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Assessing the Effects of Climate Change on Temperature and Precipitation using CMIP6 models (case study: Damghan, Iran)

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Abstract

Nowadays, one of the most fundamental challenges for human society and the natural environment is climate change. Human activities play an important role in increasing the temperature in different temporal-spatial scales. In this research, the sixth report scenarios of climate change by IPCC were used to evaluate the effects of climate change on the Temperature and Precipitation in Damghan, Iran. Climate change occurrence was predicted using the HadGEM3 and CanESM5 models under the SSP126, SSP245, and SSP585 scenarios. The rainfall data from the Damghan synoptic meteorological station and Damghan rain gauge station have been used for calibration and validation for the 2000-2020 period. Then, a prediction was made for the 2020-2040 period. To predict the future temperatures (2020-2040), minimum and maximum temperature data from the Damghan synoptic station was used. LARS-WG6 software was applied for the statistical downscaling of climatic data. Then, using the predicted temperatures and rainfall under the climate change scenarios, the outflow intensity and pollution load of the reservoir water for 2020-2040 was presented. Considering the increase in the pollution load in some seasons and months and the downstream use of water, the construction of a water treatment plant and prevention of pollutants from entering the urban drinking water network is suggested. If management methods are planned and applied, the water quality of the dam reservoir can be improved.

1. Introduction

Climate change is defined as a sustained modification of the mean weather patterns or fluctuations that lasts for multiple decades or longer and is distinguished by a statistically significant difference (Milentijević et al., 2022). Temperature change is an obvious indicator of climate change (Kwawuvi et al., 2023). The average global surface temperature has risen by 0.71 °C in the last century (Sun et al., 2021). Based on simulations from multiple climate models, it is predicted that global temperatures could increase by 2.0˚C to 2.4˚Cabove pre-industrial levels by the end of the twenty-first century (Kikstra et al., 2022).

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Goodarzi et al. (2022) conducted a study in Gilan to statistically downscale precipitation and temperature data using the LARS-WG model under diffusion scenarios of SSP119, SSP434, and SSP585. The results indicate that the most critical case is related to the CanESM5 model under the SSP585 scenario at minimum and maximum temperatures, with an average increase of 4˚C for both stations.

During recent decades, due to the industrialization of societies, deforestation, environmental degradation, land use changes, and the increase in world population, the emission of greenhouse gases, especially CO2, has increased. The release of these gases has upset the earth's energy balance. With the increase in greenhouse gases, the earth's atmosphere is getting warmer, which is called global warming.

Global warming affects the state of other components of the climate system (Khayat et al., 2020). The increase in temperature, along with future changes in precipitation patterns on a local to regional scale, will be very variable (Mendez et al., 2020). The first step in investigating the effects of climate change is to assess the effect of this phenomenon on climatic parameters (Node Farahani et al., 2018). According to the Intergovernmental Panel on Climate Change (IPCC) report, the average global temperature will increase by 1.5 °C by the end of this century (Allen et al., 2019). Changes in the air temperature will lead to serious changes in the amount of surface energy (Andrews et al., 2009), evaporation and transpiration (Dinpashoh et al., 2019), sea level rise (Nerem et al., 2018), and climate change (Nie et al., 2020), and also increase the risks of problems related to public health (Sellers et al., 2019).

According to the IPCC reports, the recent warming of the climate system has caused deviations in the average behavior of various atmospheric parameters, such as temperature and precipitation. Global warming and significant changes in temperature and precipitation in different parts of the world are the most important manifestations of climate change. They can be a great threat to water resource systems. Studies conducted in this field in recent years have shown that significant climate changes have occurred in many regions of the world, which have affected the quantity and quality of water resources (Nazari-Sharabian and Taheriyoun, 2022).

Due to these changes, the possibility of severe droughts and floods, as well as other extreme climatological events, has increased too.

It is important to note that investigating the effects of climate change depends on the output of the climate models (Chen et al., 2019). In this regard, to determine the climatic situation, it is necessary to use climate scenarios. The most reliable tool for producing climate scenarios is the atmospheric-ocean general circulation models (Bazrafshan Moghaddam and Golian, 2016). Steele-Dunne et al. (2008) studied the impact of climate change on runoff by using the ECHAM5 general circulation model (GCM) and the A1B emission scenario. The rainfall-runoff conceptual model was used to investigate the river flow situation during 2010-2060. It was concluded that rainfall will increase in the winter and decrease in the summer. Also, the river flow rate will change under these conditions. A study by Chen et al. (2013) was conducted to predict temperature and precipitation for the coming years in a part of Sudan. This study was conducted for the 2011-2030, 2046-2065, and 2080-2099 periods under the output of 7 GCMs, an A2 scenario, and using the LARS-WG downscaling model. One of the most important results was observing the increasing trend of minimum and maximum temperatures. The predicted precipitations also had a decreasing trend in all 7 GCMs. Significant uncertainty was observed in the GCMs' results.

Hassanzadeh et al. (2012) predicted the impact of climate change on river flow in the Urmia

Lake basin for the period of 2010-2100. To predict meteorological parameters, HadCM3 atmospheric GCM was used. Temperature and precipitation data were downscaled and recalibrated using the LARS-WG model and observational data. The results showed an increase in temperature and a decrease in precipitation during the studied period. Eghtetaf et al. (2015) have investigated the effects of climate change on the quantity and quality of surface water resources in the Bali Khali Chai River, Ardabil Province, Iran. In this research, by using the LARS-WG downscaling model, the outputs of the HadCM3 model under the A2 scenario at the basin level were examined in the time frames of 2011–2030, 2045–2065, and 2080–2099. Results indicate a 5 °C increase in temperature and a 14 mm decrease in the average annual precipitation during 2080–2099. The use of an artificial neural network indicates a decrease of 11, 13, and 17 percent of the runoff entering the dam reservoir in the study periods. Also, TDS and EC values will increase by 3%. The final result indicates the need for stronger management of surface water resources as well as the application of appropriate policies in the coming years.

In order to determine the influence of climate change on the amount and intensity of rainfall on the southern coasts of the Caspian Sea, Zarrin et al. (2021) predicted the rainfall components in three periods: 2011–2030, 2046–2065, and 2080–2099, using the LARS-WG downscaling model under the A1B scenario. According to the results, it is expected to see an increase in rainfall in the winter season and a decrease in the summer season. The amount of runoff, infiltration, soil erosion, and sediment rate are among the parameters that would be affected by the intensification of rainfall events, and therefore the resulting consequences need to be planned.

2. Material and methods

2.1. Study area

Shahid Shahcheraghi Dam is built on the Cheshmeh Ali River, 12 kilometers northwest of Damghan City, Semnan Province, Iran. The Cheshmeh Ali watershed is composed of two sub-basins, Damghanroud and Astaneh. The Cheshmeh Ali River is the most important perennial river in the region. One of the main goals of building this dam is to control floods, store surplus water in non-agricultural seasons, and use it at other times of the year. Shahid Shahcheraghi Dam is an embankment gravel type with an impermeable clay core. The maximum normal water level of its reservoir is 1320.5 m above mean sea level (a.m.s.l.), and considering the freeboard of 4 m, the dam crest elevation is equal to 1324.5 m a.m.s.l.. The top dam crest width is 10 m, and its crest length is 445 m. The characteristics of the catchment area of the dam are presented in Table 1. Information about the Damghan weather station is shown in Table 2.

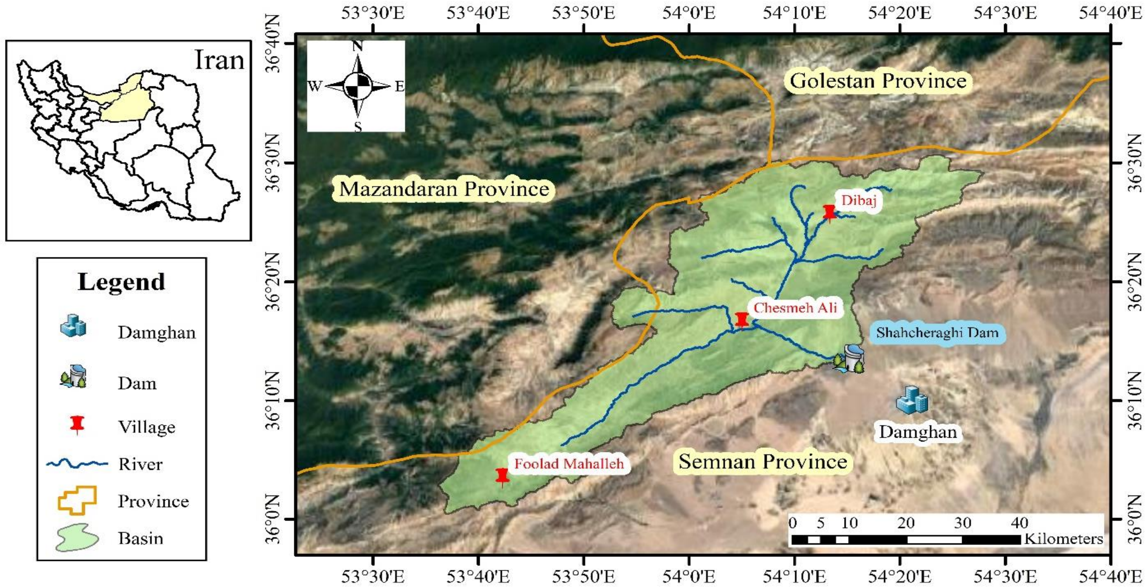

Figure 1. The of study area and location Shahid Shahcheraghi Dam.

Table 1. Characteristics of Shahid Shahcheraghi Dam catchment.

Catchment area	1378 km^2
Highest point of the catchment	3700 m amsl
Lowest point of the catchment	1273 m amsl
Average annual rainfall	185 mm
Average annual evaporation	1800 mm
Probable maximum precipitation (PMP)	200 mm
1000-year flood	427 m^3/s, equivalent to 27 MCM
10000-year flood	746 m^3/s, equivalent to 60 MCM
Probable maximum flood (PMF)	1270 m^3/s
Average dam discharge	1.03 m^3/s
50-year sediment volume	8.2 MCM

Table2. Average temperature and precipitation of Damghan station.

Parameter / **Month**	**Tmax (°C)**	**Tmin (°C)**	**Tm (°C)**	**Rain 24 hr (mm)**
January	8.25	-1.67	3.81	5.53
February	11.24	0.85	6.63	9.23
March	17.81	5.78	12.64	12.4
April	23.45	10.76	18.18	10
May	29.66	16.23	24.26	5.07
June	34.62	20.32	28.90	3.56
July	36.81	22.86	31.14	1.49
August	35.20	21.27	29.66	1.29
September	31.50	17.72	25.85	3.51
October	24.90	12.20	19.46	2.81
November	15.48	4.87	10.75	5.77
December	9.23	-0.44	4.89	5.34

In this research, the meteorological parameters of temperature and rainfall in the period 2020-2040 were obtained using HadGEM3 and CanESM5 models. Due to the large scale of this information, the output of these models cannot be used directly for the basin scale. Therefore, it is necessary to convert their output to the basin scale using downscaling models. For this purpose, the LARS-WG6 model was used to downscale these data.

Different statistical performance indicators can be used as measures for assessing the ability of GCMs to simulate the observed data. In the present study, two performance indicators are used: Root Mean Square Deviation (RMSD), R-squared correlation(R2).

$$RMSD = \sqrt{\frac{1}{T}\sum_{I=1}^{T}(y_i - x_i)^2} \quad (1)$$

$$R^2 = \left[\frac{\sum_{i=1}^{T}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{T}(x_i - \bar{x})^2 \sqrt{\sum_{i=1}^{T}(y_i - \bar{y})^2}}}\right]^2 \quad (2)$$

In order to investigate the effect of the climate change, the sixth-generation scenarios of IPCC have been used in this research. The models were run with LARS-WG6 software under the SSP126, SSP245, and SSP585 scenarios. The emission scenarios used in this research have the following characteristics:

1) SSP126 scenario (pessimistic): This scenario includes a world in which countries act independently and are self-reliant, the world's population increases steadily, and economic development is regionally oriented.

2) SSP245 scenario (balanced): Based on this scenario, a unified and convergent world with population growth in the middle of the century (2050) and a gradual decline after that is similar to scenario A1 of the fourth IPCC report. In this scenario, economic issues take precedence over environmental issues, and the views are generally global.

3) SSP585 scenario (optimistic): The universe is considered unified. The increase of social and cultural interactions in the world, rapid economic growth, rapid expansion of new and efficient technologies, and the increase of the world population to 9 billion in 2050 and then its gradual decrease are the characteristics of this scenario.

In climate change research, it is necessary to know the base-period data. In this regard, daily values of precipitation and temperature in the statistical period of 2002 to 2020 were used for selected stations of the basin (i.e., Damghan rain gauge and Damghan synoptic stations).

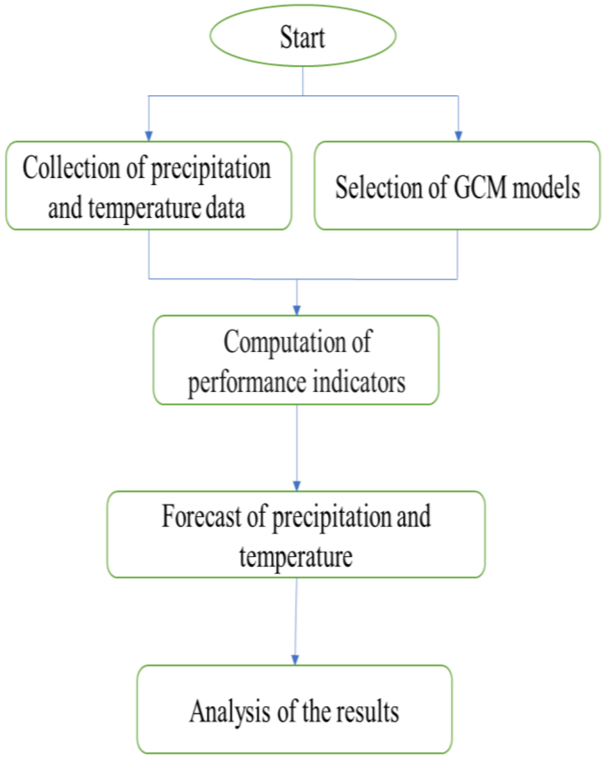

Figure 2. The research process flowchart.

2.2. Checking and analyzing the results

The first step in assessing the effects of climate change is to examine historical data. It is intended to determine whether there is an effect of climate change on past climatic and hydrological parameters. If a change is observed in precipitation and temperature, it is possible to produce scenarios for the occurrence of changes in the future by examining the causes of these changes. In this study, the capability of CMIP6 AGCM was evaluated in the prediction of meteorological parameters by examining the changes in average monthly temperature and precipitation from 2020 to 2040 under the three scenarios of SSP126, SSP245 and SSP585.

3. Results and discussion

3.1. Rainfall prediction

The results of the statistical performance indicators of GCM models for precipitation and temperature are presented in Table 3.

Table 3. The statistical indices of the GCM models for precipitation data.

Parameter	Model	Index	
		RMSD	R^2
Precipitation	CanESM5	18	0.86
	HadGEM3	23	0.87
Minimum Temperature	CanESM5	2.4	0.88
	HadGEM3	3.6	0.86
Maximum Temperature	CanESM5	2.2	0.91
	HadGEM3	3.2	0.87

According to Figures 3 to 5, rainfall under the three scenarios of the CanESM5 model of the Damghan synoptic station had the highest increase in December and also increased in January in all three scenarios. In March and June, there has been a decrease in rainfall. In some months, such as July and August, no great changes are observed.

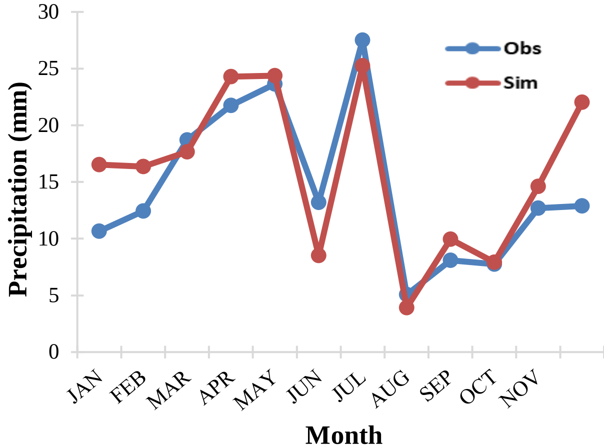

Figure 3. Evaluation results of the SSP126 scenario of the CanESM5 model for rainfall for Damghan synoptic station.

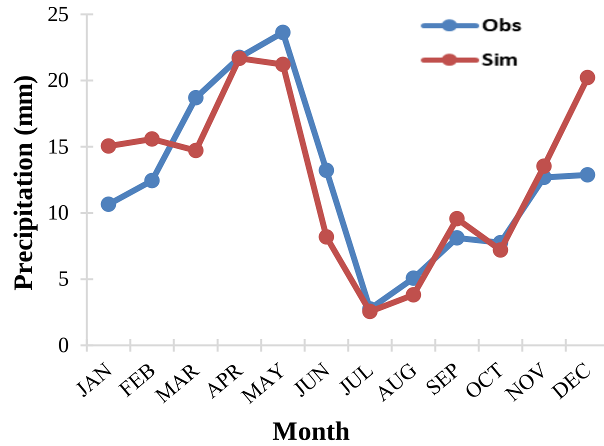

Figure 4. Evaluation results of the SSP245 scenario of the CanESM5 model for rainfall for Damghan synoptic station.

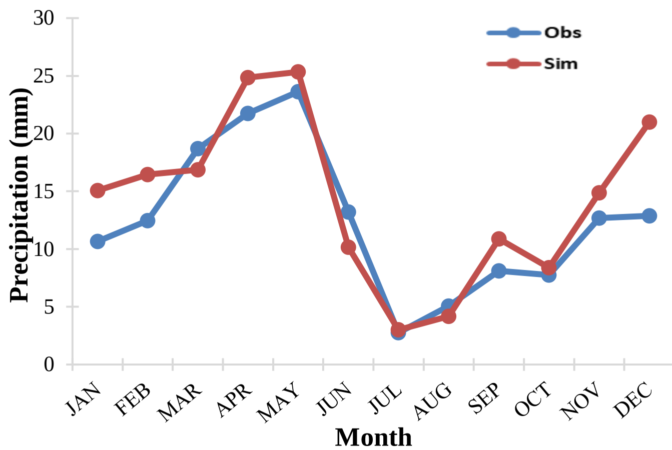

Figure 5. Evaluation results of the SSP585 scenario of the CanESM5 model for rainfall for Damghan synoptic station.

According to Figures 6 to 8, the effects of the three HadGEM3 model scenarios in December and April are obvious in all three cases. In January, February, and November, there is an increase in rainfall. Not much change has occurred in September and October. In all three scenarios, a decrease in rainfall was observed in June. Results show that the changes in the HadGEM3 model are greater than those in the CanESM5 model. Also, the highest amount of change is related to the SSP126 scenario.

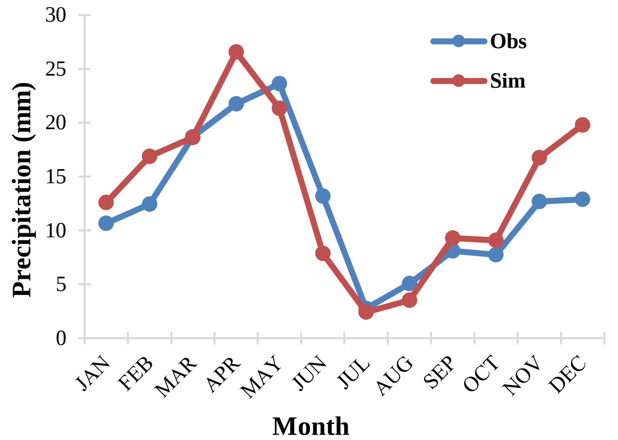

Figure 6. Evaluation results of the SSP126 scenario of the HadGEM3 model for rainfall for Damghan synoptic station.

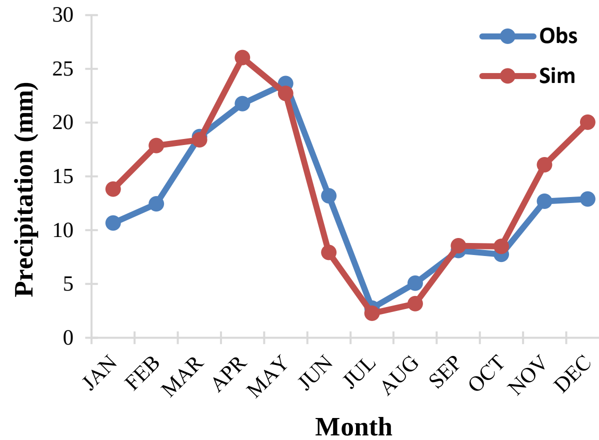

Figure 7. Evaluation results of the SSP245 scenario of the HadGEM3 model for rainfall for Damghan synoptic station.

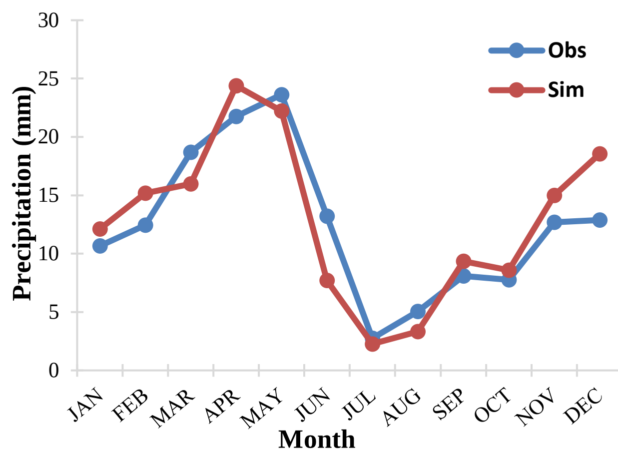

Figure 8. Evaluation results of the SSP585 scenario of the HadGEM3 model for rainfall for Damghan synoptic station.

In Figures 9 to 11, the outputs of the CanECM5 model under the three scenarios indicate that there is a significant increase in rainfall at the Damghan rain gauge station in May. In other months, such as January, October, and December, the rainfall trend is increasing too. In June and April, there is a decrease in rainfall.

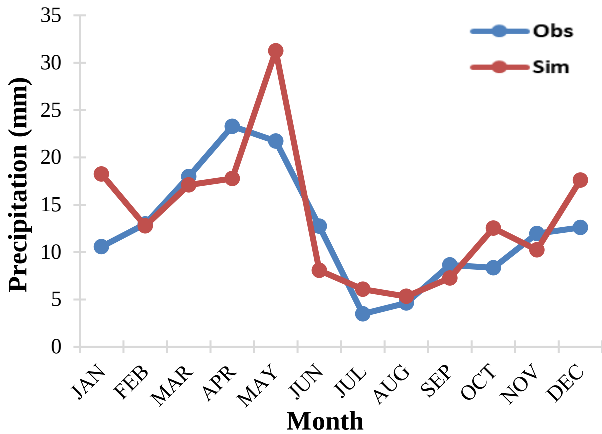

Figure 9. Evaluation results of the SSP126 scenario of the CanESM5 model for rainfall for Damghan rain gauge station.

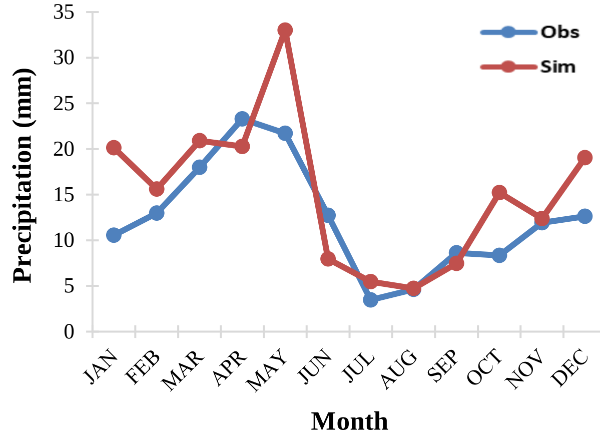

Figure 10. Evaluation results of the SSP245 scenario of the CanESM5 model for rainfall for Damghan rain gauge station.

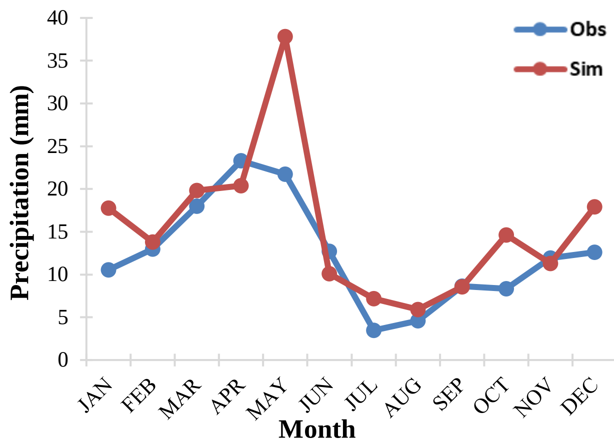

Figure 11. Evaluation results of the SSP585 scenario of the CanESM5 model for rainfall for Damghan rain gauge station.

Figures 12 to 14 illustrate that HadGEM3 and CanESM5 models produce similar results. From the closeness of the output of both models, it can be inferred that the obtained results and answers have high reliability. Therefore, these answers can be cited more definitively.

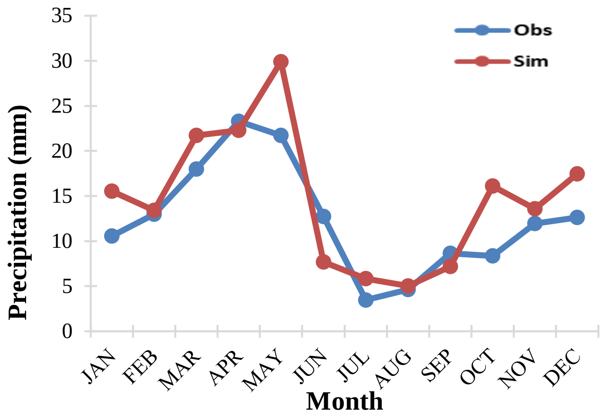

Figure 12. Evaluation results of the SSP126 scenario of the HadGEM3 model for rainfall for Damghan rain gauge station.

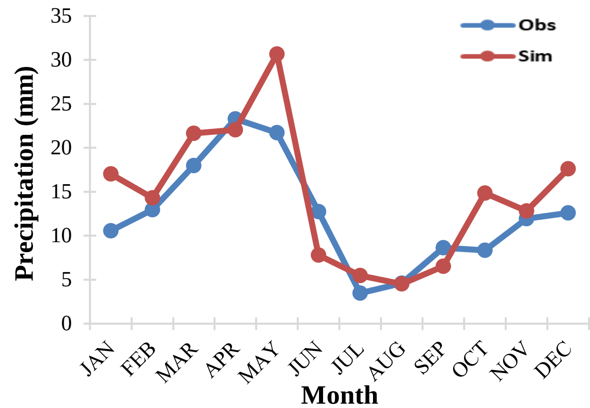

Figure 13. Evaluation results of the SSP245 scenario of the HadGEM3 model for rainfall for Damghan rain gauge station.

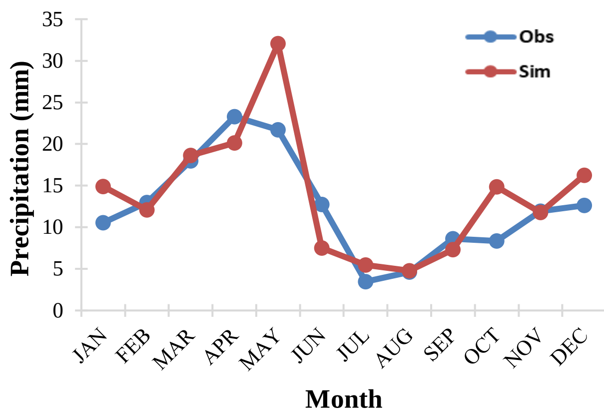

Figure 14. Evaluation results of the SSP585 scenario of the HadGEM3 model for rainfall for Damghan rain gauge station.

3.2. Minimum and maximum temperature prediction

Figures 15 to 18 show the trend of minimum and maximum temperature changes for the 202–2040period based on the CanESM5 and HadGEM3 models under the three emission scenarios of SSP126, SSP245 and SSP585. As can be seen in these figures, the temperature will change throughout the studied future period.

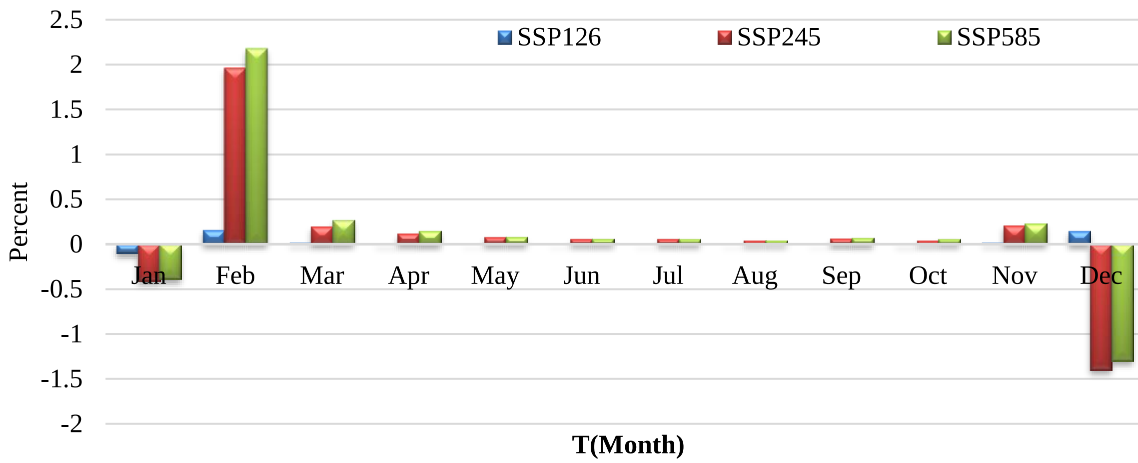

Figure 15. Evaluation results of the minimum temperature by CanESM5 model under different emission scenarios in the 2020-2040 period for Damghan synoptic station.

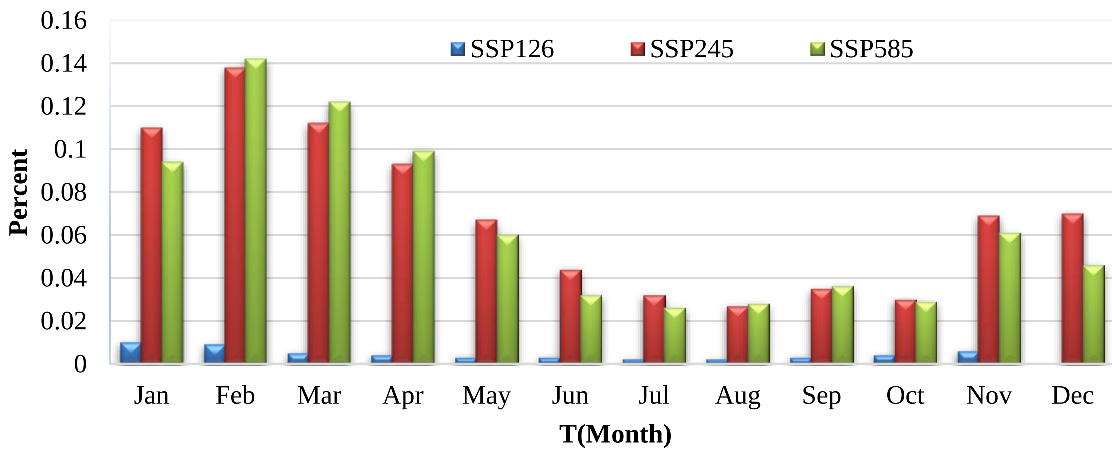

Figure 16. Evaluation results of the maximum temperature by CanESM5 model under different emission scenarios in the 2020-2040 period for Damghan synoptic station.

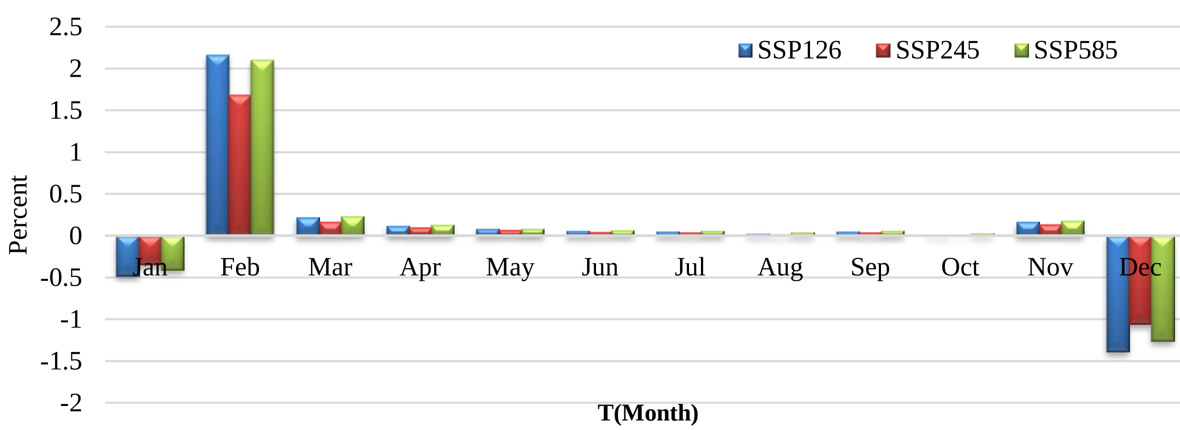

Figure 17. Evaluation results of the minimum temperature by HadGEM3 model under different emission scenarios in the 2020-2040 period for Damghan synoptic station.

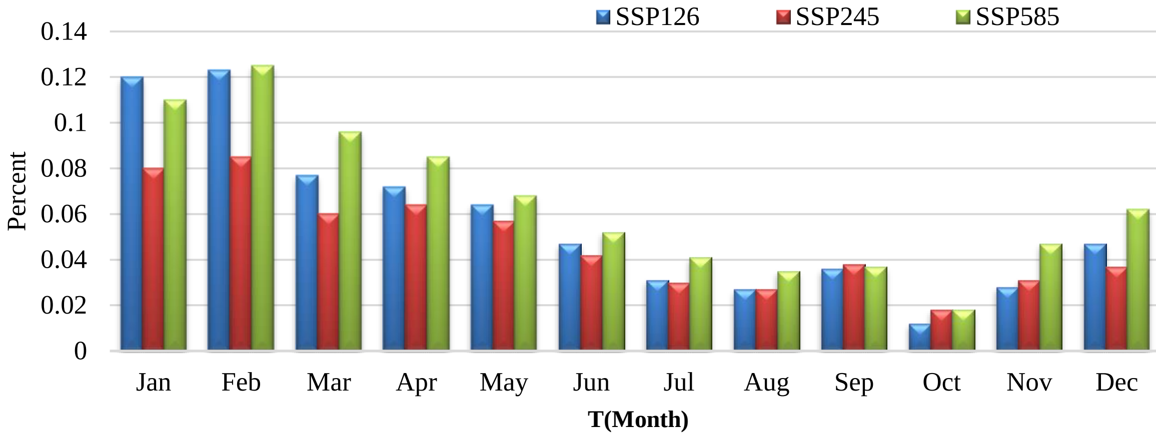

Figure 18. Evaluation results of the maximum temperature by HadGEM3 model under different emission scenarios in the 2020-2040 period for Damghan synoptic station.

Also, according to Tables 4 to 7, the minimum and maximum temperatures will increase in most of the coming months of the studied period. According to Table 4, the minimum temperature increase occurs at least in November and February under the SSP245 and SSP585 scenarios. Also, the lowest minimum temperature falls in December and January under these scenarios.

Table 4. Evaluation results of the minimum temperature by the CanESM5 model under different emission scenarios in the 2020-2040 period for Damghan synoptic station.

Scenarios	Jan	Feb	March	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SSP-1	0.1	0.16	0.018	0.009	0.006	0.005	0.004	0.004	0.005	0.008	0.02	0.15
SSP-2	-0.41	1.96	0.2	0.118	0.079	0.061	0.059	0.042	0.065	0.042	0.21	-1.4
SSP-5	-0.39	2.18	0.27	0.15	0.08	0.06	0.056	0.041	0.072	0.057	0.23	-1.3

According to Table 5, the maximum temperature increase occurs in April, March, February, and January under the SSP245 and SSP585 scenarios. Also, the maximum temperature did not decrease in any month.

Table 5. Evaluation results of the maximum temperature by the CanESM5 model under different emission scenarios in the 2020-2040 period for Damghan synoptic station.

Scenarios	Jan	Feb	March	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SSP-1	0.01	0.009	0.005	0.004	0.003	0.003	0.002	0.002	0.003	0.004	0.006	0
SSP-2	0.11	0.138	0.112	0.093	0.067	0.044	0.032	0.027	0.035	0.03	0.069	0.07
SSP-5	0.094	0.142	0.122	0.099	0.06	0.032	0.026	0.028	0.036	0.029	0.061	0.046

Table 6 shows the results of temperature changes obtained by applying the HadGEM3 model under three different emission scenarios in the future period of 2020–2040. The highest minimum temperature increase will happen in February. The biggest temperature drop will be in January and December. The HadGEM model had the largest temperature decrease in January and December at the Damghan synoptic station.

Table 6. Evaluation results of the minimum temperature by CanGEM3 model under different emission scenarios in the 2020-2040 period for Damghan synoptic station.

Scenarios	Jan	Feb	March	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SSP1	-0.48	2.16	0.22	0.12	0.082	0.056	0.049	0.028	0.05	0.014	0.17	-1.38
SSP2	-0.34	1.68	0.169	0.1	0.068	0.046	0.04	0.018	0.041	0.007	0.135	-1.06
SSP5	-0.41	1.1	0.23	0.13	0.08	0.065	0.06	0.04	0.06	0.029	0.18	-1.26

According to Table 7, the maximum temperature increase by the HadGEM3 model occurs in February and January under the SSP126 and SSP585 scenarios. Also, the maximum temperature has not decreased in any month. The results obtained from the model have similarities and differences with the CanESM5 model. February and January are incremental in both models. This increase in temperature can be very effective in evaporating water bodies and soil surfaces.

Table 7. Evaluation results of the maximum temperature by CanGEM3 model under different emission scenarios in the 2020-2040 period for Damghan synoptic station.

Scenarios	Jan	Feb	March	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SSP1	0.12	0.123	0.077	0.072	0.064	0.047	0.031	0.027	0.036	0.012	0.028	0.047
SSP2	0.08	0.085	0.06	0.064	0.057	0.042	0.03	0.027	0.038	0.018	0.031	0.037
SSP5	0.11	0.125	0.096	0.085	0.068	0.052	0.041	0.035	0.037	0.018	0.047	0.062

4. Conclusions

In the context of climate change, by using the https://esgf-node.llnl.gov/search/cmip6 website and extracting the 6th generation climate data from the climate models, the HadGEM3 and CanESM5 models, which according to the previous research records have been found suitable for the climatic conditions of Iran and have widely been used in the region, were selected. When extracting climate data, it was tried to use three emission scenarios (SSP126, SSP245, and SSP585) to predict the temperature and precipitation changes in the Shahid Shahcheraghi catchment, near Damghan City, for the 2020–2040period. Since the extracted statistical information required the downscaling of the simulated data, the LARS-WG model was used for this purpose. Results showed that more significant changes in precipitation and temperature were predicted by the HadGEM3 model as compared to the CanESM5 model. Therefore, the HadGEM3 model showed better performance than the CanESM5 model. Based on the results, it could be argued that if appropriate measures are not implemented to reduce water evaporation in the Shahcheraghi reservoir caused by the increased temperature, we will witness an increase in the concentration of pollutants in the dam reservoir, and this will not only lead to a water shortage crisis but also deteriorate the water quality.

Data Availability

The data used to support the findings of this study is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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