

Mohammad BAGHER RAISI,
Mehdi VAFAKHAH*, Hamidreza MORADI ¹

MODELING SNOWMELT-RUNOFF UNDER CLIMATE CHANGE SCENARIOS IN THE BEHESHTABAD WATERSHED

SUMMARY

The aim of this study was to evaluate the variability of time distribution and contribution of runoff from snowmelt under the influence of climate change in the Beheshtabad Watershed, Iran using the Snowmelt-Runoff Model (SRM) and Long Ashton Research Station Weather Generator Model (LARS-WG). The LARS-WG model accuracy in downscaling of GCMHadCM3 output with A1B emissions scenario was evaluated based on data for the base period (1986-2010) and climatic data for the future periods (2011-2030 and 2046-2065) were obtained. The SRM variables and parameters were prepared from the Shahrkord station and Snow Cover Areas (SCAs) were obtained by MODIS satellite images. After the calibration and validation of SRM model, then the SRM model was run with the future data and revealed the effects of climate change on snowmelt runoff. The results show the displacement of the peak flow from April to March, and reducing the contribution of snowmelt runoff from 27.2 to 24.5 and 22.3 percent for two future periods. The present study confirmed the effects of climate change on future climate data and discharge and temporal pattern of snowmelt-runoff.

Keywords: Climate change, Snowmelt-runoff model, LARS-WG model, Temporal pattern of runoff.

INTRODUCTION

The changes in future climate and its implications have always been very important aspect for world's water resources (Adnan *et al.* 2017). The snow is one of the important forms of precipitation in the hydrologic cycle in mountainous regions and plays a valuable role to provide drinking water and agricultural resources. The snow is one of the major sources of water in most parts of the world. The estimation of the equivalent water of snowmelt is considered as one of the most important activities of hydrologists. Because more than 10 percent of the earth's surface is covered permanently by glaciers and 30% of its surface is covered by snow in the northern hemisphere in winter (Sayedi Elmabad *et al.* 2010).

¹Mohammad Bagher Raisi, Mehdi Vafakhah *(corresponding author: vafakhah@modares.ac.ir), Hamidreza Moradi Department of Watershed Management Engineering, Faculty of Natural Resources, Tarbiat Modares University, IRAN.

Notes: The authors declare that they have no conflicts of interest. Authorship Form signed online.

According to studies conducted in Iran by about 60 percent of surface water and 57 percent of groundwater in the snowy regions feed by snowmelt water (Sayedi Elmabad *et al.* 2010). However, in most watersheds, the required meteorological and hydrologic data for the simulation, similar to snow survey data usually are not available (Barovic *et al.*, 2015; Khaledi Darvishan *et al.*, 2017; Spalevic *et al.*, 2017)). Thus, it can be formulated with factors affecting environmental energy needed to melt and snowmelt (Ferguson 1999). In this field, snowmelt is estimated with various models classified as energy balance, degree-day and radiation-temperature. Cline *et al.* (1998) and Homan *et al.* (2011) calculated snowmelt-runoff using energy balance. Although the energy balance model has strong physically base, but it needs many data and not be used due to lack of data on mountain watersheds (Vafakhah *et al.* 2015). Some models such as snowmelt runoff model (SRM) have been designed to predict the daily snowmelt and applied widely for snowmelt simulation (Martinec *et al.* 2008).

Previous studies show that in most parts of the world, climate change led to increase in temperature, extreme events and entropy and to decrease rainfall. In addition, the amount of snow and snow period will decrease and therefore, the volume of runoff will increase in winter and reduce in the spring due to climate change (Hugo 2003). The investigation of climate change effect on water resources and specifically on the snowmelt runoff can greatly enhance the accuracy of the simulation and regardless of the fact that the climate is changing, we can't carry out realistic planning of exploitation of water and snow resources (Hardy 2003).

Several attempts have been made to investigate the effects of climate change on snowmelt-runoff. A study conducted by Payne *et al.* (2003) in the Columbia River basin for period the 2040-2060 predicted temperature increase of 1.2°C and the average winter precipitation decrease of 3 percent, relative to base time. Ma and Cheng (2003) showed that temperature increase of 4°C, the snow cover area (SCA) and snowmelt season shift towards earlier dates, and the snowmelt runoff using SRM model is changed significantly in the Gongnaisi River basin in the western Tianshan Mountains. Stewart *et al.* (2004) showed that a shift 30–40 days would occur in the timing of springtime snowmelt in Western North America for the 1995–2099 period. Miller *et al.* (2004) for a set of California river basins predicted that late winter snow accumulation decreases by 50 percent toward the end of this century. Jian and Shuo (2005) simulated the changes of snowmelt runoffs in response to a warming of 4°C using SRM on the upper Heihe Watershed in northwestern China. The result of the simulation indicated that a forward shifting of snow melting season, an increase in water flows in earlier melting season, and a decline in flows in later melting season would result. Hreiche *et al.* (2007) simulated the changes of flow characteristics in response to a warming of 2°C on Lebanese catchments. Their results showed that droughts would occur days to one month earlier and snowmelt floods would often replace by rainfall floods. Changchun *et al.* (2007) analyzed annual temperature and precipitation time series and SCA for the 1982–2001 period. The

SCA slowly increased and the effect of precipitation on SCA is larger than that of temperature. Ma *et al.* (2013) analyzed the impact of climate change on snowmelt runoff using Hadley Centre Coupled Model version 3 (HadCM3) and SRM in Kaidu Watershed, Northwest China. The results indicated that the streamflow in spring would increase with the increased mean temperature and the discharge and peak flow in summer would decrease with the decreased precipitation. Khadka *et al.* (2014) investigated the impact of climate change on SCA and snowmelt runoff in the Tamakoshi basin of Nepal. The results showed that temperature, precipitation, streamflow and the number of days with high discharge would increase. A comprehensive study of response of snow basins to climate change in the mountains is still lacking in Iran, mainly because of the inaccessible terrain, lack of observed climatic data, and the fact that response of snow is not uniform throughout the all mountains. The aim of this study is to investigate the effect of climate change on SCA and the snowmelt runoff in the Beheshtabad Watershed as a part of the Karun basin, Iran.

MATERIALS AND METHODS

Study area

The Beheshtabad Watershed is located in the northern part of the Karun basin and Chaharmahal and Bakhtiari Province with an area of about 3905 km² and a geographical position of 50° 23' to 51°25' east and 31°49' to 32°34' north (Fig. 1). The elevation ranges from 1660 m above sea level at the outlet of the watershed to 3620m a.s.l. on Saldaran Mountain. The mean annual temperature and the mean annual precipitation are 11°C and 471 mm, respectively of which 245 mm falls during the winter months, 89 mm during spring, 5 mm during summer and 132 mm during autumn. About 55% of precipitation in the Beheshtabad Watershed falls as snow. Approximately 42% of the watershed is covered by pasture, 12% by rocks and 46% of the land is used for agricultural activities (Rostamian *et al.* 2008).

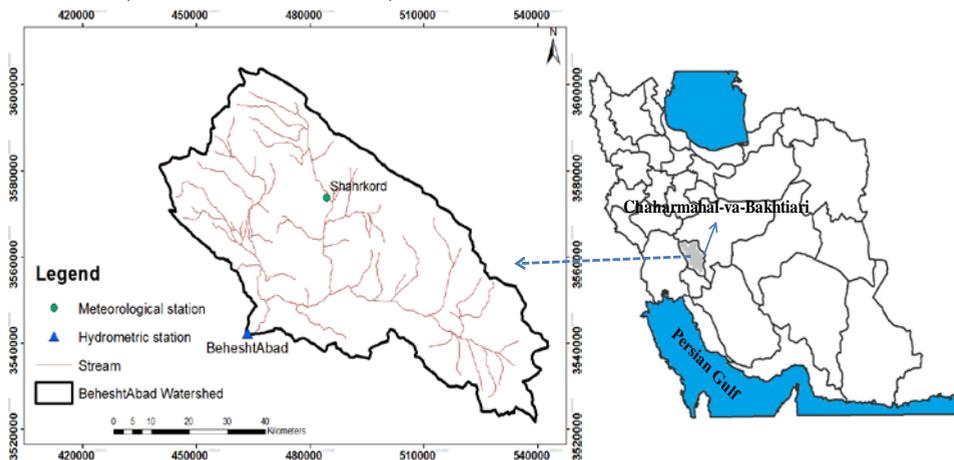


Fig 1. Location of the Beheshtabad Watershed in Iran

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

LARS-WG is a stochastic weather generator (Semenov 2008), and it is widely used for the climate change assessment. This model is useful for producing the daily precipitation, daily solar radiation, and daily maximum and minimum temperatures at a particulate site under the present and future climate conditions.

The LARS-WG uses input observed daily weather data for a station to determine probability distributions of parameters specifying for weather variables as well as correlations between the variables (Semenov and Brooks 1999; Khordadi *et al.* 2015).

Complex statistical distribution model is employed by LARS-WG model for the purpose of modeling meteorological variables. The duration of wet and dry periods, semi-empirical distribution of radiation series and daily precipitation data are the basis for modeling. Calibration of the model, assessment of model, and production of meteorological data are the main parts of this model (Babaiya and Najafinik 2006; Hashmi *et al.* 2011).

HadCM3 is a coupled atmosphere-ocean general circulation model (AOGCM) developed at the Hadley Centre in the United Kingdom with a spatial resolution of $2.5^{\circ} \times 3.75^{\circ}$ (Khadka *et al.* 2014).

In order to downscale using LARS-WG, the ability of LARS-WG for producing the weather time series i.e. daily precipitation, daily maximum and minimum temperatures in the period of 1986–2010 from the Shahrekord station was analyzed. To do this, the weather time series include daily precipitation, daily maximum and minimum temperatures were used as an input to LARS-WG for simulating the weather time series. The statistical properties of the simulated time series were compared to those of the observed time series using t-test, Nash-Sutcliffe coefficient efficiency (NS) (Equation 3) (Nash and Sutcliffe 1970) and coefficient of determination (R^2).

Snowmelt Runoff Model (SRM)

Meteorological and hydrological characteristics of watershed and variables are necessary data to implement SRM model. Model input variables are distributed among elevation zones (each with approximately 500 m of relative relief), and include daily average air temperature, daily total precipitation, and SCA (Vafakhah *et al.* 2015). The following equation is used in SRM to simulate daily streamflow discharge:

$$Q_{n+1} = [c_{S_n} a_n (T_n + \Delta T_{n+1}) S_n + c_{R_n} P_n] \frac{10000}{86400} (1 - k_{n+1}) A + Q_n k_{n+1} \quad (1)$$

where Q (m^3/s) is the average daily discharge, c is runoff coefficient expressing the losses as a ratio (runoff/precipitation), with c_S referring to snowmelt and c_R to rain, a ($cm/^{\circ}C.day$) is the degree-day factor indicating the snowmelt depth resulting from 1 degree-day, T ($^{\circ}C.day$) is number of degree-days, ΔT_{n+1} ($^{\circ}C.day$) is the adjustment by temperature lapse rate when

extrapolating the temperature from the station to the average hypsometric elevation of the basin or zone, $P(\text{cm})$ is the precipitation (rainfall) contributing to runoff, S is ratio of the snow covered area to the total area, A (km^2) is the area of the basin (or elevation zone), k is the recession coefficient indicating the decline of discharge in a period without snowmelt or rainfall, n is the sequence of days during the simulation period, and $10000/86400$ converts $\text{cm.k m}^2/\text{day}$ to m^3/s .

The Beheshtabad Watershed has been divided into four elevation zones using the topography maps at a scale of 1:50000 obtained from geographical organization in Iran (Fig. 2).

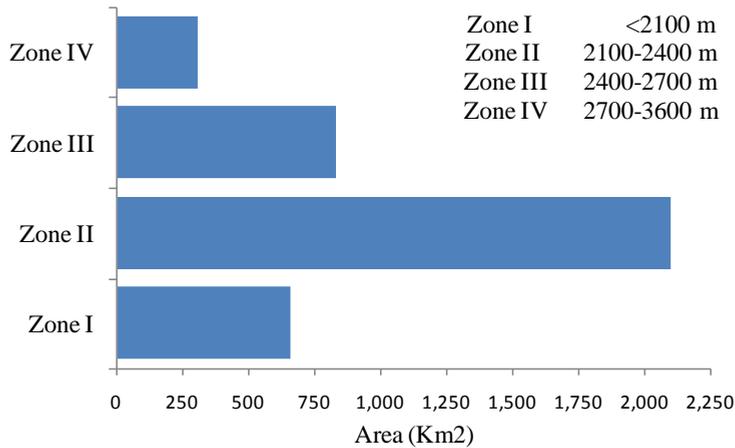


Fig 2. Elevation zones in the Beheshtabad Watershed

In this study, MODIS TERRA satellite with spatial resolution of 250 and 500 m was used to estimate SCA in the watershed. Normalized Difference Snow Index (NDSI) is used as a criterion to separate snow cover from other land covers. Snow has high reflectance of visible radiation and strong absorption in middle infrared wavelength which are used to separate it from other land covers. Reflectance in band 4 (0.545–0.565 μm) and band 6 (1.628–1.652 μm) are used to calculate NDSI as:

$$NDSI = \frac{MODIS_{Band4} - MODIS_{Band6}}{MODIS_{Band4} + MODIS_{Band6}} \quad (2)$$

In the non-forest area, NDSI threshold value of 0.4 is used to delineate snow area along with reflectance in band2 $\geq 11\%$ and reflectance in band4 $> 10\%$ (Hall *et al.*, 1995). MODIS images for water years of 2012-2013 and 2013-2014 were used for SRM calibration and validation periods, respectively in the study.

The statistical properties of the simulated time series were compared to those of the observed data using NS and volume difference (D_v) in order to test the ability of SRM model for reproducing the observed data statistics:

$$NS = 1 - \frac{\sum_{i=1}^n (Q_o - Q_e)^2}{\sum_{i=1}^n (Q_o - \bar{Q}_o)^2} \quad (3)$$

where Q_o and Q_e are the observed and simulated discharge, \bar{Q}_o is average observed discharge.

$$D_V[\%] = \frac{V_o - V_e}{V_o} \times 100 \quad (4)$$

where V_o is the observed yearly runoff volume, V_e is the estimated yearly runoff volume.

RESULTS AND DISCUSSION

LARS-WG model was performed based on the historical climate data obtained from 1986-2010 for verification of the model. For this purpose, a large number of years of simulated daily weather data were generated. In addition, to evaluate the model's ability to simulate meteorological data in observed period, p-value, NS and R^2 were used and the results were analyzed (Table 1). The results of statistical index showed high accuracy of model in production climate data. So that the minimum and maximum temperature values have the highest correlation and the rainfall is the lowest correlation. The model shows a better performance for the maximum and minimum temperatures than precipitation. In general, simulation of precipitation is more complex and difficult to obtain a good agreement between observed and simulated compared with downscaling of temperature (Fowler *et al.* 2007; Hassan *et al.* 2014).

Table 1. Results of LARS-WG evaluation in the Beheshtabad Watershed

Variable	p-value	Nash-Sutcliff	R^2
Precipitation	0.022	0.94	0.98
Minimum temperature	0.29	0.97	0.99
Maximum temperature	0.71	0.99	0.99

Figs. 3 and 4 summarize results of climate change analysis. As can be seen from the Figs. 3 and 4, both temperature and precipitation are predicted to increase in the future periods.

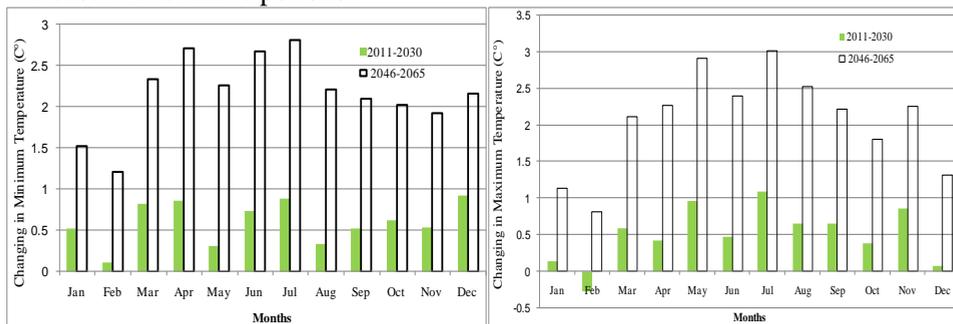


Fig 3. Future changes in Tmax and Tmin with respect to the historical data (1986–2010) under HadCM3 A1B scenario

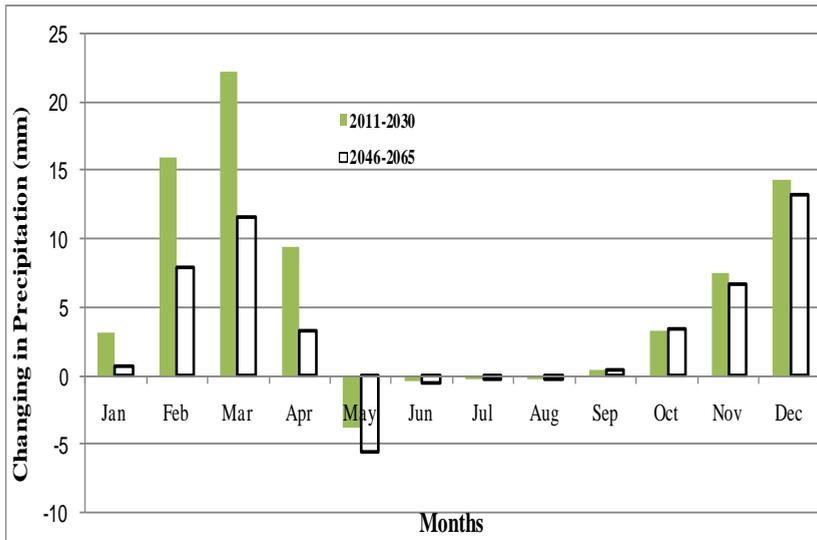


Fig 4. Future changes in precipitation with respect to the historical data (1986–2010) under HadCM3 A1B scenario

As shown in Fig. 3, LARS-WG shows increasing minimum temperature in all months for two study future periods. Results also indicated that maximum temperature will increase except Feb.

In future periods, the greatest increasing of T_{max} is in Jul. about 1 and 3 °C for the 2011-2030 and 2046-2065 periods, respectively. The results showed that the mean annual T_{max} increase from 19.8 °C (in baseline period: 1986-2010) to 20.4 °C and 21.9 °C for the 2011-2030 and 2046-2065 periods, respectively. The increase of temperature in study area is in agreement with previous studies (Ashraf *et al.* 2011; Farzanmanesh *et al.* 2012; Hassan *et al.* 2014; Goodarzi *et al.* 2014).

Future changes in precipitation for the future periods in comparison with the observation period don't follow a uniform trend. In other words, in some months the amounts of future precipitation are more than the observation period and in some months are less than the observation period. As shown in Fig. 4, the future precipitation would increase for the 2011-2030 and 2046-2065 periods, in comparison with the observation period except May, June, July and August.

SCA analysis

SCA for the 2001-2010 period and SCA in each elevation zones for the base period were obtained from the MODIS images. Fig. 5 shows the mean seasonal SCA of zones. Also, based on the relationship between SCA and daily temperature and rainfall variables, regression relations were obtained in each zone for different months (Table 2). These relationships were used to estimate SCA in zones for future periods.

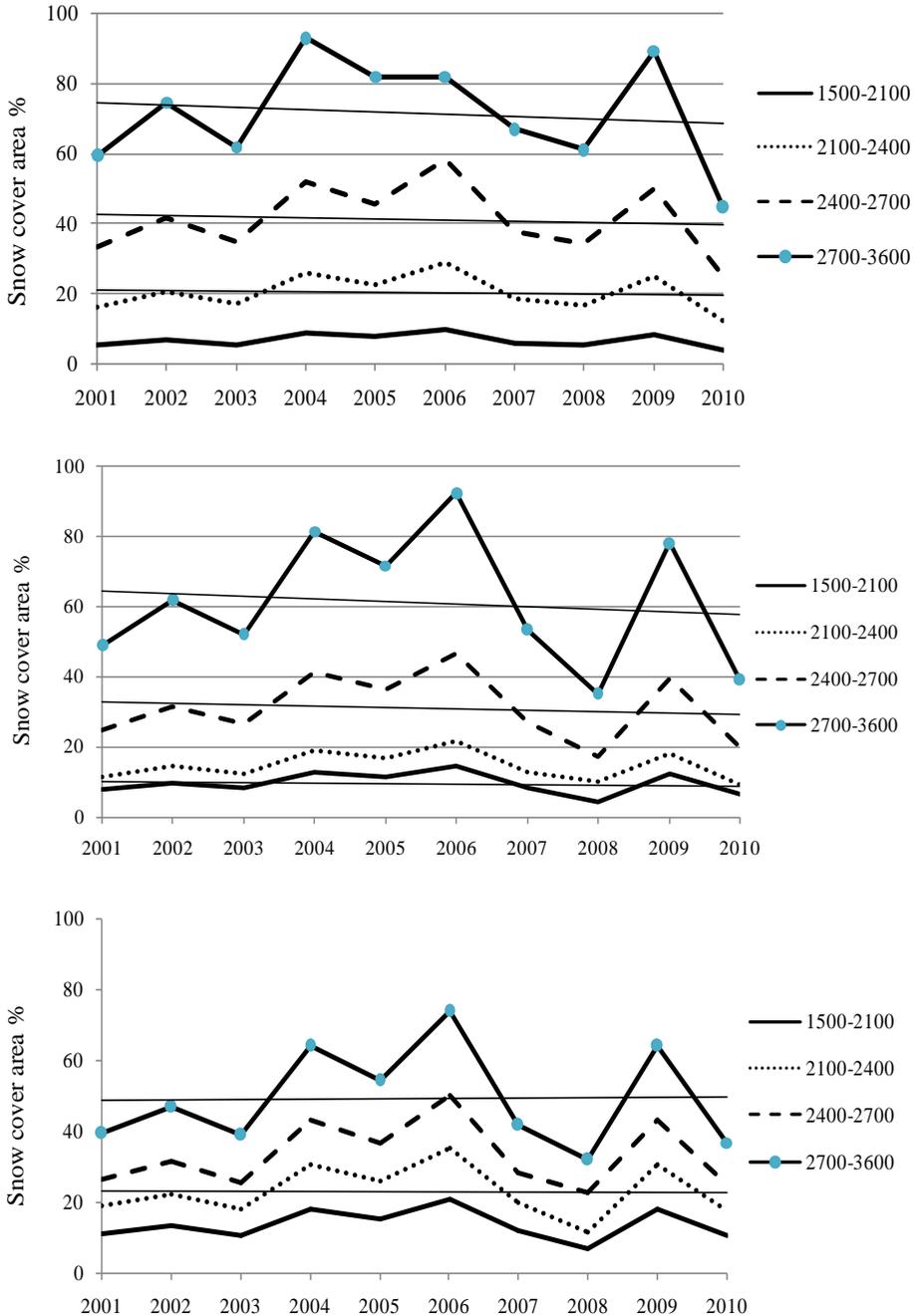


Fig. 5. Average SCA area in elevation zones for autumn, winter and spring (respectively, from top to bottom) in the base period

Table 2. Regression equations coefficients for estimating SCA in different months

Month	elevation zones	Coefficients of independent variables				Constant coefficient	R ²	P-value
		T _{i-1}	P _{i-1}	T _i	P _i			
December	1500-2100	2.78	4.65	-3.90	0.41	1.68	0.91	0.003
	2100-2400	-20.47	47.06	-16.72	1063	44.86	0.91	0.003
	2400-2700	0.00	14.01	-34.75	0.00	127.86	0.69	0.003
	2700-3600	-5.09	1.32	-18.92	-7.03	77.11	0.64	0.091
January	1500-2100	-10.49	12.90	-56.80	0.00	79.67	0.66	0.029
	2100-2400	36.28	59.50	203.62	0.00	383.32	0.84	0.001
	2400-2700	24.61	12.74	-68.85	0.00	45.23	0.92	0.000
	2700-3600	5.92	0.35	-10.65	0.00	189.48	0.81	0.001
February	1500-2100	15.90	9.83	-44.80	385.06	206.00	0.93	0.000
	2100-2400	6.54	3.24	-134.84	702.14	162.73	0.88	0.002
	2400-2700	8.05	3.32	-49.24	140.03	281.86	0.66	0.078
	2700-3600	-1.60	1.81	-12.28	91.82	143.00	0.51	0.036
March	1500-2100	-1.44	0.85	-2.30	0.16	27.07	0.32	0.549
	2100-2400	0.00	17.08	-72.63	5.05	425.38	0.35	0.295
	2400-2700	0.00	12.92	-40.45	1.90	222.98	0.35	0.304
	2700-3600	-2.95	5.78	-11.32	3.28	103.50	0.41	0.382
April	1500-2100	2.92	0.64	-5.80	3.52	30.37	0.54	0.862
	2100-2400	-14.39	1.70	15.80	6.64	8.89	0.26	0.602
	2400-2700	-6.01	0.64	5.70	0.00	13.27	0.21	0.447
	2700-3600	5.18	1.79	-12.01	0.00	47.79	0.57	0.014
Annual	1500-2100	1.10	0.06	-21.57	2.22	189.45	0.46	0.000
	2100-2400	-9.11	11.57	-73.72	4.98	475.98	0.54	0.000
	2400-2700	-1.30	5.45	-35.54	3.33	225.33	0.67	0.000
	2700-3600	-2.58	1.95	-11.37	3.75	108.68	0.68	0.000

* The dependent variable in all relations is SCA in the elevation zone .

**In these equations, P_i, T_i, P_{i-1} and T_{i-1} are precipitation in current day, temperature in current day, precipitation in pervious day and temperature in previous day, respectively .

***In cases where the R² of monthly relations is not acceptable, the annual relationship was used .

Snowmelt runoff estimation

Table 3. Intervals search parameters for SRM calibration and optimal calibrated and sensitive parameters

Parameter name	Symbol	Normal range	Interval change	Optimal value	Sensitive rank
Recession coefficient (k)	x	0.1-1.5	0.01	1.02-1.04	1
	y	0.01-0.1	0.01	0.06-0.1	6
Rain runoff coefficient	C _R	0.01-0.99	0.02	0.70-0.76	3
Snowmelt runoff coefficient	C _S	0.01-0.99	0.02	0.68-0.78	2
Degree-day coefficient*	$a \left(\frac{cm}{^{\circ}Cd} \right)$	0.01-1	0.05	0.20-0.35	4
Critical temperature	T _{crit} (°C)	0-4	0.2	2	5

*From snow density data

The results of SRM calibration and manually sensitivity analysis are given in Table 3. As can be seen from the Table 3, recession coefficient (k) and snowmelt runoff coefficient (c_s) were found to be the most sensitive parameters. After successful daily runoff calibration, validation and sensitivity analysis of the model with $NS=0.60$ and $D_v=-14.72\%$ in calibration period and $NS=0.58$ and $D_v=-28.31\%$ in validation period. SRM model was run to simulate daily runoff for the 2011-2039 and 2046-2065 periods.

Results of the influence of climate change on snowmelt-runoff

Hydrological impacts of climate change in terms of changes in rainfall and temperature in the basin is determined. The resultant effects of climate change on the hydrological Beheshtabad Watershed can be observed at fluctuations in flow rate in the Beheshtabad hydrometric station. For this purpose, the SRM model by anticipated climatic variables of GCM models for specific scenarios was run and compared with changes of runoff for different periods. SRM model was run 40 times for the 2011-2039 and 2046-2065 periods and calculated the daily estimated runoff (as the monthly average) for each period. The monthly average discharge in the 1986-2010 period were used as the base period. Fig. 6 shows the observed hydrograph (for the base period) compared with the predicted hydrographs for the next two periods. In addition to variation in the Beheshtabad discharge, change at the peak time is also clearly visible in this graph.

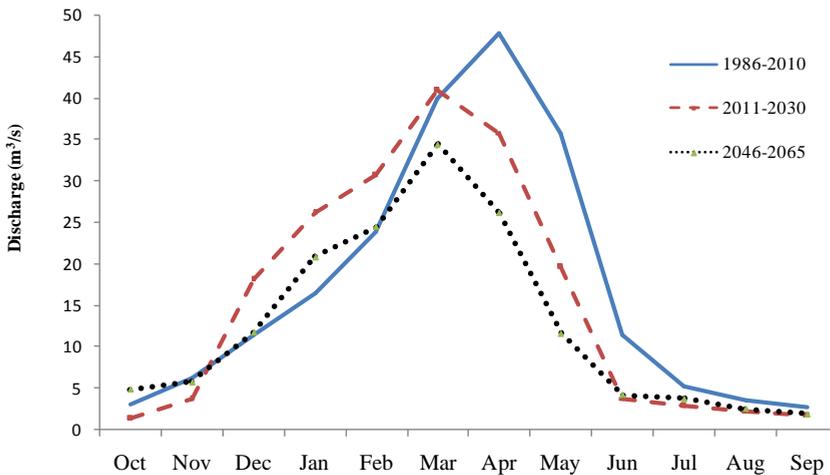


Fig 6. The observed and estimated hydrograph in the Beheshtabad Watershed during three periods

Flow duration curves (FDCs) for future periods were drawn based on discharge data from the SRM and were compared with the base period (Fig. 7). As can be seen from the Fig. 7, FDCs in future periods have the same trend with FDC in the base period, but streamflow value will decrease significantly in

future. This shows that a significant change in the number of days with low flow in about 50% of year will be very low and close to zero (especially in the 2046-2065 period). The more important point is to reduce the annual volume of river flow, reduce low flows during dry period in years that river cant supply agricultural water needs in dry season .

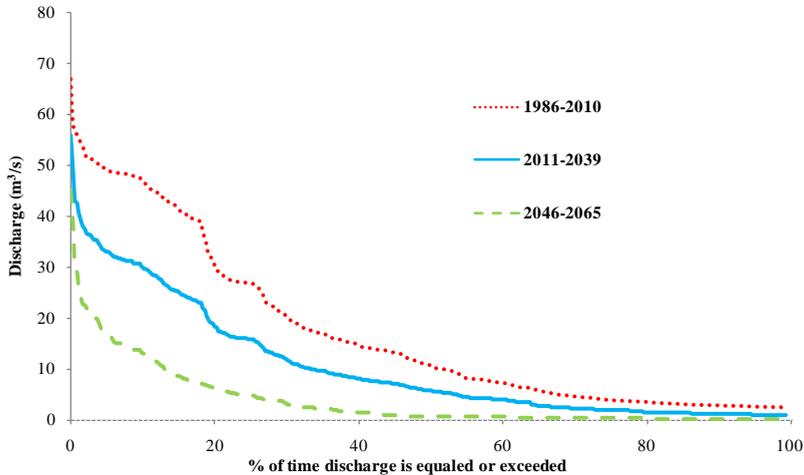


Fig.7. Comparison of exceedance flow in three periods

Impact of climate change on the Beheshtabad River discharge

Fig. 7 shows the general decrease annual runoff in the Beheshtabad River by 10 and 26 percent, respectively, for the periods of 2030-2011 and 2065-2046. This finding is consistent with those of Mansouri *et al.* (2014) in the Zarinerood Watershed who found to reduce in runoff after the significant increase in rainfall. Despite the significant increase rainfall in future periods (Fig. 4), may seem unreasonable decrease in runoff. However, exacerbated the negative effects by increase temperature on water resources by increasing the evaporation, and will reduce the quality and quantity of water resources.

The results also show the relative increase runoff compared with the base period in January and February. This increase due to rising temperatures in future periods and the subsequent change in type of rainfall and will increase snowmelt and runoff. In the other words, as the weather warms one side more precipitation as rain, which is directly converted to runoff and increase the runoff and on the other hand in case of snow, rising temperatures melt faster and prevents the accumulation of snow. Results showed a significant reduction peak flow in the 2011-2030 and 2046-2065 periods respectively 7 and 13 m³/s.

Moreover peak monthly rate in future periods compared with the base period is takes place a month earlier, that's mean moves from April to March. The reason for this is rising temperatures, especially in March. Because as increase in temperatures in March, precipitation turned to rain rather than snow accumulation, and becomes the direct runoff. The results obtained in this study

on the reduction of runoff under climate change, correspond as well as with the results of Massah Bavani (2005), Huang *et al.* (2013), Zarghami *et al.* (2011) and Modaresi *et al.* (2011).

The contribution of snowmelt runoff in the Beheshtabad River

SRM model can separate the snowmelt runoff and precipitation runoff. In addition, the model was run for the future periods (40 years), the model was performed for the 2001-2010 period as the base period. Table 4 shows the separation results of runoff from rain and snowmelt runoff during observation and two next periods (2011-2030 and 2046-2065).

Table 4. Percent of snowmelt runoff in the Beheshtabad Watershed

period season	2001 -2010	2011-2030	2046-2065
Spring	33.0	25.1	20.3
Summer	15.9	13.5	12.8
Autumn	14.1	14.2	16.0
Winter	24.6	29.0	29.3
Annual	27.2	24.5	22.3

Table 3 shows that snowmelt runoff has a relatively large contribution in the Beheshtabad River runoff that is different in seasons of the year. During the observation period, the highest contribution of snowmelt runoff is in spring. While contribution of snowmelt has changed in future periods and the highest contribution of this will happen in winter. In other words, snow stored during January and February would be quickly melted due to increase in temperature in March, and increases the snowmelt runoff contribution of winter.

Also changes in land use and land cover increased absorption of temperature and accelerating the snow melting. On the other hand, decrease the snow accumulation for spring and decrease snowmelt runoff contribution from the rainfalls. So disturbed the balance between rain and snow and then decrease contribution of snowmelt runoff from the total. The results of Khadka *et al.* (2014) shows as well as changes in the contribution of snowmelt runoff during the decades of 2000 and 2050, but the changes are not significant.

CONCLUSIONS

The results obtained in this study indicate that the SRM model performed successfully for snowmelt-runoff simulation. The results of the study also indicate that rainfall would increase with 2.17 and 9.7 percent for the 2011-2030 and 2046-2065 periods, but rainfall would decrease in May, which is very essential for agriculture activates especially dry farming in the study area. Finally, monthly peak discharge under climate change scenarios in the

Beheshtabad watershed would decrease 10 and 26 percent for future periods (2011-2030 and 2046-2065) compared with base period (2001-2010). Therefore, all annual runoff would reduce during spring, which is crucial period for irrigation. In addition, monthly peak discharge in future periods compared with the base period is takes place a month earlier (from April to March) due to increase in temperature. These findings indicate impact of climate change on water resources and temporal distribution of water availability in the study area, which is important for water resources management planning.

ACKNOWLEDGMENTS

Hereby, many thanks go to Iran Water Resources Management for providing the rainfall, temperature and discharge data, and to the anonymous reviewers whose comments improved this manuscript.

REFERENCES

- Adnan M, Nabi G, Poomee MS, Ashraf A (2017) Snowmelt runoff prediction under changing climate in the Himalayan cryosphere: A case of Gilgit River Basin *Geoscience Frontiers* 8:941-949
- Ashraf B, Mousavi Baygi M, Kamali G, Davari K (2010) Prediction of water requirement of sugar beet during 2011–2030 by using simulated weather data with LARS-WG downscaling model *J Water Soil* 25:1184-1196
- Babaiya A, Najafinik Z (2006) Introducing and evaluation of Lars model for modeling of meteorological parameters in Khorasan province during 1961-2003 *Neyvar Magazine* 62:49-65
- Barovic, G., Leandro Naves Silva, M., Veloso Gomes Batista, P., Vujacic, D., Soares Souza, W., Cesar Avanzi, J., Behzadfar M., Spalevic, V. (2015) Estimation of sediment yield using the IntErO model in the S1-5 Watershed of the Shirindareh River Basin, Iran. *Agriculture and Forestry* (61): 3: 233-243
- Changchun X, Yaning C, Weihong L, Yapeng C, Hongtao G (2008) Potential impact of climate change on snow cover area in the Tarim River basin *Environmental Geology* 53:1465-1474
- Cline D, Elder K, Bales R (1998) Scale effects in a distributed snow water equivalence and snowmelt model for mountain basins *Hydrological Processes* 12:1527-1536
- Cline D, Elder K, Bales R (1998) Scale effects in a distributed snow water equivalence and snowmelt model for mountain basins *Hydrological Processes* 12:1527-1536
- Farzanmanesh R, Abdullah AM, Shakiba A, Amanollahi J (2012) Impact Assessment of Climate Change in Iran using LARS-WG Model *Pertanika Journal of Science & Technology* 20
- Ferguson R (1999) Snowmelt runoff models *Progress in Physical Geography* 23:205-227
- Fowler HJ, Blenkinsop S, Tebaldi C (2007) Linking climate change modelling to impacts studies: recent advances in downscaling techniques for hydrological modelling *International Journal of Climatology* 27:1547-1578
- Gent PR, McWilliams JC (1990) Isopycnal mixing in ocean circulation models *Journal of Physical Oceanography* 20:150-155
- Goodarzi E, Massah Bavani A, Dastorani M, Talebi A (2014) Evaluating effect of downscaling methods; change-factor and LARS-WG on surface runoff (A case study of Azam-Harat River basin, Iran) *Desert* 19:99-109

- Hall DK, Riggs GA, Salomonson VV, DiGirolamo NE, Bayr KJ (2002) MODIS snow-cover products Remote Sensing of Environment 83:181-194
- Hardy JT (2003) Climate change: causes, effects, and solutions. John Wiley & Sons,
- Hashmi MZ, Shamseldin AY, Melville BW (2011) Comparison of SDSM and LARS-WG for simulation and downscaling of extreme precipitation events in a watershed Stochastic Environmental Research and Risk Assessment 25:475-484
- Hassan Z, Shamsudin S, Harun S (2014) Application of SDSM and LARS-WG for simulating and downscaling of rainfall and temperature Theoretical and Applied Climatology 116:243-257
- Homan JW, Luce CH, McNamara JP, Glenn NF (2011) Improvement of distributed snowmelt energy balance modeling with MODIS-based NDSI-derived fractional snow-covered area data Hydrological Processes 25:650-660
- Homan JW, Luce CH, McNamara JP, Glenn NF (2011) Improvement of distributed snowmelt energy balance modeling with MODIS-based NDSI-derived fractional snow-covered area data Hydrological Processes 25:650-660
- Hreiche A, Najem W, Bocquillon C (2007) Hydrological impact simulations of climate change on Lebanese coastal rivers/Simulations des impacts hydrologiques du changement climatique sur les fleuves côtiers Libanais Hydrological Sciences Journal/Journal des Sciences Hydrologiques 52:1119-1133
- Huang S, Krysanova V, Hattermann F (2013) Projection of low flow conditions in Germany under climate change by combining three RCMs and a regional hydrological model Acta Geophysica 61:151-193
- Hugo AL (2003) Climate Change and Ground Water Journal of American Geographers 93:30-41.
- Khadka D, Babel MS, Shrestha S, Tripathi NK (2014) Climate change impact on glacier and snow melt and runoff in Tamakoshi basin in the Hindu Kush Himalayan (HKH) region Journal of Hydrology 511:49-60
- Khaledi Darvishan A., Behzadfar M., Spalevic V., Kalonde P., Ouallali A., Moutassime E. S., (2017) Calculation of sediment yield in the S2-1 watershed of the Shirindareh river basin, Iran, Agriculture and Forestry, 63 (3): 23-32. DOI: 10.17707/AgricultForest.63.3.03
- Li L, Simonovic S (2002) System dynamics model for predicting floods from snowmelt in North American prairie watersheds Hydrological Processes 16:2645-2666
- Ma H, Cheng G (2003) A test of Snowmelt Runoff Model (SRM) for the Gongnaisi River basin in the western Tianshan Mountains, China Chinese Science Bulletin 48:2253-2259
- Ma Y, Huang Y, Chen X, Li Y, Bao A (2013) Modelling snowmelt runoff under climate change scenarios in an ungauged mountainous watershed, Northwest China Mathematical Problems in Engineering 2013
- Mansouri B, Ahmadzadeh H, Bavani AM, Morid S, Delavar M, Lotfi S (2015) Assessment of Climate Change Impacts on Water Resources in Zarrinehrud Basin Using SWAT Model Iran Journal of Soil and Water 28:1203-1291
- Martinez J, Rango A, Roberts R (2008) SRM snowmelt runoff model user's manual In: Baumgartner MF, Apfl GM (eds) USDA Jornada Experimental Range, New Mexico State University, Las Cruces, NM, USA:177
- Massah Bavani A, Morid S (2005) Climate change effects on water resources and agricultural production Iran Water Resource Research 1:40-47.

- Modaresi F, Araghinejad S, Ebrahimi K, Kholghi M (2011) Assessment of Climate Change Effects on the Annual Water Yield of Rivers: A Case Study of Gorganroud River Iran *Journal of Water and Soil* 25:1365-1377.
- Nash JE, Sutcliffe JV (1970) River flow forecasting through conceptual models part I—A discussion of principles *Journal of Hydrology* 10:282-290
- Payne JT, Wood AW, Hamlet AF, Palmer RN, Lettenmaier DP (2004) Mitigating the effects of climate change on the water resources of the Columbia River basin *Climatic change* 62:233-256
- Rostamian R, Jaleh A, Afyuni M, Mousavi SF, Heidarpour M, Jalalian A, Abbaspour KC (2008) Application of a SWAT model for estimating runoff and sediment in two mountainous basins in central Iran *Hydrological Sciences Journal* 53:977-988
- Sayedi Elmabad M, Moradi HR, Ghanbarpour MR (2010) Estimation of Snowmelt Runoff Using IRS Satellite Data and Statistical Models (The Case Study: Zarinerood Basin) *Iranian Journal of Watershed Management Science and Engineering* 3:35-44.
- Semenov MA (2008) Simulation of extreme weather events by a stochastic weather generator *Climate Research* 35:203-212
- Semenov MA, Barrow EM (1997) Use of a stochastic weather generator in the development of climate change scenarios *Climatic Change* 35:397-414
- Semenov MA, Brooks RJ (1999) Spatial interpolation of the LARS-WG stochastic weather generator in Great Britain *Climate Research* 11:137-148
- Spalevic, V., Radanovic, D., Skataric, G., Billi, P., Barovic, G., Curovic, M., Sestras, P., and Khaledi Darvishan A. (2017) Ecological-economic (eco-eco) modelling in the mountainous river basins: Impact of land cover changes on soil erosion. *Agriculture and Forestry*, 63 (4): 9-25. DOI:10.17707/AgricultForest.63.4.01
- Stewart IT, Cayan DR, Dettinger MD (2004) Changes in snowmelt runoff timing in western North America under a business as usual climate change scenario *Climatic Change* 62:217-232
- Vafakhah M, Nouri A, Alavipanah SK (2015) Snowmelt-runoff estimation using radiation SRM model in Taleghan watershed *Environmental Earth Sciences* 73:993-1003
- Wang J, Li S (2006) Effect of climatic change on snowmelt runoffs in mountainous regions of inland rivers in Northwestern China *Science in China Series D: Earth Sciences* 49:881-888
- Zarghami M, Abdi A, Babaeian I, Hassanzadeh Y, Kanani R (2011) Impacts of climate change on runoffs in East Azerbaijan, Iran *Global and Planetary Change* 78:137-146