Original Article

Journal of Drought and Climate change Research (JDCR)

Winter 2026, Vol. 4, No. 12, pp 1-22

10.22077/jdcr.2025.9386.1141

Impact of Climate Change on Meteorological Parameters Using the CMIP6 Model

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Keywords:
Climate change, Khorramabad, Simulation, General circulation model

Received:
13 May 2025

Revised:
10 Jun 2025

Accepted:
11 Jul 2025

Abstract

Human society and the environment face significant challenges due to climate change. Climate change is predicted to cause an increase in global surface temperatures. These changes do not occur uniformly across the globe, making it necessary to examine them at a regional level. Investigating and evaluating these changes in each region is essential for a more accurate understanding of future challenges and related planning. Therefore, this research investigates the impact of climate change on meteorological parameters in the Khorramabad plain, located in Lorestan province, using the CanESM5.0 climate prediction model, in accordance with the CMIP6 sixth assessment report. The study utilizes temperature and precipitation data recorded from 2002 to 2022. Subsequently, based on designed emission scenarios—including the optimistic SSP1-2.6, and the pessimistic SSP5-8.5 scenarios—the future atmospheric conditions for a twenty-year period (2022-2042) were predicted.The LARS-WG method was used for downscaling The results indicate that CanESM5.0 performs well in simulating temperature parameters but has less capability in simulating precipitation. The results also show that the simulated temperature under the SSP1-2.6 emission scenario increases in all months during the future period (2022-2042) compared to the baseline period. The average precipitation in the future period does not show a specific pattern for the three models used. Overall, the results of this research can contribute to future water resource management, the creation of effective programs to combat climate change, and provide a basis for informed decision-making and appropriate planning.

How to cite this article:
Nohani, E., Babaali, H. & Dehghani, R. (2026). Impact of climate change on meteorological parameters using the CMIP6 model. *Journal of Drought and Climate change Research* (JDCR), *4*(12), 1-22. https://doi.org/10.22077/jdcr.2025.9386.1141

Introduction

Climate change is one of the most challenging issues of recent decades. Human life and the environment will be affected by climate change. Global warming, through water scarcity, temperature changes, and altered precipitation patterns, will have significant impacts on human society in the future. Changes in key climatic variables will increase the occurrence of extreme weather events such as floods and droughts. In arid and semi-arid regions, these effects are expected to be more severe and catastrophic due to their vulnerability to climate change (Waha et al., 2017). Iran faces various environmental challenges due to human activities and anthropogenic climate change. In recent years, many rivers and lakes in Iran have shrunk, groundwater levels have declined dramatically, and various parts of the country have experienced severe droughts (Ashraf et al., 2021; Ghazi et al. 2023). Climate change, population growth, and economic problems are expected to exacerbate environmental issues in Iran. For example, water scarcity exacerbates tensions, especially in regions that rely on rivers fed by glaciers and snowmelt from the Zagros and Alborz mountain ranges. Therefore, it is essential to assess various aspects of the impact of climate change on Iran.

Modeling the impact of climate change on food resources in a specific region is challenging due to several factors, such as the uncertainty in regional climate change predictions and the potential for adaptation to climate change. There are methods for estimating precipitation changes in recent decades, including the use of general circulation models (GCMs). These models require downscaling to be accurate at the regional level of interest. However, it should be acknowledged that the outputs of these models are always subject to uncertainty and must be evaluated and examined to address this uncertainty. GCM model uncertainty stems from incomplete knowledge of fundamental geophysical processes, coarse grid resolution, and unresolved processes that lead to limitations in model accuracy and precision. Scenario uncertainty arises from the unpredictable nature of future socio-economic behavior, and consequently, future greenhouse gas emission scenarios.

General Circulation Models (GCMs) are used to predict climate change impacts on various systems, including water resources. These models provide targeted and high-quality simulations to better understand past climate changes and to make predictions and uncertainty assessments for the future (Annan & Hargreaves, 2011). GCMs do not have uniform resolution and accuracy, and their precision and efficiency vary in different regions. Furthermore, the reliability of GCMs depends on their ability and accuracy in reproducing the baseline climatic characteristics and future periods. These capabilities are valuable for water resource engineers because they facilitate effective planning and strategic decision-making. Ultimately, evaluating the performance of GCMs is crucial, as it enables the simulation and prediction of various climate scenarios, allowing for informed choices. The sixth phase of the Coupled Model Intercomparison Project (CMIP6) brings significant advancements compared to its previous phase, CMIP5 (O'Neill et al., 2017). The set of sixth assessment reports provided by the Intergovernmental Panel on Climate Change (IPCC), as one of the most important scientific resources in the field of climate change, examines climate change scenarios and their effects on societies and the environment (IPCC, 2021). Regarding climate change based on the fifth assessment report, various studies have been conducted worldwide, but these studies are limited concerning the sixth report. In recent years, various studies have been conducted regarding the prediction of climatic parameters using the sixth report, which are described as follows. Feyissa et al. (2024) investigated the impact of climate change on the hydrological processes of the Amur River in Ethiopia under the Shared Socioeconomic Pathways (SSPs) SSP245 and SSP585. The results showed that the predicted flow of the basin, except for the months of March, April, and May under the SSP245 scenario, decreased. Furthermore, the flow prediction on an annual and monthly scale increases in June, July, August, and September. Shahi et al. (2024) examined the impact of climate change on temperature and precipitation using CMIP6 models in the Damghan Plain. They used the sixth assessment report's scenarios of climate change by the IPCC to evaluate the effects of climate change on temperature and precipitation in Damghan. The occurrence of climate change was predicted using the HadGEM3 and CanESM5 models under the SSP126, and SSP585 scenarios. The results indicated that the HadGEM3 model predicted greater changes in precipitation and temperature compared to the CanESM5 model. Therefore, the HadGEM3 model performs better than the CanESM5 model. Kouman et al. (2024) investigated future changes in precipitation, temperature, and the resulting drought conditions based on six Global Climate Models (GCMs) from CMIP6 models under the Shared Socioeconomic Pathways (SSPs) - and SSP5-8.5 in Côte d'Ivoire. The results showed that by 2100, annual precipitation would decrease on average by 133 mm and 177 mm under the and SSP5-8.5 scenarios, respectively. Cruz González et al. (2025) evaluated General Circulation Models (GCMs) including HadGEM3-GC31-LL, MRI-ESM2-0, and ACCESS-ESM1-5 under two Shared Socioeconomic Pathways (SSPs): and SSP5-8.5 in Mexico. The results indicated that the annual minimum temperature would increase to 2 degrees Celsius under the scenario and 3.1 degrees Celsius under the SSP5-8.5 scenario by the distant horizon. While the annual maximum temperature would increase to between 2.5 degrees Celsius under the scenario and 3.8 degrees Celsius under the SSP5-8.5 scenario by the distant horizon. Based on the research conducted, it is clear that the selection of General Circulation Models (GCMs) is critical and important due to computational limitations and fundamental uncertainties. Furthermore, with the increase in global surface temperature, it is necessary to evaluate its regional impact for a more accurate understanding of future challenges and related planning. On the other hand, considering that the Khorramabad plain has faced a significant decrease in rainfall and increase in temperature in recent years, and also the production of crops in this plain has decreased, therefore, investigating the climatic conditions of the Khorramabad plain is a necessary and essential matter, which can greatly help in developing a plan for adaptation to water scarcity.Therefore, this research will examine the impact of climate change on temperature and precipitation parameters using CMIP6 climate models in the Khorramabad County of Lorestan Province, utilizing data from the CanESM5 prediction model and the LARS-WG downscaling model based on designed emission scenarios in the baseline period of 2002 to 2022 to predict the atmospheric conditions during the future period. Three scenarios will be used for the twenty-year period in the near future from 2022 to 2042: the optimistic SSP126, the intermediate , and the pessimistic SSP585.

Materials and Methods

Study Area

The Khorramabad Plain is located in the center of Lorestan Province, Iran, between latitudes 33°13' N to 33°35' N and longitudes 47°52' E to 48°46' E. The maximum elevation of the region is 1903 meters, and the minimum elevation is 929 meters, with a study area of 2517 square kilometers. The average annual precipitation of the Khorramabad study area is 509 mm, and the average temperature is 17.2°C. The location of the study area is shown in Figure 1. Precipitation and temperature graphs are displayed in Figures 2 and 3.

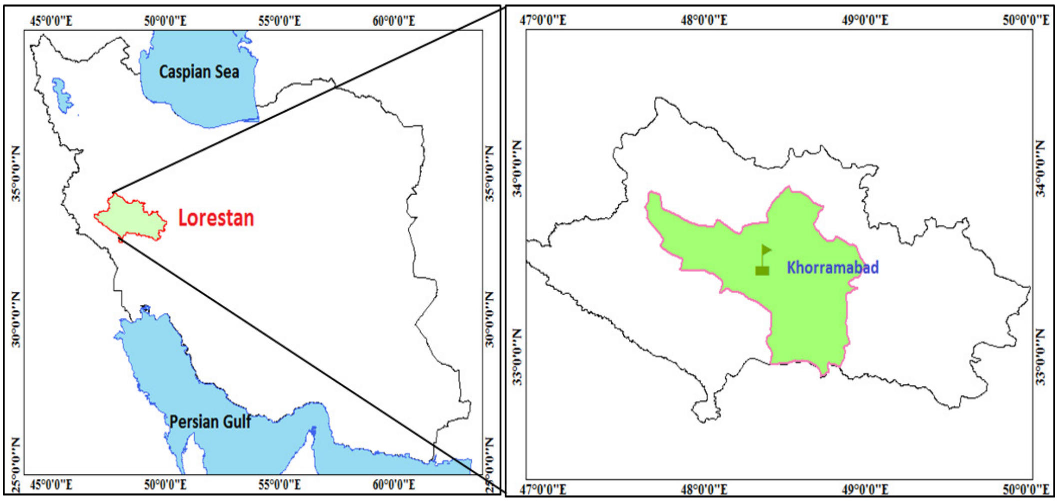

Fig 1. Study area

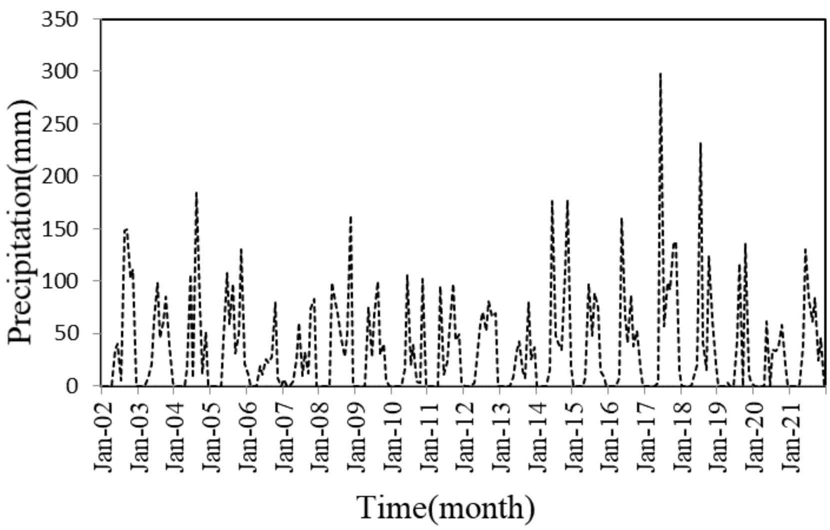

Fig 2. Precipitation status of the study area

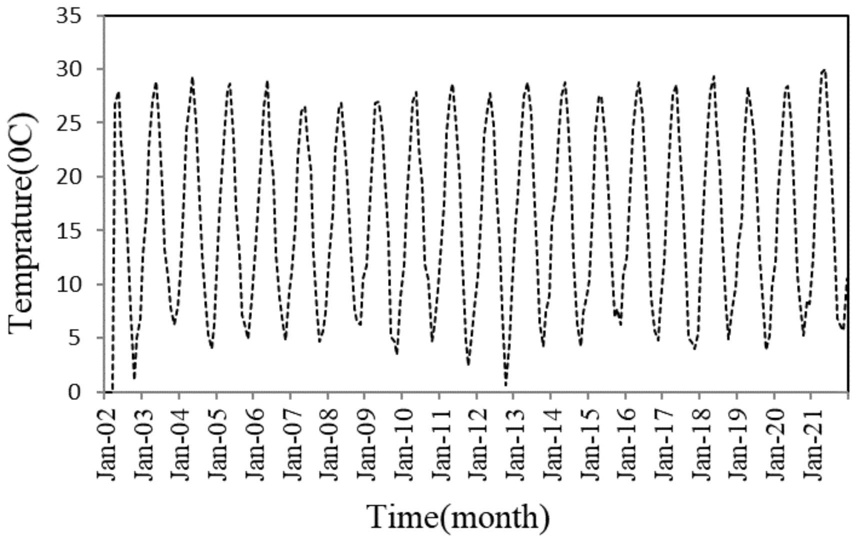

Fig 3. Temperature status of the study area

Methodology

First, meteorological data for Khorramabad County was obtained from the Lorestan Province Meteorological Organization. Then, by collecting observational time series data of daily temperature and precipitation over a 20-year baseline period (2002-2022), examining their characteristics and trends, and performing statistical tests on the two parameters of Minimum temperature, maximum temperature, average temperature and precipitation, they were analyzed. Subsequently, the general circulation model (GCM) predictor was selected by referring to existing databases related to the Sixth Assessment Report, and the time series generated by various models were received. The projected climate data from these models for Lorestan Province can be obtained based on the latitude and longitude ranges. To achieve the objective of this study, historical data from the CanESM5.0 climate model in NetCDF format, on daily and monthly scales, were obtained from climate websites, and converted to Excel format by ArcMap software for statistical operations. The performance of the selected model in simulating temperature and precipitation parameters during the baseline period was assessed using historical model data. In the next stage, the desired climate data for the future period were statistically downscaled and predicted for the CanESM5.0 model, based on the IPCC Sixth Assessment Report, for two future 20-year periods (2022-2042) using the LARS-WG software environment.

General Circulation Model

General Circulation Models (GCMs) are capable of simulating changes in climate parameters in various scenarios. This model is based on the laws of physics and uses mathematical relationships to predict climate variables in each cell of the grid. GCMs are divided into three categories: atmospheric general circulation models (AGCMs), oceanic general circulation models (OGCMs), and coupled atmosphere-ocean general circulation models (AOGCMs). Currently, the most reliable tool for climate change studies is the (AOGCM) model. The most important input to these models is the amount of greenhouse gas emissions, which is presented in the form of emission scenarios for future periods (Semenov & Stratonovitch, 2015)

Climate models exhibit varying performance in predicting meteorological variables across different locations. Therefore, it is essential to evaluate their capability before utilizing their output. Accordingly, in the present study, to select suitable models for the study area, the precipitation and temperature predictions obtained from climate models (pertaining to the nearest computational cell to the Khorramabad watershed) during the baseline period (2002-2022) will first be acquired from the Lorestan Province Meteorological Organization. Subsequently, by comparing the output of these models with observational data, models that demonstrate adequate performance will be selected for predicting precipitation in the future period. In this research, the Root Mean Square Error (RMSE), Normalized Root Mean Square Error (NRMSE), coefficient of determination (R), and Mean Absolute Error (MAE) indices were used to evaluate the performance of climate models, and their formulas are provided below.

$$R=\frac{\sum_{i=1}^{N}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{N}(x_i-\bar{x})^2\sum_{i=1}^{N}(y_i-\bar{y})^2}} \quad -1\leq R\leq 1 \tag{1}$$

$$RMSE=\sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i-y_i)^2} \tag{2}$$

$$MAE=\frac{\sum_{i=1}^{n}|x_i-y_i|}{n} \tag{3}$$

Scenarios of the Sixth Assessment Report of the General Circulation Model

The latest scenarios presented for examining climate parameters are the scenarios of the Sixth Assessment Report (AR6). These scenarios explore how the general circulation model behaves in future periods based on a combination of Representative Concentration Pathways (RCPs) and Shared Socioeconomic Pathways (SSPs). In fact, according to this report, future scenarios, in addition to describing different climates, must also include aspects of economic and social progress. The SSP scenarios emphasize simulating how socioeconomic conditions such as population growth, economic growth, education, urbanization, development, and technology change (Kriegler et al., 2016;Yang et al., 2021).

Downscaling

One of the challenges of using climate model outputs is the large scale of their computational cells. Therefore, raw data from these models cannot be used in studies related to smaller scales. In this regard, the output of these models must be downscaled using appropriate methods.

Downscaling is performed using three categories of methods: statistical, dynamical, and proportional. In statistical methods, downscaling is performed using regression methods and statistics, establishing a quantitative relationship between large-scale variables and small-scale variables. One of the statistical methods is the LARS-WG model (Riahi et al., 2017). By receiving historical information about the region and recognizing its statistical characteristics, this model predicts the status of climate variables in the future. In this research, information on precipitation, maximum temperature, minimum temperature, and sunshine hours for the Khorramabad meteorological station during the years 2002-2022 will be provided to the LARS model. After ensuring the model's ability to recognize the statistical characteristics of the station, this model will be used to downscale the output of climate models under two scenarios: SSP1-2.6 and SSP5-8.5. Since the Sixth Assessment Report models are not defined in the LARS-WG software, it is necessary to downscale the output of each model by defining a scenario. For this purpose, the precipitation, maximum temperature, and minimum temperature data related to the output of each model for the future period under both SSP1-2.6 and SSP5-8.5 scenarios will be extracted. Then, for the precipitation parameter, the ratio of the long-term monthly average of the future period to the baseline period will be calculated, and for the maximum and minimum temperature parameters, the difference between the long-term monthly average of the future period and the baseline period will be calculated. Therefore, a coefficient will be obtained for each parameter in each month, which will be used to create a scenario in the WG-LARS software and downscale the output of the Sixth Assessment Report models.

In the study, SSP1-2.6 (low emissions) and SSP5-8.5 (high emissions) were chosen to represent the plausible range of future socio-economic pathways and their associated greenhouse gas emissions. This approach allows us to examine scenario uncertainty in our projections. Historical temperature and precipitation data were obtained from the Iran Meteorological Organization. Quality control procedures included outlier removal and gap-filling using interpolation. We acknowledge that data gaps and potential measurement errors introduce uncertainty into the characterization of the baseline climate. Due to the uncertainty in climate predictions arising from structural differences in global climate models, as well as uncertainty regarding changes in initial conditions or model parameterization, the use of multiple scenarios in predictions is recommended(Semenov and Stratonovitch., 2010). By doing so, uncertainty in the generation of future climate data can be minimized. Because the output of the LARS–WG model is different each time it is run, this is also one of the sources of error in the forecasting process. For this purpose, the aforementioned statistical downscaling model was run 100 times in this study. In some statistical downscaling models, such as the auto statistical exponential downscaling model, the model selects the best answer and presents the prediction results after 100 runs and statistical analyses. However, in the LARS–WG model, this process does not occur, and a different answer is obtained with each model run, even though the differences are minor, it can be one of the sources of uncertainty in the prediction (Souvignet & Heinrich, 2011).

Results and Discussion

Analysis of the precipitation data for the validation period using the statistical T and F tests is presented in Table 1. The results in this table indicate that only in two months, March and August, are the values of the statistical tests less than 0.05. For the remaining data, the results are generally favorable and acceptable, and there is no significant difference between the simulated (synthetic) precipitation values and the actual values at the 0.05 level. The existing error is random.

In this study, the CanESM5.0 model was used to generate daily rainfall, maximum temperature, and minimum temperature values at Khorramabad station during the historical and future periods. This was done to provide an accurate evaluation of the selected model's ability to simulate the aforementioned parameters within the

Table 1. Statistical F and T tests for precipitation values in the validation period

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P-value (T)	0.55	0.36	0.52	0.76	0.51	0.75	0.24	0.93	0.54	0.54	0.53	0.72
P-value (F)	0.23	0.74	**0.00**	0.78	0.45	0.41	0.42	**0.01**	0.14	0.65	0.41	0.54

study area. The statistical analysis of the model simulation for rainfall and temperature parameters during the historical period is shown in Table 1. The results obtained from evaluating the data generated using the LARS-WG model and the observed data during the historical period are shown in Table 2 and Figure 4. The results indicate that the coefficient of determination (r^2) was calculated to be greater than 0.96 for all parameters studied. The Mean Absolute Error (MAE) for simulating precipitation, minimum temperature, and maximum temperature was 0.25, 0.03, and 0.04, respectively, indicating that the error in simulating precipitation is higher than the other parameters. The RMSE and NRMSE indices were also significantly higher in precipitation simulation compared to other parameters (5.18 and 12.36, respectively), indicating a greater error. Therefore, the ability of the LARS-WG model to simulate meteorological parameters is confirmed; however, the model exhibits less accuracy in simulating precipitation, which is consistent with the findings of Hosseini et al. (2015) and Dehghani et al. (2022). Additionally, in this research, the CMIP6 general circulation model was used to predict meteorological parameters such as precipitation and temperature during the years 2022 to 2042. In order to predict meteorological parameters in the general circulation model, three climate scenarios, SSP126, and SSP585, were used. As observed, the SSP126 scenario is considered optimistic , and SSP585 is considered pessimistic. The CanESM5 climate model, which has the greatest compatibility with the region, was also considered. The Lars WG 8 model was used for downscaling. By examining the data in Tables 3 and 4 , it is observed that, during the period from January to September, an increase in temperature is accompanied by a decreasing trend in precipitation. However, considering the long-term annual average precipitation across the different scenarios, no significant difference is observed. The SSP126 scenario, with a lower annual average temperature, exhibits a higher precipitation amount compared to the other scenarios. Therefore, despite the inverse correlation between temperature and precipitation during the period under investigation, it cannot be definitively concluded that an increase in temperature is solely responsible for the decrease in precipitation, as other factors also play a role in determining long-term precipitation levels. Results regarding changes in temperature and precipitation in the future period compared to the base period in the selected models are presented in Figures 5 and 6. Figures 5 and 6 show that the simulated temperature for all models under the SSP126 emission scenario in the future period (2022-2042) shows an increase compared to the base period in all months. The highest temperature increase in the SSP585 and models in July was 3.80°C and 3.67°C, respectively. The lowest temperature increase for all models used in this research occurred in January, which was 3.34°C, 3.39°C, and 3.46°C for SSP126, and SSP585 models, respectively. Therefore, the SSP585 model predicted the highest temperature increase compared to the base period among the selected models. The average precipitation also changed in the future period for the three models used in the research in all months, but no specific pattern is observed.

In figure 5, Analysis of projected maximum temperatures (Tmax) reveals a consistent warming trend across all months between the baseline period (2002-2022) and the future scenarios (2022-2042). Under the SSP126 scenario, the average Tmax is projected to increase from 25.38°C to 27.06°C, while the SSP585 scenario shows a larger increase to 27.93°C. The most significant warming is projected during the summer months. For instance, in July, Tmax is projected to increase from 35.96°C in the baseline period to 38.26°C under SSP126 and 38.80°C under SSP585. November shows a substantial increase from 20.19°C to 22.81°C and 23.94°C under SSP126 and SSP585, respectively. These results suggest a considerable shift in temperature patterns, with potentially significant implications for agriculture, water resources, public health.

In figure 6, Projected changes in precipitation (P) for the period 2031-2050, relative to the base period of 1997-2017, indicate notable seasonal variations under both SSP126 and SSP585 scenarios. Generally, the SSP585 scenario projects lower precipitation amounts compared to SSP126 across most months. Both scenarios suggest a decrease in precipitation during the summer months (June-August), with the most significant reductions occurring under SSP585. Conversely, during the late fall and early winter months (October-December), both scenarios project an increase in precipitation, particularly in November. These shifts in precipitation patterns could have significant implications for water resource management, agricultural practices, flood risk.“Analysis of projected precipitation (P) reveals significant shifts in seasonal patterns between the baseline period (2002-2022) and the future scenarios (2022-2042). The average precipitation is projected to decrease from 44.48 mm in the baseline period to 34.56 mm under the SSP126 scenario and further to 30.01 mm under the SSP585 scenario. Notably, summer months experience substantial reductions. For example, July sees a decrease from 2.35 mm in the baseline to 0.35 mm and 0.34 mm under SSP126 and SSP585, respectively. In contrast, while November experiences a general decrease in precipitation, the baseline value of 91.87 mm is reduced to 60.47 mm under SSP126 and 49.86 mm under SSP585. December shows a similar trend, with precipitation decreasing from 96.41 mm to 94.95 mm and 72.82 mm under SSP126 and SSP585, respectively. These shifts in precipitation patterns, characterized by drier summers and variable changes in other months, could have cascading effects on khorramabad plain.

The precipitation amount in the SSP126 model shows an increasing trend for all months of the year, with only a decreasing trend in May. In the model, there is also an increasing trend in all months of the year, except for May which does not experience a decreasing trend. In the SSP585 model, there is also an increasing trend in all months of the year. Also, Future research should prioritize a comprehensive uncertainty analysis, incorporating probabilistic assessments of climate models, downscaling techniques, and scenario assumptions, to better quantify the range of potential future outcomes.

The results of this study, predicting increasing temperatures across the study region, are broadly consistent with those of Nateghi et al. (2022), who used RCP emission scenarios in the Halil-rud Watershed in the southeastern Kerman Province. Nateghi et al. projected temperature increases of 10 degrees Celsius over the next 20 years under RCP 1.2.6, which is similar to our projected increase of 10 degrees Celsius under the comparable RCP 1.2.6 scenario. This consistency is likely due to the shared use of RCP 1.2.6 and the relatively close proximity of the Halil-rud Watershed to our study area. Similarly, Fazeli Khiavi et al. (2020), using CMIP5 scenarios in the Moghan Plain, also indicated an increase in temperature under all RCP scenarios in future periods. While Fazeli Khiavi et al. used CMIP5, and our study employs CMIP6, the overall direction of change remains consistent, suggesting a robust signal of warming in the region. The projected increases in minimum and maximum temperatures, as also highlighted by Fazeli Khiavi et al. (2020), have significant implications for various sectors in the Moghan Plain, including water resources, agricultural practices (planting times, crop selection), and human living conditions. Therefore, managers, planners, and decision-makers can utilize the results of this research to inform water resource management strategies, adaptation planning for agriculture, public health initiatives.

Table 2. Statistical indices for the evaluation of the LARS-WG 8 model

Parameters	R2	RMSE	NRMSE	MAE
Precipitation	0.960	5.18	12.36	0.25
Minimum temperature	0.980	0.25	2.41	0.03
Maximum temperature	0.980	0.30	0.97	0.04

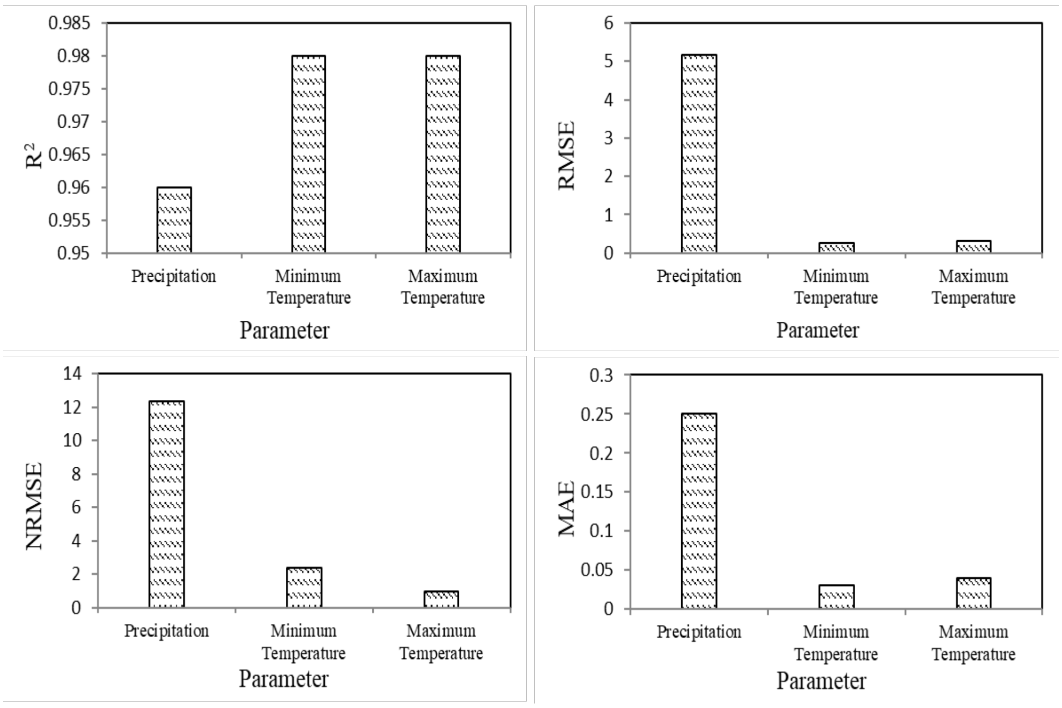

Fig 4. Charts of evaluation indices

Table 3. Performance of sixth assessment report scenarios in precipitation prediction

	T_{max}(°C)		
Month	Base Time (2002-2022)	SSP126 (2022-2042)	SSP585 (2022-2042)
Jan	15.99	16.98	17.65
Feb	18.06	19.13	19.81
Mar	21.76	23.07	23.98
Apr	23.41	24.19	25.30
May	27.09	27.35	28.72
Jun	32.20	33.47	34.64
Jul	35.96	38.26	38.80
Aug	35.50	38.14	38.51
Sep	31.78	34.55	35.12
Oct	26.03	28.40	29.24
Nov	20.19	22.81	23.94
Dec	16.58	18.34	19.43
Average	25.38	27.06	27.93

Table 4. Performance of sixth assessment report scenarios in precipitation prediction

	P (mm)		
Month	Base Time (2002-2022)	SSP126 (2022-2042)	SSP585 (2022-2042)
Jan	63.47	60.19	46.95
Feb	49.04	37.54	29.37
Mar	35.60	16.64	16.00
Apr	52.84	39.41	42.32
May	31.76	32.53	30.10
Jun	9.60	8.12	7.49
Jul	2.35	0.35	0.34
Aug	5.21	3.65	3.34
Sep	27.95	17.36	17.39
Oct	67.61	43.50	44.13
Nov	91.87	60.47	49.86
Dec	96.41	94.95	72.82
Average	44.48	34.56	30.01

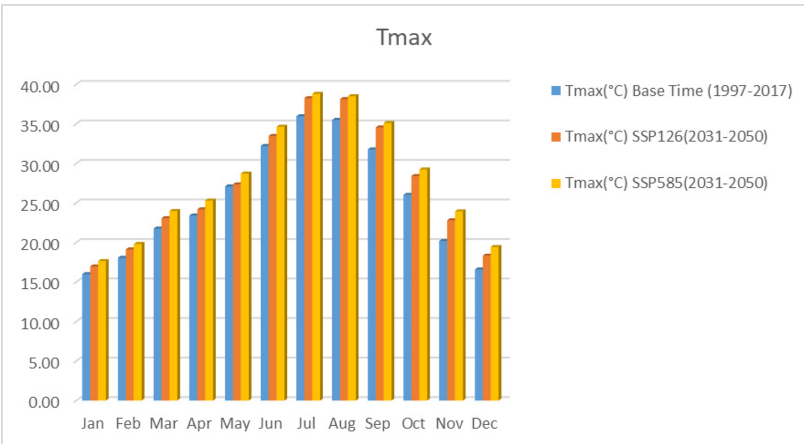

Fig 5. Monthly mean temperature in the base period versus the 2022-2042

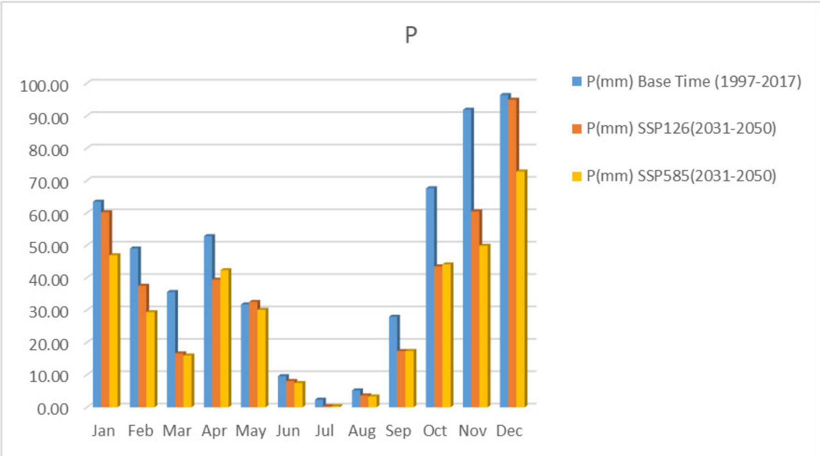

Fig 6. Monthly mean precipitation in the base period versus the 2022-2042

The box plot for precipitation values corresponding to the mentioned scenarios is shown in Figure 7. Figure 7 illustrates the SSP126 scenario. The box plot derived from monthly data indicates significant variations in the distribution of values across different months. The months of June to August (Jun-Aug) clearly show values close to zero, characterized by highly compressed boxes with no noticeable variations. In contrast, November and December (Nov-Dec) exhibit significant dispersion, represented by taller boxes and numerous outliers. The overall pattern suggests that the highest variability is observed in the colder months of the year, while the warmer months display very high stability. Additionally, as evident, the maximum precipitation occurred in November with a value of 117.49, while the minimum value for this parameter across all months is zero. Furthermore, the highest skewness and standard deviation of the data were observed in November. Analysis of rainfall predictions for Khorramabad County under the SSP126 scenario indicates that climate change will lead to a 30-50% increase in extreme precipitation events (exceeding 50 mm in 24 hours) by 2050. Extreme values, such as the 117.5 mm predicted for November 2048, fall within the upper range of the model's uncertainty. This uncertainty primarily stems from (1) the high sensitivity of Sudanese precipitation systems to changes in atmospheric patterns (±25% error), (2) limitations in the resolution of global models in representing the complex topography of the Zagros Mountains (±15% altitudinal error), and (3) the inherent variability of Atlantic Ocean oscillations. Although the range of predictions is broad (40-200 mm for extreme events), the increasing trend is statistically significant with a 75% confidence level ($p<0.05$), making it imperative to adopt flexible strategies for flood risk management and water storage in this vulnerable region. Figure 7, under the SSP585 scenario, demonstrates a significant increase in extreme precipitation events (with a maximum of 78.05 mm in November 2048) within the context of climate change, albeit accompanied by considerable uncertainties. These uncertainties mainly arise from (1) inherent limitations of climate models in representing local-scale processes (±25% error in estimating convective precipitation), (2) the region's high sensitivity to fluctuations in Sudanese and Mediterranean atmospheric patterns, and (3) challenges in parameterizing the topographic effects of the Zagros Mountains (±15% altitudinal error). Although the range of predictions is wide (40-120 mm for extreme events), statistical tests confirm the increasing trend with 75% confidence ($p<0.05$), which necessitates the adoption of smart adaptive strategies that consider these uncertainties in the region's water and flood management. These findings align with IPCC report predictions regarding the intensification of extreme events in mountainous areas of western Iran but emphasize that operational planning must cover a wide range of possible scenarios.

Table 5 and Figure 8 display the values of the analyzed scenarios on a seasonal basis. Based on precipitation and temperature data across the four seasons and under different climate scenarios, the results indicate that climatic changes will have significant impacts on the precipitation and temperature patterns of the studied region. In the SSP5-8.5 scenario, which represents a severe increase in greenhouse gas emissions, the annual average precipitation experiences a noticeable reduction, especially in spring and autumn. Spring precipitation decreases from 21.43 to 15.9 units, and autumn precipitation from 25.37 to 20.94 units. This precipitation decrease can lead to an increased risk of drought and water stress during these seasons. On the other hand, air temperature increases in all seasons under both SSP1-2.6 and SSP5-8.5 scenarios, but this increase is much more pronounced in the SSP5-8.5 scenario. For instance, summer temperature rises from 111.32 units in the base period to 113.63 units in this scenario, which could bring longer and more intense heatwaves.

The findings of this study indicate that climate change not only leads to reduced precipitation in wet seasons like spring and autumn but also

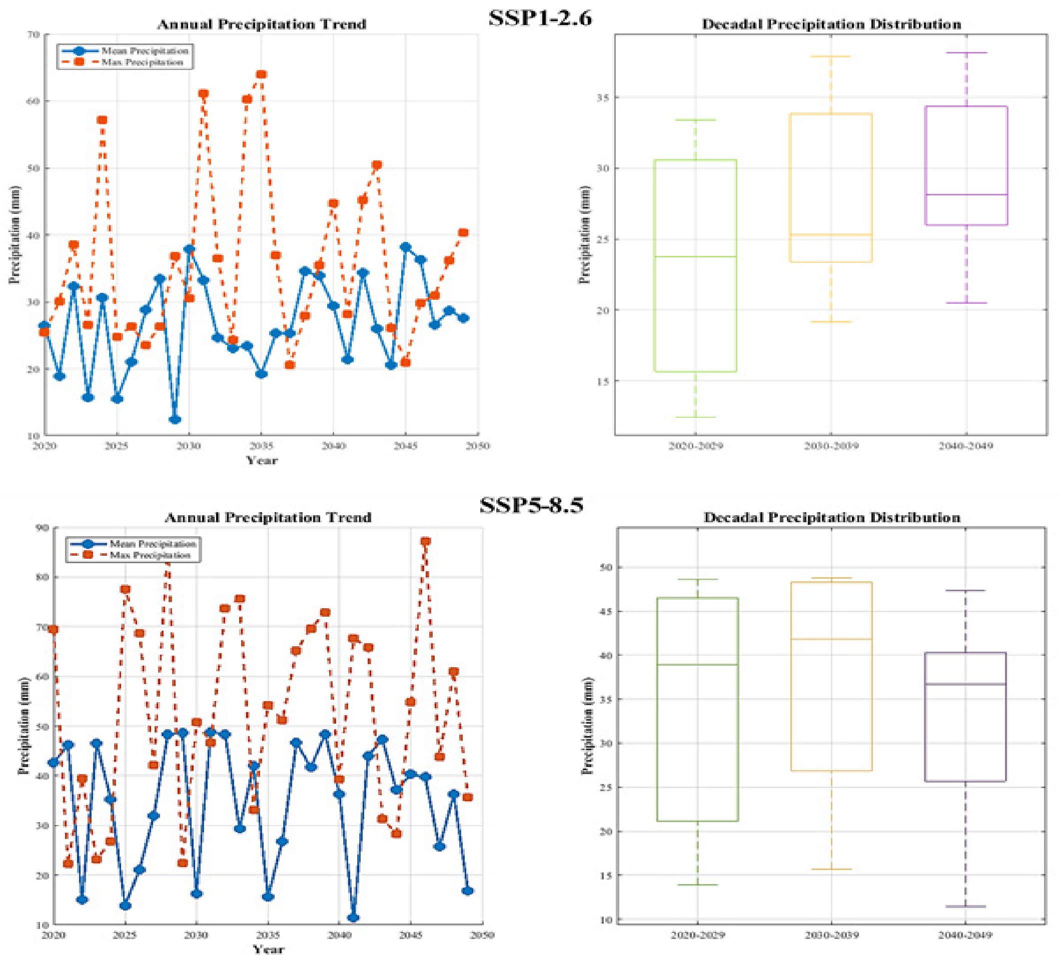

Fig 7. Combined time series charts and box plots of the stuidied scenarios

exacerbates air temperature increases across all seasons, particularly in summer and winter. These changes can have widespread consequences for natural ecosystems, agriculture, and water resource management. Reduced precipitation alongside increased temperatures heightens the risk of frequent and severe droughts, necessitating adaptation planning. Therefore, broad policies should focus on reducing greenhouse gas emissions and adapting to these new conditions to mitigate the negative impacts of climate change.

Conclusion

This research investigated the effect of climate change on the climate variables of temperature and precipitation recorded at the Khorramabad synoptic station in Lorestan province, using the CanESM5.0 climate prediction model in the CMIP6 Sixth Assessment Report. The study used scenarios based on a base period of 2002-2022

Table 5. Performance of the sixth report scenarios seasonally in predicting meteorological parameters

Parameters	seasons	Base Time	SSP1-2.6	SSP5-8.5
Precipitation	Spring	21.43	20.44224	15.90595
	Summer	0.0003	0.000288	0.003744
	Autumn	25.37	24.22656	20.94307
	Winter	42.34	40.63766	37.88755
Temperature	Spring	63.47	64.78748	64.92845
	Summer	111.32	112.8928	113.6322
	Autumn	83.23	84.0519	85.44019
	Winter	32.16	33.14811	34.09974

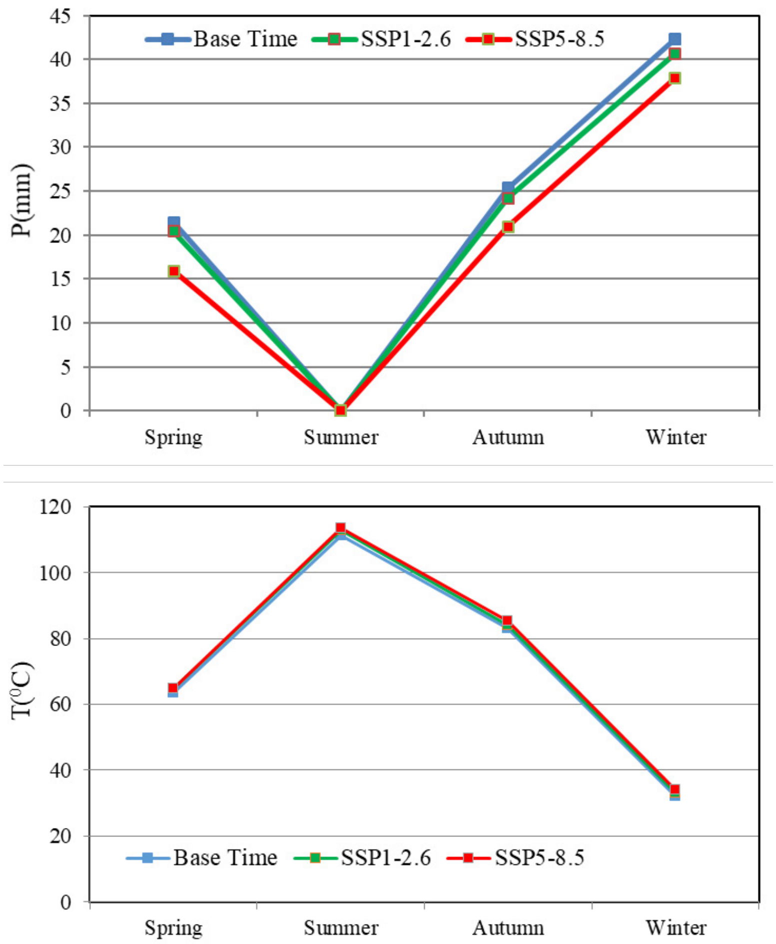

Fig 8. Comparison of the trend of seasonal fluctuations of meteorological parameters of the Khorramabad synoptic station in the future time period compared to the base period

to predict future weather conditions based on three scenarios: the optimistic SSP1-2-6 , and the pessimistic SSP5-8-5 over a 20-year period in the near future (2022-2042). The results of the model performance error analysis showed that CanESM5.0 is able to simulate maximum and minimum temperature parameters with high accuracy, but shows a greater error in simulating the precipitation parameter compared to the other two parameters. The simulated temperature under the SSP126 emission scenario in the future period (2022-2042) increases in all months compared to the base period. The average precipitation in the future period for the three models used shows a specific pattern: in the SSP126 scenario, there is an increasing trend for all months of the year, with only a decreasing trend in May. By correcting the output of the selected model in the future emission scenario, acceptable values for temperature and precipitation can be obtained.Comparative analysis of SSP1-2.6 and SSP5-8.5 scenarios for Khorramabad (2020-2050) shows distinct precipitation patterns with inherent uncertainties. SSP1-2.6 indicates limited, yet significant, changes, whereas SSP5-8.5 projects a more substantial and uncertain increase (25-45%) in extreme precipitation, primarily due to modeling limitations. Despite broad ranges (15-70%), SSP5-8.5 consistently signals a significant rise in extreme rainfall frequency, emphasizing the need for probabilistic risk management.The results from seasonal changes showed that climate change, especially under the SSP5-8.5 scenario, leads to drought, water stress, and more intense heatwaves. In contrast, under the SSP1-2.6 scenario, precipitation in spring and autumn is less affected compared to other scenarios, and the temperature experiences a milder increase on average than in more severe scenarios. This scenario is recognized as a more sustainable model aimed at maintaining optimal climatic conditions and reducing the risks associated with climate change. These reports serve as a reliable source for organizations, policymakers, and the scientific community to make appropriate decisions regarding the management and mitigation of the effects of climate change.

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