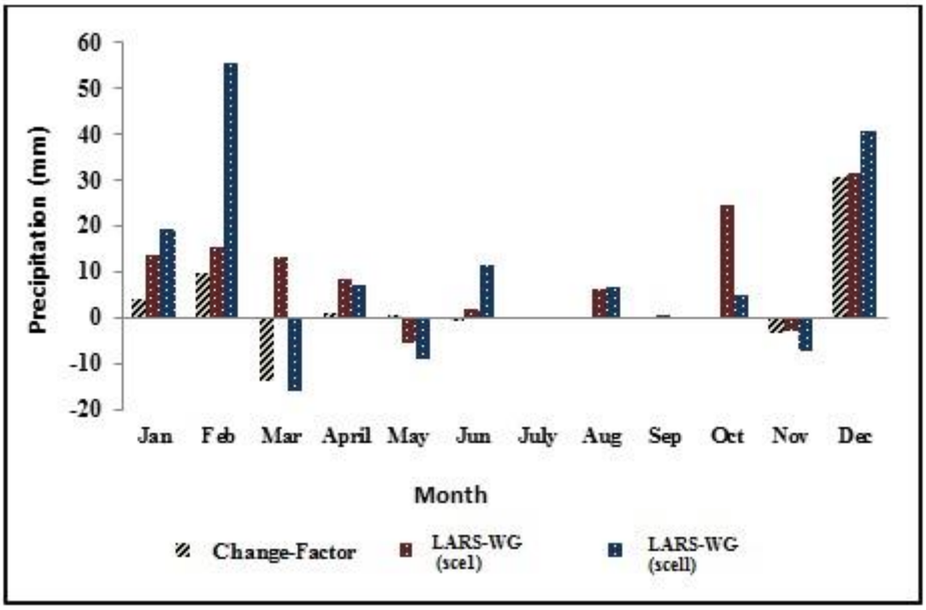


Figure 3 Long-term monthly average changes of precipitation of future period relative to observation period under three downscaling methods (CF, LARS-WG I and II)

3.3 Wet and dry series changes under climate change scenarios in the future

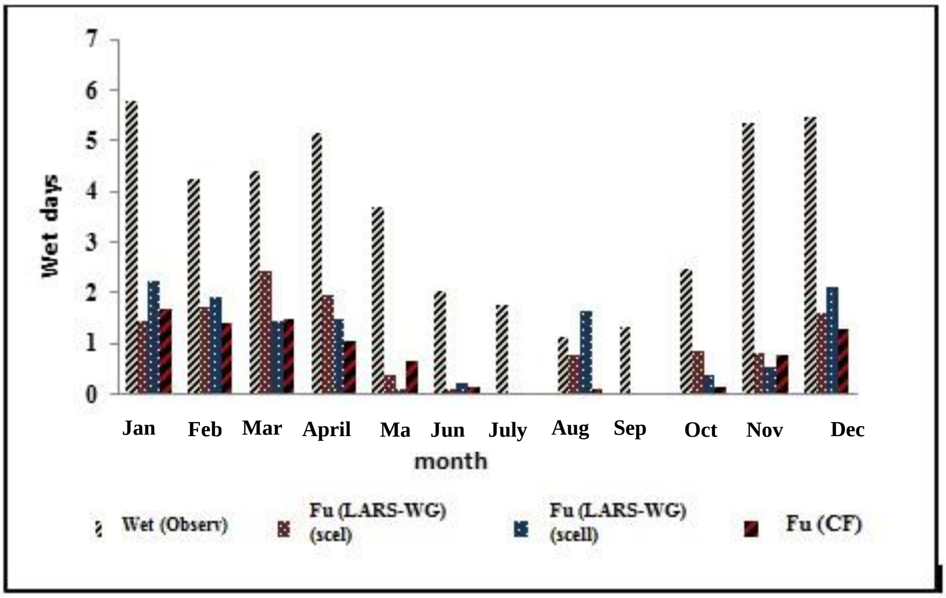
Wet series are defined as series of consecutive days with precipitation greater than 0.1 mm. Wet and Dry series were computed based on the outputs of LARS-WG model and CF method for the future. Then these were compared to the length of wet and dry series of observation data.

Results of both downscaling methods show that the number of wet days and dry days will decrease and increase in the future, respectively. More decreasing number of wet series is occurred in November based on the results of both downscaling methods. Based on statistical method outputs, the highest increase of dry series would occur in May, while according to CF method, it is observed in October. As shown in Figures 4 and 5, more decrease of wet days is based on CF method results and more increase of dry days is based on LARS-WG results under scenario II.

3.4 Precipitation variability

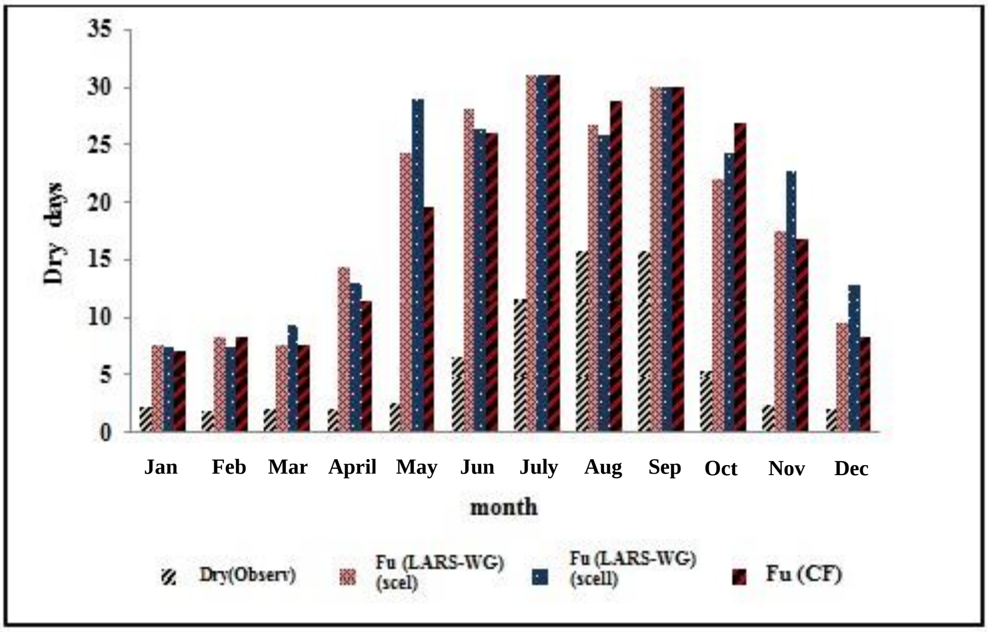
One of the main features of precipitations is their variabilites in Iran, especially in arid and semi-arid areas. Due to this fact, water resources have no uniform changes in these areas. If the spatial variations of precipitation are less, of course water resources will be more stable. Hence, the variability of precipitation is important role in evaluation of water resources in local and regional scales. In this regard, coefficient of variation of precipitation ($CV = STD/\bar{X}$) produced by using outputs of both downscaling methods were computed for the baseline and the future time periods (Figure 6).

As Figure 6 illustrated, the coefficient of variation of monthly precipitation has no changes in the future in comparative with baseline by CF method while this parameter in statistical method affected changes in future compared to baseline. The coefficient of variation of monthly precipitation due of statistical method by both scenarios (scenarios I and II) showed increase of precipitation variability in May and July, but it decreases in August. Of course, this change is not equal in both scenarios.



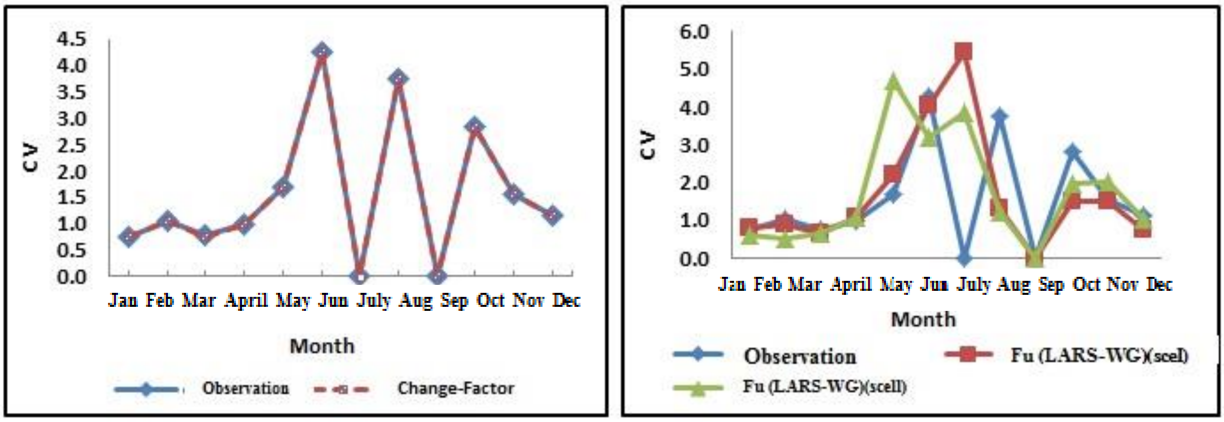
Observ: observation, Fu: Future, CF: Change-Factor, Sce: scenario

Figure 4 The frequency of wet series in the future compared to the period of baseline based on the results of CF and LARS-WG under climate change scenarios



Observ: Observation, Fu: Future period, Sce: Scenario, CF: Change-Factor

Figure 5 The frequency of dry series in the future compared to the period of baseline based on the results of CF and LARS-WG under climate change scenarios



Fu: Future period, sce: scenario

Figure 6 The coefficient of variation of monthly observed precipitation during the period 2010-2039 compared to baseline predicted by CF and LARS-WG under climate change scenarios

4 CONCLUSION

In this study, impact of climate change on climatic variables of Azam River Watershed of Herat located in Yazd Province was studied for the period of 2010-2039 under uncertainty of downscaling methods. For this purpose, simulations of CGCM3-AR4 model under emission scenario A2 were applied by two downscaling methods including; CF and two different modes of LARS-WG. Results of projection of two downscaling methods for temperature and precipitation variables under three scenarios of climate change in the period of 2010- 2039 (a scenario of CF and two scenarios of LARS-WG) showed differences in the outputs of the two downscaling methods for the climatic variables. The average of temperature downscaled by two methods for the future periods show differences of 3 to 4 percent, but for precipitation is about 30 percent.

Results of this work revealed that although the calculation of CF is easy and simple for downscaling, but in this method the fluctuations of future period has are not sufficiently modeled, while in the LARS-WG model, these fluctuations are well modeled. Therefore, selecting the appropriate method for downscaling climate variables taken from the AOGCM model is highly depended on the type of project and case study, so that it confirms by other researchers (Semenov *et al.*, 1998; Qian *et al.*, 2004; Semenov, 2008; Muluye, 2012; Hu *et al.*, 2013).

The work presented in this paper strongly suggests the use of multimodels ensemble downscaling for providing the required data for hydrological impact assessment. Generally, precipitation variability is an important feature of arid and semi-arid climates, and climate change is likely to increase that variability in many of these regions. Ulltimately, these results compared with the results of Kamal *et al.* (2010), order to effect of different sources uncertainty. In both studies is shown the improved results of simulated climate variables by statistical downscaling rather than CF method. Also, they found that the most effective source of uncertainty in simulated temperature and precipitation data of study area related to downscaling methods of AOGCM models.

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ارزیابی روش‌های ریز مقیاس‌نمایی عامل تغییر و LARS-WG در شبیه‌سازی متغیرهای اقلیمی در دوره‌های آتی (مطالعه موردی: حوزه آبخیز رودخانه اعظم هرات- یزد)

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چکیده مدل‌های گردش عمومی جو به‌دلیل بزرگ مقیاس بودن شبکه محاسباتی آن‌ها قادر به پیش‌بینی متغیرهای اقلیمی در مقیاس محلی نیستند. لذا روش‌های ریز مقیاس‌نمایی برای رفع این مشکل به کار برده می‌شوند که البته انواع مختلف این روش‌ها کارایی متفاوتی دارند. از آن‌جا که پدیده تغییر اقلیم می‌تواند سیستم‌های مختلف دیگری نظیر منابع آب، کشاورزی، محیط زیست، بهداشت، صنعت و غیره را تحت تأثیر قرار دهد، بنابراین انتخاب مناسب‌ترین روش ریز مقیاس‌نمایی ضروری است. این تحقیق با هدف پیش‌بینی تغییرات اقلیمی حوزه آبخیز رودخانه اعظم در استان یزد، در دوره آتی (۲۰۳۹-۲۰۱۰) با استفاده از دو روش ریز مقیاس‌نمایی عامل تغییر (CF) و LARS-WG صورت گرفته است. به این منظور از مدل CGCM3-AR4 و سناریوی انتشار A2 تحت دو روش ریز مقیاس‌نمایی عامل تغییر و آماری استفاده شده است. نتایج نشان از افزایش دما در حوزه آبخیز مورد مطالعه تحت هر دو روش ریز مقیاس نمائی دارد. متوسط دمای به‌دست آمده از هر دو روش در دوره آتی اختلاف ۳ تا ۴ درصد را نشان داد. از طرف دیگر بارندگی در کل حوزه بسته به شرایط جوی افزایش و کاهش قابل ملاحظه‌ای از خود نشان داده به‌طوری‌که در دوره آتی اختلاف بارش ناشی از دو روش ریز مقیاس‌نمائی حدود ۳۰ درصد بوده است.

کلمات کلیدی: تغییر اقلیم، ریزمقیاس نمایی، عامل تغییر، CGCM3-AR4، LARS-WG