International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Downscaling of Climate Parameters under CanESM2 Model Based on Different Scenarios (Case Study: Qazvin Station)

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ABSTRACT

nowaday, with the increase of the world population, the use of fossil fuels, land use change, and groundwater shortage to meet the needs of the world's population have caused changes in the climate of the world. In a specific place or condition, climate change causes changes in atmospheric conditions and affects various factors directly and indirectly, and this disrupts the balance of the system, which is often caused by an increase in greenhouse gases, causing an increase in hydrological parameters such as evaporation and transpiration. In this article, the SDSM model has been used to predict climate change, which is based on the study data of the Qazvin station, which has long-term statistics. It has been downscaled and evaluated considering climate change scenarios for the year 2050. In this study, the temperature and precipitation of the Qazvin province basin for the period (2020-2050) were simulated and predicted using the CanESM2 climate model and the SDSM linear multiple model. The results showed an increase in temperature in all months and a decrease in annual precipitation in most months. In evaluating the results of different scenarios, the results indicated that the 2.6 scenario had the best prediction for minimum and maximum temperatures, but for precipitation, the best RCP 8.5 scenario showed better results.

Keywords: Downscaling, climate change, land usage

Introduction

One of the most discussed issues about drought is climate change. Humans have shown their role as one of the most effective factors in climate change to date. According to the Fourth Assessment Report of the Intergovernmental Panel of Climate Change (IPCC), global climate model projections for the twenty-first century show that global warming will continue to increase even if humans can curb greenhouse gas emissions. It is predicted that by the year 2100, the average global temperature change will increase from 4.8 degrees to 1 degree Celsius and the average sea level will rise between 3.48 and 3.52 meters. For climate systems on a global scale, models called GCMs are used, which mathematically simulate the physical behavior of the Earth, atmosphere, and ocean systems. Downscaling refers to the process of moving from large-scale predictors to local-scale predictors. Even if global climate models are run with high technical power to predict the future, there is a need to downscale the results of these models to station scales (“2018. Journal of Saffron Research). Downscaling techniques provide us with information about the watershed at a smaller scale. Downscaling is done in two ways: dynamic downscaling and statistical downscaling. The SDSM model is one of the statistical downscaling models. The statistical downscaling model SDSM was developed by Wilby et al. as a tool for statistical downscaling (Wilby, Dawson, and Barrow 2002). This model is based on multivariate regression and predicts climate parameters such as precipitation and temperature in the long term according to large-scale climate signals (NCEP variables). Since the statistical downscaling model is constructed using a combination of two probabilistic and regression methods, it is one of the best models for various classifications (Wilby, Dawson, and Barrow 2002). So far, the SDSM model has been used in many cases for downscaling in water resources studies [3,4,5,6]. Many studies have been done on SDSM, of which we mention a few examples: In one study, the statistical model (SDSM) was simulated and predicted for the background temperature, minimum and precipitation in Neyshabur watershed using two statistical and graphical methods. Using the HadCM3 and CGCM1 models, the results showed that in the three studied periods, the average precipitation decreased by 6, 10, and 17 mm compared to the base period (Yousefi et al. 2018). The meteorological drought of Yazd province was evaluated based on the output of the CanESM2 model by SPI and SPEI indices, and the results showed that more severe droughts will occur in the future (Mesbahzadeh et al. 2020). The SDSM model was applied to the observational data of daily temperature and precipitation from 1981 to 2006 using the global HadCM3 model, and the results showed that the downscaled temperature and precipitation data were almost consistent with the observed data. Nury and Alam 2014 studied the effect of climate change on the meteorological and hydrological parameters of the Ghezel Ozan watershed in Zanjan province. They compared the monthly precipitation and temperature regimes obtained from the HadCM3 model under two climate scenarios A2 and B1 with observational data. The results of the approximate prediction of meteorological and hydrological parameters until 2057 AD showed a decrease in the average annual precipitation of about 21 mm, an increase in the average annual temperature of about 2.5 degrees Celsius, and a decrease in the average annual runoff of about 10 cubic meters per second compared to the average of the observation period (1972-1999) (Mohammadi, Mehdinejad, and Amiraslani 2010). In an article, they examined the impact of climate change on the severity-duration-frequency curves of drought in the Qarasu basin using detailed functions. The results showed that the monthly precipitation and temperature variables in the basin generally decrease and increase respectively in the future period under different scenarios, and in the base period, the return period of a drought event with a severity level of 11 and a duration equal to or less than 2 months is 5 years. The return period of the same drought event under RCP2.6, RCP4.5, and RCP8.5 scenarios is 21, 17, and 4 years, respectively (Azizabadi Farahani et al. 2016). Future changes in extreme temperatures have been studied using the Statistical Downscaling Model (SDSM) in the transboundary region of the Chelom River Basin Mahmood and Babel 2014 in a study titled modeling spatial changes in climate elements case study: Annual Precipitation in Isfahan province, spatial changes in annual precipitation in Isfahan province have been investigated based on three factors: latitude, longitude, and altitude. Since there is a linear relationship between latitude and longitude and altitude, part of the precipitation variance is jointly explained by three factors. Therefore, to achieve overlapping variance and eliminate collinearity, the ridge regression method has been used to explain spatial variability (Asakereh 2004). In a study, four global models were examined in the Karkheh watershed. The results showed that the reanalyzed data of the HadCM3 model and the geopotential at an altitude of 500 hectopascals are the best reanalyzed data and independent variable for downscaling precipitation and temperature, respectively [9,10]. Jahangir and Sadatinejad according to the studies conducted, showed that the SDSM model predicts the minimum and maximum temperatures well and is a suitable model for downscaling the temperature climatic parameters for the Lar synoptic station. According to the outputs of the CanEMS2 model, in each scenario (2.6RCP, 4.5RCP, 8.5RCP) and all three periods (S2020, S2050, S2070), the minimum and maximum temperatures have increased (Mohammad Hossein Jahangir, Seyyed Javad Sadatinejad, and Parsa Haghighi 2018).

Innovation

In this article, the aim is to use a microscale model to predict climate parameters for Qazvin province for the coming years. This will help us to take better measures in the drought management process. SDSM is used as a software to predict parameters, which are predicted using the CanESM2 model under three RCP scenarios.

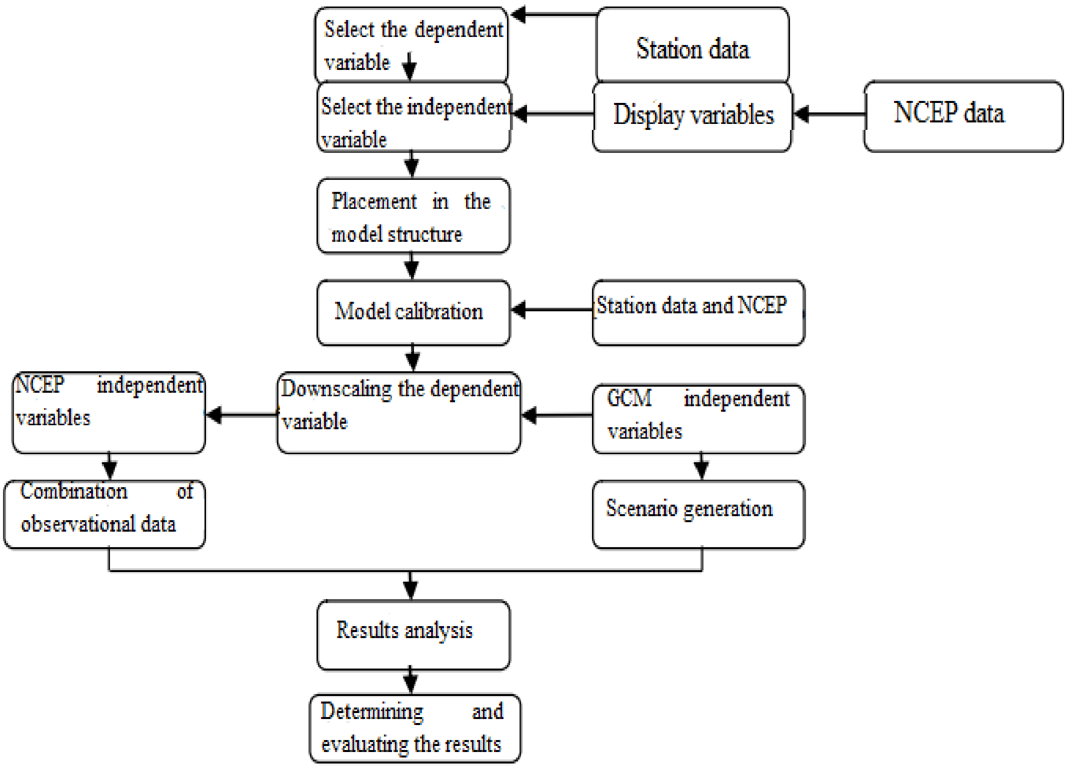

Figure 1. SDSM model climate scenario scaling and generation process (Maryam Rezaei et al. 2014)

Materials and Methods

Location of the Study Area

The present study is conducted at the Qazvin station with 40 years of data (1965-2005) of three parameters: daily precipitation, average temperature, and maximum temperature. Qazvin province, which is located in the central basin of Iran with an area of 15,821 square kilometers between 48 degrees and 45 minutes to 50 degrees and 50 minutes east longitude and 35 degrees and 37 minutes to 36 degrees and 5 minutes north latitude. (Figure 1). (Bagheri et al. 2022) It is limited to Mazandaran and Gilan provinces from the north, Hamadan and Zanjan provinces from the west, Markazi province from the south, and Tehran province from the east. According to the report of the General Meteorological Department of Qazvin Province, the average annual rainfall in the province varies from 210 mm in the eastern parts to more than 550 mm in the northeastern heights, and the lines of precipitation are more or less parallel to the horizontal lines. The rainiest points in the province are the northeastern slopes in the Alamut region with rainfall of more than 550 mm, which is more or less visible in the northern highlands of Qazvin County. In addition, in the southwestern heights of the province (Avaj region), we also encounter areas with annual rainfall of more than 450 mm. Similarly, the driest areas of the province start from the southeast of the province and the desert areas of Buin Zahra and extend to the southern parts of Takestan County, which experience annual rainfall between 210 and 230 mm. In the northwestern regions of the province, a trend of decreasing rainfall due to decreasing altitude has also been evident, such that by reaching the Lushan and Manjil regions outside the province, the rainfall reaches 210 mm. According to the Amberge climate classification method, the climate of this region is arid and semi-arid. The altitude of the studied region is between 1100 and 2971 meters.

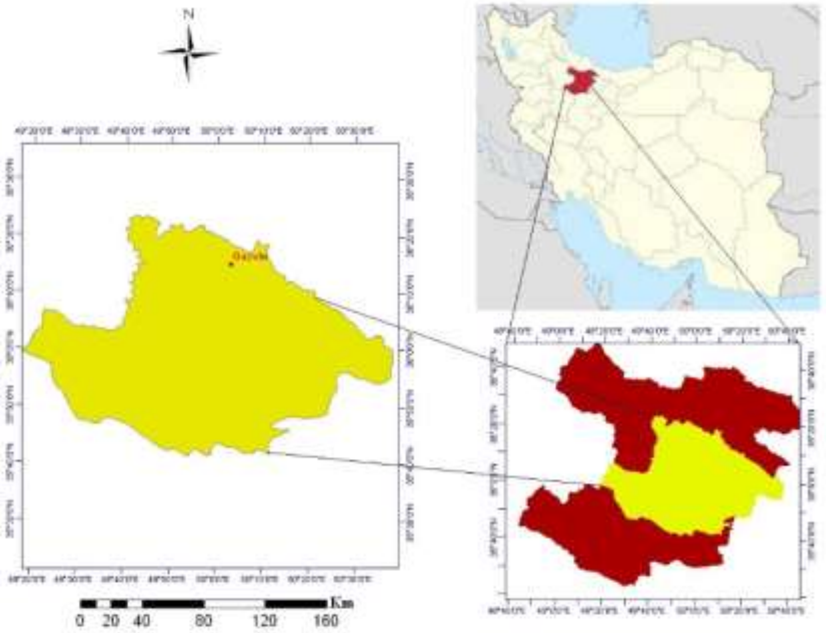

Figure 2. Geographical location of Qazvin

General Circulation Models (GCMs)

General circulation models (GCMs) provide the best information about the response of the atmosphere to increasing greenhouse gas concentrations. These models are time-dependent and provide three-dimensional numerical simulations of atmospheric motion, heat exchange, and interactions between ice, ocean, and land.

Results

Exponential Downscaling by SDSM Model

The SDSM model is a statistical downscaling model that has the ability to rapidly develop downscaled data at the station scale on a daily, monthly, seasonal or annual basis. The SDSM model uses regression statistical methods for downscaling operations. In this model, first the relationships between predictors (output of the general circulation model) and predictors (historical data from the meteorological station) are examined and analyzed, and the empirical relationships between them are determined. In the next step, the model is calibrated according to the variables selected by the user, and then the calibrated model is validated by generating historical data and comparing them with observational data. If the calibrations are correct, the model produces climate data for the future.

The statistical downscaling process in this model is carried out in the following steps:

1) Initial assessment of the microscale exponential capability using predictor variables (largescale),

2) Calibration of the microscaling model. The largescale variables introduced in step 1 are used to determine the multivariate linear correlation relationships.

3) Generation of several series of the current climate state using the observational predictors. Immediately after the statistical model is designed, it can be evaluated. The SDSM random component can generate different series of simulated data (up to 100 series) that have the same statistical characteristics; but the daily values of each series are different from each other.

4) Generation of different series of meteorological data using the GCM predictor variables. These data series are obtained using the multivariate linear regression statistical relationships obtained from step 2,

5) The final stage is the analysis of the predicted data (climate change scenarios) and observations. At this stage, the statistical characteristics of the climate change scenario can be compared and analyzed with the observational behavior of the station.

In this study, the period (1965-2005) was selected as the base period for downscaling and the production of climate data (precipitation, minimum temperature, maximum temperature) in three RCP scenarios (8.5, 4.5, 2.6) was carried out. Finally, in order to evaluate and compare the accuracy of the methods and model scenarios used and to identify the best scenario for predicting temperature and precipitation, the criteria of Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) were compared.

$$MAE = \frac{\sum_{i=1}^{n} |y_{i}-x_i|}{n}$$

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(\bar{Y} - x_i)^2}{n}}$$

$$NS = 1 - (\frac{\sum_{i=1}^{n}(o_i - p_i)^2}{\sum_{i=1}^{n}(o_i - \bar{o}_i)^2}$$

Isaacs and Srivastava suggested that RMSE and MAE can be used as a criterion that includes both the characteristics of deviation and accuracy of estimation to compare the accuracy of different factors. The lower the RMSE and MAE, the more efficient the model is in estimating temperature and precipitation parameters. The accuracy of the model is determined by MAE, whose value of zero indicates 100% accuracy, and the further away from zero its value indicates the decrease in the accuracy of the model.

Table 1. CanESM2 model simulation criteria based on different scenarios

	RCP 8.5			RCP4.5			RCP2.6		
Variable	NS	RMSE	MAE	NS	RMSE	MAE	NS	RMSE	MAE
Maximum temperature	0.969	0.451	1.191	0.933	0.475	1.393	0.971	0.480	1.187
Minimum temperature	0.971	0.456	1.198	0.928	0.457	1.314	0.969	0.483	1.171
Rainfall	0.829	1.615	4.005	0.771	1.88	4.294	0.735	2.013	4.733

Discussion and Conclusion

The annual standard rainfall index chart of the station in question was drawn. The results show that the lowest rainfall was in 1985 and the highest rainfall was in 1992.

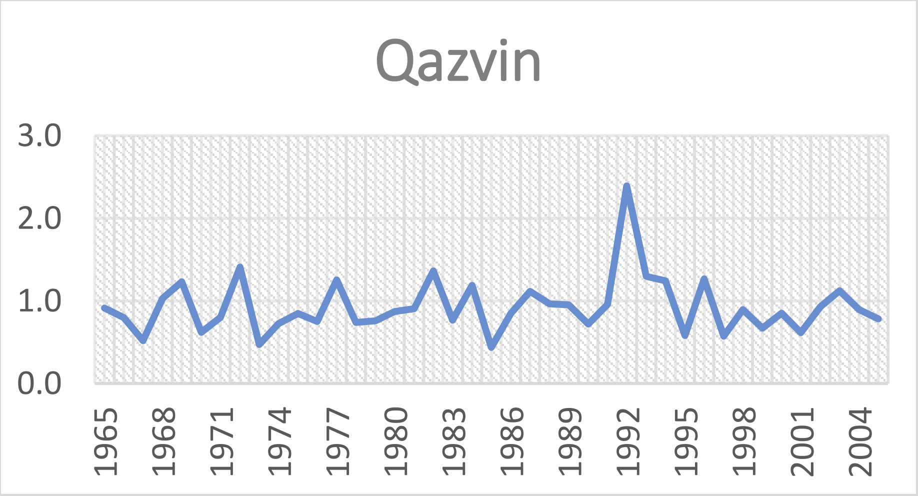

Chart 1. 40 year rainfall in Qazvin province

The results of downscaling in the period (1965-2005)

According to the observational data and Table 1 show that the temperature scenario 2.6 is correlated, but in precipitation the RCP8/5 scenario has the highest correlation with our data.

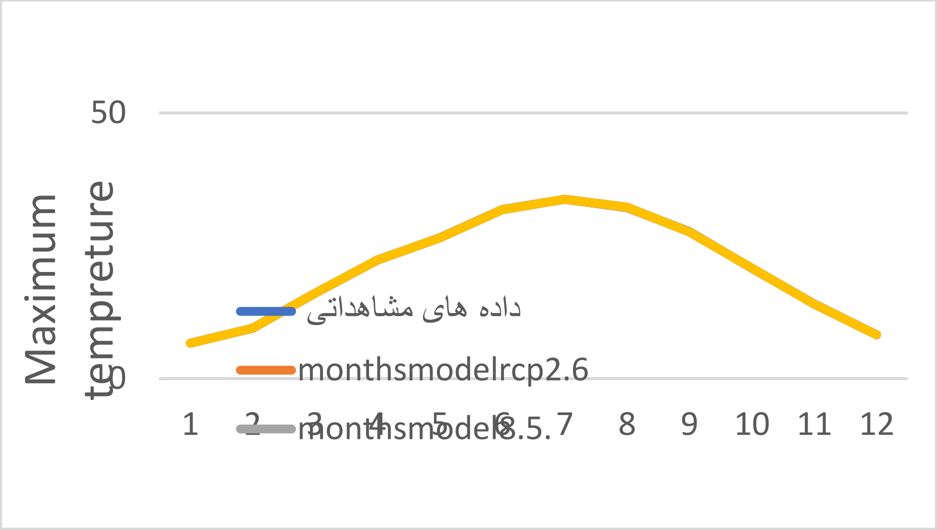

Chart 2. Maximum temperature and observational data for the period (1965-2005)

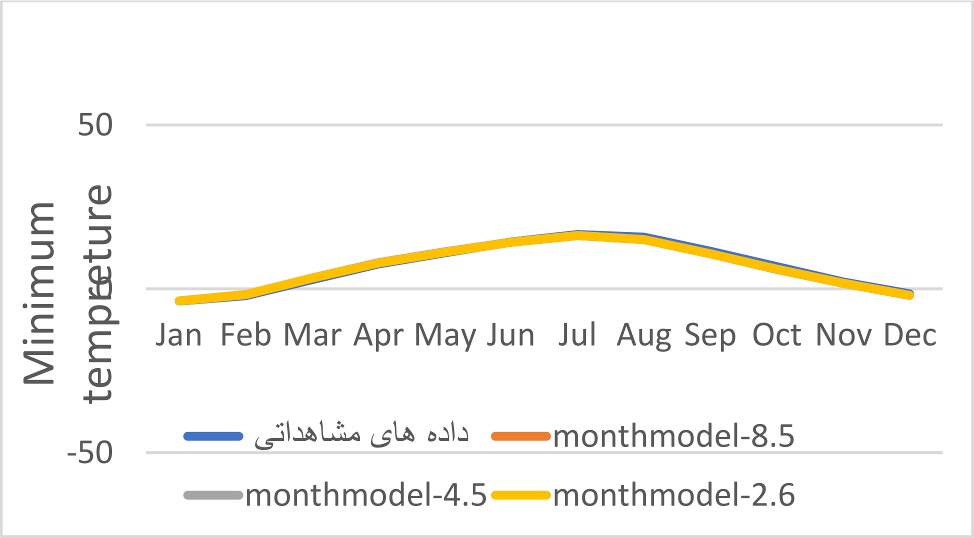

Chart 3. Minimum temperature and observational data for the period (1965-2005)

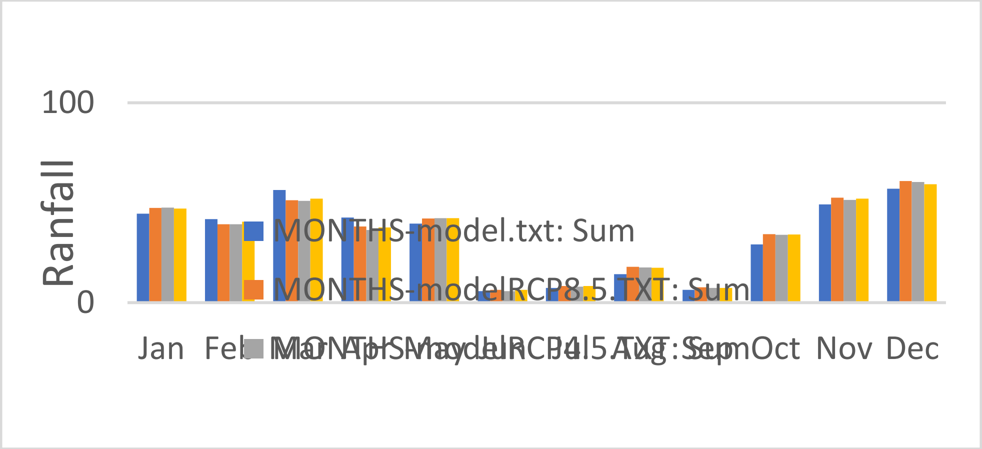

Chart 4. Precipitation and observational data for the period (1965-2005)

Simulation results in the period (2020-2050)

The simulation results of the minimum and maximum temperatures of the basin in the period (2020-2050) indicate that they reached their maximum in June and July and then decreased. Among the different scenarios, the RCP 8.5 scenario has the highest correlation with the other scenarios.

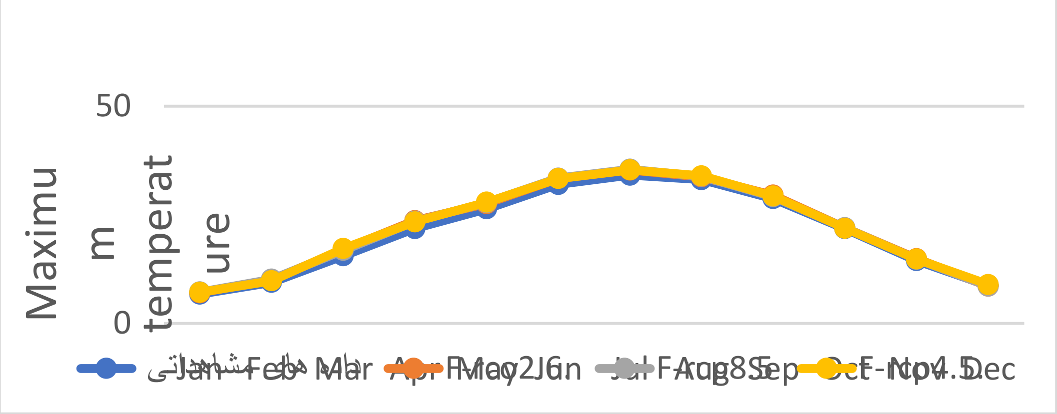

Chart 5: Simulated maximum temperatures in the period (2020-2050)

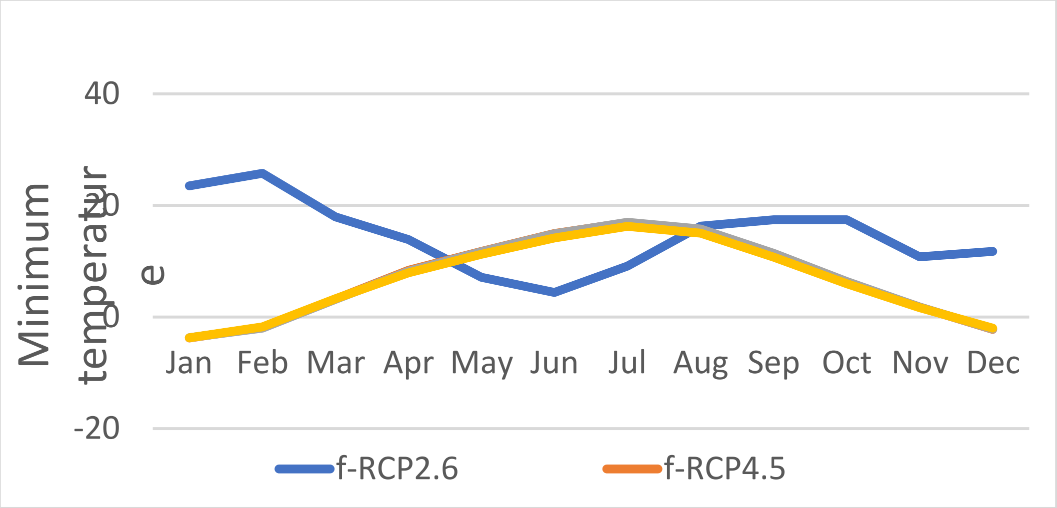

Chart 6. Simulated minimum temperature in the period (2020-2050)

The results of the precipitation simulation show that the months of June and September have the least precipitation, with the greatest decrease occurring in June, and the summer season experiences the least precipitation.

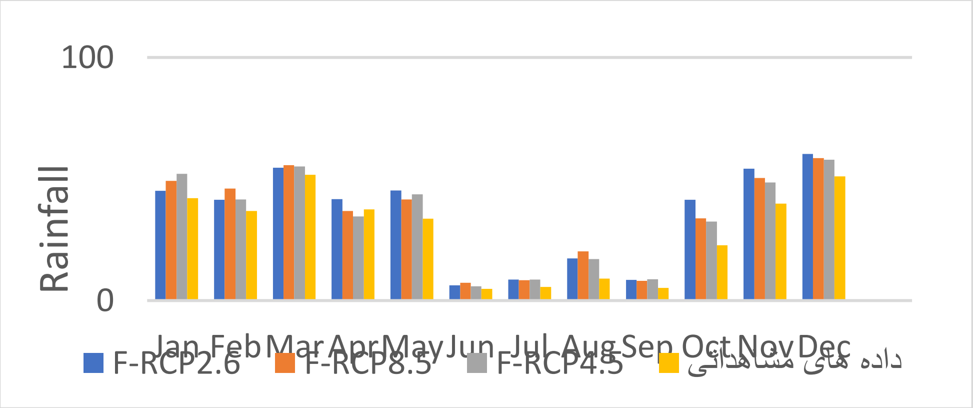

Chart 7. Simulated rainfall in the period (2020-2050)

Conclusion

In this study, the climatic variables of temperature and precipitation in the Qazvin province basin were simulated using the CanESM2 atmospheric general circulation model based on three scenarios: 6.RCP2, 5.RCP4, and 5.RCP8 and the SDSM exponential downscaling model for two periods (1965-2005) in order to validate and simulate the period (2020-2050). The results indicated that the SDSM model performed well in simulating temperature and precipitation, but temperature data had a greater correlation than precipitation, which was due to the conditional nature of precipitation and the unconditional nature of temperature. The simulation results for the period (1965-2005) showed an increase in temperature in all months and a decrease in precipitation in most months.

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