DOI:10.28974/idojaras.2026.3.5

IDŐJÁRÁS

Quarterly Journal of the HungaroMet Hungarian Meteorological Service
Vol. 130, No. 3, July – September, 2026, pp. 317–342

Spatial analysis of evapotranspiration and drought under climate change scenarios in the Qazvin region of Iran

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(Manuscript received in final form on December 23, 2025)

Abstract— The simultaneous assessment of evapotranspiration and drought is imperative for adaptive water resource planning due to the growing challenges posed by climate change on agricultural production. A downscaling exercise was carried out using the SDSM model for three climate scenarios developed as part of the Sixth Assessment Report (CMIP6): an optimistic scenario (SSP126), a moderate scenario (SSP245), and a pessimistic scenario (SSP585). For model calibration and validation, long-term meteorological data from five stations were used, and drought conditions were assessed using the standardized precipitation index (SPI). Based on the validation results, the model demonstrated high accuracy for simulating temperature and reference evapotranspiration. However, precipitation simulations demonstrated moderate accuracy. Under all scenarios, annual temperatures increased, with the largest increase projected under SSP585. In spite of the fact that changes in precipitation did not reach statistical significance, it is likely that a moderate decline will occur by 2062, under SSP126. Under future climate conditions, there will be a decrease in precipitation in the southeast of the province, an intensified warming in Buin-Zahra, and an increase in evapotranspiration. It was noted that there were frequent severe droughts over the past years. Based on projections for the next decade, drought and wet periods are expected to alternate, with adverse effects expected in the southeast and Buin-Zahra regions. It is evident, from these findings, that sustainable water resource management, climate-adapted agricultural methods, and spatially targeted planning are urgently required to reduce the vulnerability of the province of Qazvin. Hence, adaptation policies should prioritise highly vulnerable areas based on the presented spatial analysis in order to enhance agricultural resilience to drought and climate change.

Key-words: CMIP6, evapotranspiration, temperature, climate change adaptation, standardized precipitation index

1. Introduction

Climate change and the increasing trend and magnitude of extremes in the past decades, particularly in arid and semi-arid regions, have become the most important environmental, economic, and social challenges worldwide (*Nazari et al.*, 2023, 2024). The fluctuations of temperature, rainfall, solar radiation, and relative humidity and other climatic variables directly affect the hydrological cycle and threaten the sustainability of water resources, food security, and agricultural yield. Evapotranspiration is the most significant pathway of water loss in the hydrological cycle and plays a critical role in estimating crop water requirements, irrigation planning, reservoir management, and evaluating the sustainability of groundwater resources (*Karimi et. al.*, 2028, *Dehghanisanij et al.*, 2020; *Kanani et al.*, 2022). Evapotranspiration reflects the energy balance and moisture status of the environment and is considered a very sensitive indicator of climate change. Higher temperatures, decreased relative humidity, increased longwave radiation, altered wind speed, and changed precipitation can directly increase the rate of evapotranspiration. Consequently, climate change is often first manifested in evapotranspiration and then emerges as reduced soil moisture, increased plant water stress, and eventually the onset of meteorological, agricultural, and hydrological droughts (*Nazari et al.*, 2023). The interlinking between evapotranspiration and drought emphasizes that both should be evaluated together when studying climate change. Since increasing evapotranspiration increases the demand for water but decreases renewable water supply, understanding the spatial-temporal evolution of evapotranspiration provides critical insights into future drought tendencies. Hence, neglecting evapotranspiration in the assessment of droughts probably leads to a partial understanding of the hydrological cycle and misinformed decisions about water management (*Kanani et al.*, 2025).

Several studies have looked at the effects of climate change on precipitation, evapotranspiration, and drought characteristics at local, regional, and global scales. Climate projections for countries within the MENA region demonstrate that, with a few exceptions, annual precipitation will decrease significantly, by about 15–20%, combined with increased reference evapotranspiration for nearly all countries. Changes will be most prevalent in North Africa; middle and eastern Iran; and parts of Syria, leading to increased frequency and intensity in existing water deficits, especially in countries such as Morocco (*Terink et al*., 2013). On the global level, long-term variability studies indicate that rising temperatures and increased atmospheric evaporative demand have caused an expansion in dryness and increased frequency of droughts since the 1970s, which has been especially apparent in Africa, the Middle East, southern Europe, North America, and parts of East and South Asia, and is also expected to continue through the 21st century (*Lhotka et al*., 2018, *Dai*, 2011). Continental-scale assessments using NASA's NEX-GDDP downscaled models indicate future severe droughts to potentially become increasingly widespread in frequency in the United States, particularly in the western states and during summer months, in response to changes in precipitation and temperature (*Ahmadalipour et al*., 2016). Basin-scale studies report analogous results. For instance, multi-model studies evaluating future changes in ETref in the Segura River Basin (southeastern Spain) point out a significant upward trend in ETref in accordance with most of the climate scenarios, particularly RCP8.5, with stronger increases in the upstream regions of the basin. Amongst the multi-model methods utilized, the Random Forest algorithm indicated the best accuracy in the reproduction of daily ETref (*Ruíz Álvarez et al*., 2021). Studies that have examined the climatic drivers of evapotranspiration change further highlight the dominating role of solar radiation, relative humidity, and minimum temperature. In the case of Zhejiang Province in China, for example, these three projected variables for 2011–2040 contribute most to future PET variability, showing marked seasonal and spatial differences according to the climate model used (*Xu et al*., 2014).

High-resolution climate modeling in mountainous headwater systems, such as the Upper Colorado Basin, suggests that despite increases in winter precipitation, higher fractions of evapotranspiration and reduced snowfall ratios result in overall reductions in annual runoff by approximately 6%. In addition, earlier timing of snowmelt and peak discharge events under these conditions is further evidence of increasing basin dryness under projected future climate conditions. This conclusion is based on work by *Rasmussen et al*. (2014). Similarly, application of the multivariate drought indices-MDI-and entropy-based analysis in Texas reveal that climate change is likely to expand high-risk drought zones and increase socio-economic vulnerability. Such studies not only map the combined risk of drought on spatial distributions but also quantify causal relationships between hydroclimatic drivers of drought occurrence by identifying the most dominant drivers of future drought hazards. These are based on the work done by *Rajsekhar et al*. (2015). Due to its geographical position and mostly arid to semi-arid climate, Iran is one of the more vulnerable territories regarding the impacts of climate change. There is evidence that the country's mean temperature increased by almost 2 °C within the last century, with large portions of the semi-arid zones having gradually been shifted toward drier conditions according to

Gholami et al. (2017). Furthermore, being among the key greenhouse gas emitting countries of the Middle East, Iran is directly exposed to the climatic consequences in a way that the changes manifest themselves in rising temperatures and declining precipitation, changes in seasonal rainfall, and more intensive droughts according to *Daneshvar et al*. (2019).

Qazvin Province is one of the major agricultural hubs in Iran, which is located in an arid to semi-arid climate and presently faces acute challenges regarding available water resources. The province covers two major basins, Shahroud–Sefidrud and Shur River, and is very dependent on groundwater resources, with aquifers providing over 80% of the total water demand. This heavy reliance, coupled with the pressures of population growth, urban expansion, industrial development, and agricultural needs, has been associated with alarming declines in groundwater levels. The consequences include land subsidence, water quality degradation, agricultural water stress, and the weakening of natural ecosystems. Recent studies have pointed out even more severe threats to the future of water resources in Qazvin Province. *Ghorbani and Valizadeh* (2014) showed that under climate change, the first autumn frost and the last spring frost will be advanced, thereby reducing the frost period. In practice, this means an extended growing season and increased crop water needs. Moreover, *Mirsane et al*. (2011) have found that the crop water demand during 2010–2039 may increase by at least 30%, indicating a great impact of climate change on evapotranspiration and consequently the agricultural water management. Altogether, all of these pieces of evidence explain that climate change, besides altering precipitation and temperature regimes, significantly affects hydrological processes and water balance due to the increased evapotranspiration, thereby intensifying drought conditions at various levels. Therefore, a detailed and spatially explicit analysis of evapotranspiration and drought in various climate scenarios is necessary to enable planning for adaptation to future conditions. Such an analysis can be useful for identifying critical hotspots, developing agricultural water management strategies, adjusting cropping patterns, and proposing effective adaptation solutions. It is important to underline that analyzing these phenomena independently cannot give a comprehensive picture of future water stress.

Changes in one climatic component (e.g., temperature) exert direct and indirect impacts on others (e.g., evapotranspiration), ultimately influencing the severity and duration of drought. Up to date, the lack of an integrated spatial assessment, which identifies the high-risk regions with increased evapotranspiration and intensified drought, represents a major knowledge gap in water resource planning and climate adaptation policymaking. The main goal of this study is to perform the spatial analysis of evapotranspiration and drought for Qazvin Province in the context of different climate change scenarios and to analyze the interrelationship between these two important components. This study tries to bring about an overall picture of future changes through integrating climatic data, predictive modeling, and spatial indicators. Besides, region-specific and applicable adaptation strategies concerning drought resilience and sustainable water resource management are one of the key objectives of the present study.

Accordingly, to operationalize the above-mentioned objectives and to provide a clear framework for the analysis, this study addresses the following research questions**:**

- How will evapotranspiration spatial patterns change in the Qazvin region under different climate change scenarios?
- How will the frequency, severity, and spatial distribution of drought evolve under future climate conditions?
- What is the spatial relationship between changes in evapotranspiration and drought intensity across the study area?
- Which areas can be identified as high-risk hotspots due to the simultaneous increase in evapotranspiration and drought severity?
- How can the results support region-specific adaptation strategies for agricultural water management under climate change?

2. *Material and method*

2.1. Study area

Qazvin Province, with its area of approximately 15,800 km², is one of Iran's crucial regions in terms of economic, agricultural, and environmental importance. It borders the provinces of Alborz, Mazandaran, Gilan, Zanjan, Hamadan, and Markazi. This province is situated in an arid to semi-arid climatic zone with a long-term mean annual temperature of 12.4 °C and an average annual precipitation of 307.1 mm (*Fig. 1*). In this study, five synoptic and climatological stations, namely, Qazvin, Avaj, Buin Zahra, Takestan, and Moallem-Kelayeh, were used for the baseline period (1993–2020). The dataset included temperature, precipitation, relative humidity, solar radiation, and other variables required for evapotranspiration modeling and drought assessment. All data used were obtained from the Qazvin Province Meteorological Administration.

2.2. Climate change

Climate change, recognized as one of the most significant global challenges, is defined by the Intergovernmental Panel on Climate Change (IPCC) as long-term and, in some cases, irreversible alterations in the average state of the atmosphere. In recent years, the sixth phase of the Coupled Model Intercomparison Project (CMIP6) has been developed with the aim of enhancing the accuracy of climate projections and addressing the limitations of previous-generation models (CMIP5). In this study, to assess future climatic conditions in Qazvin Province, three radiative forcing scenarios – SSP126 (optimistic), SSP245 (intermediate), and SSP585 (pessimistic) – were employed, representing a wide range of socio-economic development pathways and greenhouse gas emission trajectories. Given the limitations of Global Climate Models (GCMs) in generating climate data with adequate spatial resolution, the use of statistical and dynamical downscaling techniques becomes essential. Accordingly, the Statistical Downscaling Model (SDSM), first introduced by *Wilby et al.* (2002), was applied as one of the most effective tools for climate downscaling and generating future scenario data.

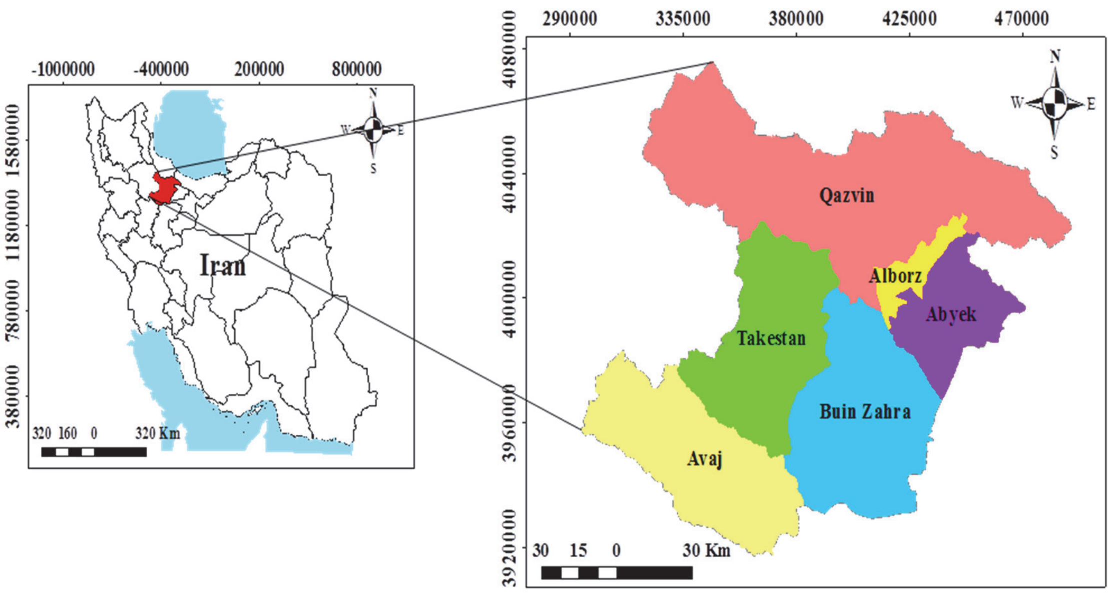

Fig. 1. Location of the study area in Iran

The Statistical Downscaling Model (SDSM) was selected in this study due to its wide use and proven reliability in regional climate downscaling (*Phuong et al*., 2020; *Munawar et al*., 2022; *Sami et al*., 2024). SDSM allows flexible selection of predictor variables, incorporates rigorous quality control procedures (Dafouf, et al., 2025), and has been successfully applied in numerous studies to generate high-resolution climate scenarios for regions with complex topography (Abed, 2021). These features make it particularly suitable for assessing future climatic conditions in Qazvin Province.

This model facilitates the simulation of future climate conditions by enabling data normalization, quality control, and the selection of appropriate predictor variables. In this study, 70% of the historical dataset was allocated for calibration and the remaining 30% for validation of the SDSM model. Prior to model implementation, quality control procedures – including the removal of outliers, reconstruction of missing data, normality testing, and the Pettitt test for homogeneity – were conducted.

2.3. Simulation of precipitation, temperature, and evapotranspiration

In the simulation of climatic components, daily meteorological observations of synoptic stations in the province were considered, together with the NCEP reanalysis data and the outputs of GCMs under the three scenarios (SSP126, SSP245, and SSP585). The steps involved in the downscaling process using SDSM are data normalization, choosing suitable synoptic predictors, and the investigation of regression relationships between the local observations and upper-air pressure fields. Since the distribution of daily precipitation is not normal, a fourth-root transformation was applied to enhance the fit of the model. For the baseline period 1993–2020, the meteorological data from five stations, Qazvin, Avaj, Buin Zahra, Takestan, and Moallem-Kalayeh, were used in the downscaling temperature, precipitation, and evapotranspiration.

2.4. Drought

One of the most widely used meteorological drought indicators, the standardized precipitation index (SPI), was applied to monitor and analyze drought conditions. The index is calculated based on precipitation deviation from the long-term mean over a specified time scale, normalized by the standard deviation over the same period. SPI can be computed for several time scales, including 1, 3, 6, 9, 12, 24, and 48 months, each representing different types of droughts, ranging from short term to long term. Drought occurs when SPI values are continuously negative, and SPI less than –1 indicates a notable drought intensity. Classes of drought severity based on SPI are shown in *Table 1*. *Yousefi-Ramandi* (2012) illustrated that longer SPI time scales have stronger relationships with variations in reservoir water levels, groundwater storage, and surface flow, hence, being specifically important for basin-scale drought assessments.

*Table 1***.** Classification of drought based on the SPI)

Drought class	**SPI values**
extremely wet	2 and above
severely wet	1.5 to 1.99
moderately wet	1 to 1.49
normal	-0.99 to 0.99
mild drought	-1 to -1.49
severe drought	-1.5 to -1.99
extreme drought	-2 and below

2.5. Data selection

Given the relevance of the record length of the precipitation for the time-series analyses, especially for trend detection and forecasting rainfall, as well as analyzing drought, this study has used monthly precipitation data from five stations with longer historical records in Qazvin Province. First, a common baseline period across all the stations was defined. Then, the quality control procedures involved the reconstruction of the missing data, removing outliers, and homogeneity and trend analysis within the dataset.

2.6. Assessment of climate model uncertainty

In simulations of climate, not all factors affecting a variable can be represented in a model, an approximation that inevitably introduces errors or uncertainties. The identification and quantification of these uncertainties are paramount in any assessment of model prediction reliability. A probabilistic model is considered appropriate if it can reproduce an accurate distribution with an acceptable level of certainty. The certainty of a distribution is commonly assessed by the width of the prediction interval. In the present study, model uncertainty was estimated using 95% confidence intervals. Model predictions, which were calculated from outputs using the posterior probability density function of parameters, excluded the most extreme 2.5% values at both ends as outliers. The resulting values determined the 95% confidence range, which was considered to reflect the model prediction uncertainty. With the objective of assessing overall model performance and uncertainty, a combined metric called the Uncertainty Performance Index (UPI) was used. This index combines two coefficients: P, representing the percentage of predicted data falling within the 95% confidence interval, and R, a normalized thickness factor of the confidence range. A higher value of UPI corresponds to better model reliability and less uncertainty, reflecting more desirable predictive performance

$$NUE_{CI}=\frac{P_{CI}}{R_{CI}}, \quad (1)$$

where NUE_{CI} denotes the normalized uncertainty performance, P_{CI} represents the percentage of predicted data (P) falling within the confidence interval (CI), and R_{CI} indicates the normalized thickness factor of the confidence interval (CI).

3. Results and discussion

3.1. Impacts of climate change on precipitation, temperature, and reference evapotranspiration

Fig. 2 shows the simulated precipitation, temperature, and reference evapotranspiration at Qazvin station (used here as representative) against observed values in the validation period (2009–2014). Because the daily precipitation is not normally distributed, a fourth-root transformation was applied in order to increase the fitness of the model. *Fig. 2a* shows the observed and simulated monthly precipitation patterns in the validation period. As with any kind of accumulation data, precipitation inherently bears high variability, discrete behavior, and a skewed distribution. Notwithstanding this natural heterogeneity, the overall annual precipitation pattern was successfully replicated with satisfactory accuracy by the model. From March to May, the peak precipitation occurs, and the pattern of this was well captured. In addition, the value of precipitation in July and August was correctly simulated around zero, which is reasonable in the semiarid region with dry summers. There is some mismatch between the observed and simulated precipitation in some months, particularly in March and April, due to its extreme and nonlinear nature. The fourth-root transformation reduced dispersion and aligned the simulated and observed data reasonably well. Given that one of the most challenging variables to simulate is precipitation, the capability to reproduce its seasonal pattern indicates the reliability of the model in studying the impacts of climate change on precipitation and drought of the region.

The successful simulation of monthly and annual precipitation patterns in Qazvin aligns with findings from other studies in semi-arid regions, demonstrating that statistical downscaling approaches, such as the Statistical Downscaling Model (SDSM), can effectively capture seasonal variability despite the high variability and non-normal distribution of rainfall (*Wilby et al.*, 2012). Similar results were reported by *Tabari et al.* (2021), who found that SDSM accurately reproduced precipitation patterns in semi-arid regions and outperformed some other downscaling approaches in capturing extreme events. In addition, *Woyessa* (2024) highlighted that SDSM is particularly suitable for semi-arid basins due to its flexibility in predictor selection and rigorous quality control. The minor discrepancies observed in March and April are consistent with the inherent challenges in simulating extreme and nonlinear precipitation events, as noted in previous studies (*Rezaei et al.*, 2014; *Ahmadalipour et al.*, 2017). Overall, these comparisons with existing literature confirm the reliability of SDSM for assessing climate change impacts on precipitation and drought in the Qazvin region.

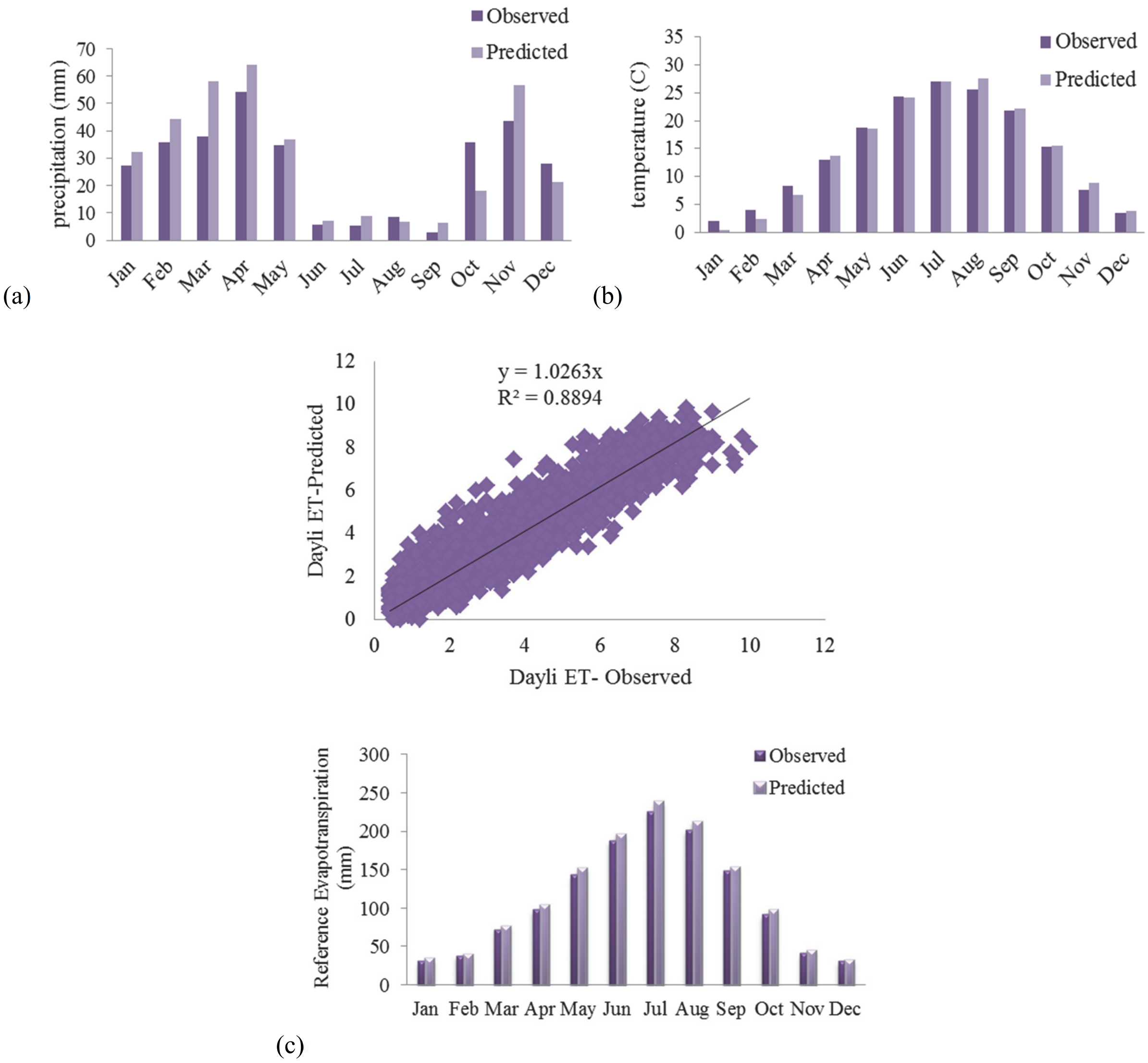

Fig.2. Monthly mean observed values compared with simulated values at Qazvin Meteorological Station for the validation period (2009–2014): (a) precipitation, (b) temperature, and (c) reference evapotranspiration (ET_0).

3.2. Temperature and reference evapotranspiration

Fig. 2b shows the observed and simulated monthly temperature patterns for the Qazvin station during the validation period (2009–2014). As can be seen, the model satisfactorily simulated the annual trend of temperature increas e –from the end of January up to the peak of summer (July and August) – and then its decline at the end of the year. The maximum temperatures of both datasets occurred during July and August, with an approximate value of 30 °C, and the minimum temperature occurred during December and January. The differences between the observed and simulated values varied usually from 1 to 2 °C, indicating a good fitness of the model. In fact, temperature is one of the most stable climatic variables; therefore, such high performance by the model is expected. This accurate representation signifies that the model is reliable enough for future scenario analyses, investigating temperature changes, and assessing their impacts on evapotranspiration and drought indices. *Fig. 2c.* shows the monthly variations of the simulated versus the observed reference evapotranspiration, ET_0. The model simulated the monthly pattern of ET_0 with a very high accuracy. The pattern starts growing from February and March toward the warm months to reach its peak in July and August at about 250–280 mm and fits well with the climatic behavior of the region. Considering that ET_0 is primarily driven by temperature, solar radiation, wind speed, and relative humidity, all of which are satisfactorily generated by the model, the close agreement between the observed and the simulated ET_0 is expected. Small discrepancies (less than 5%) are mostly related to short-term fluctuations in relative humidity and wind variations, which might not fully be grasped by the model. In any case, high accuracy in ET_0 is an important added value since ET_0 is a key variable in estimating crop water requirements, water balance studies, and agricultural drought modeling. Thus, this model would be highly applicable for climate change scenario analyses.

The SDSM model accurately reproduced the annual temperature pattern in Qazvin, with differences of only 1–2 °C and a summer peak around 30 °C, reflecting the inherent stability of temperature. Similar performance has been reported in other semi-arid regions. For instance, in the Vu Gia Thu Bon Basin, Vietnam, SDSM captured seasonal patterns and extremes well, with NSE > 0.8 and projected maximum and minimum increases of 2.67–3.9 °C and 1.24–1.96 °C under RCP8.5, respectively (*Phuong et al*., 2020). In the Jhelum Basin, Himalaya, SDSM simulated daily maximum and minimum temperatures with low MAE and RMSE (KGE = 0.67–0.71), reproducing predicted warming of 2.37–4.66 °C (max) and 2.47–4.52 °C (min) under RCP4.5/8.5 and seasonal patterns including stronger winter and pre-monsoon warming. (*Munawar et al*., 2022). These comparisons confirm that SDSM consistently reproduces seasonal temperature patterns and extremes in semi-arid regions, with accuracy comparable to that observed in Qazvin.

3.3. Evaluation of distribution and median differences

Non-parametric tests, such as the K-S and Wilcoxon tests, were carried out to investigate the distribution and median differences between observed and simulated data. The test results for these three climatic variables, as tabulated in *Table 2*, reveal that all the KS test statistics are below the critical value of 0.665. Also, based on the P-value obtained from the Wilcoxon test, all are above the 0.05 significant level. Thus, both tests state that no significant difference exists between historical observations and model-generated data during the validation period. These results indicate that the model's predictions are reliable and acceptable.

Table 2. Results of the Wilcoxon and Kolmogorov-Smirnov non-parametric tests for simulated temperature, precipitation, and reference evapotranspiration (ET_0) at a 0.05 significance level

Statistical parameter	Precipitation	Temperature	Reference evapotranspiration
Wilcoxon (Pvalue)	1.0	0.724	0.84
Kolmogorov-Smirnov	0.083	0.25	0.166

For model validation and a more detailed assessment of simulation errors, the statistical metrics including mean absolute error (MAE), root mean square error (RMSE), Nash–Sutcliffe efficiency (NSE), and the coefficient of determination (R^2) were employed. The results are presented in *Table 3*.

Table 3. Comparison of simulated precipitation and reference evapotranspiration (ET_0) with observed values during the validation period (2009–2014)

Statistical parameter	Temperature (°C)	Precipitation (mm/month)	Reference evapotranspiration (mm/month)
MAE	0.84	7.80	5.40
RMSE	1.10	9.90	6.40
R^2	0.90	0.81	0.90
NSE	0.98	0.63	0.99

The results show satisfactory performances of the model in the simulation of precipitation, ET_0, and temperature. Regarding this, the MAE values for ET_0, precipitation, and temperature were found to be 5.46 mm, 7.8 mm, and 0.84 °C, respectively, indicating relatively low errors at the monthly scale. The RMSE was 6.4 mm for ET_0, 9.9 mm for precipitation, and 1.1 °C for temperature, confirming these findings on the goodness of the simulations. The R^2 was 0.9 for ET_0 and temperature and 0.81 for precipitation, showing good agreement between simulated and observed values. Also, the NSE values were 0.99 for ET_0, 0.98 for temperature, and 0.63 for precipitation. This shows a high model skill regarding the reproduction of ET_0 and temperature trends and medium accuracy for precipitation. In general, the validation results indicated that the model provides a reliable and robust representation of hydrological processes of the region and is suitable for further scenario analyses.

3.4. Analysis of annual temperature and precipitation trends in Qazvin using the Mann–Kendall test and Sen's slope

3.4.1. Temperature

In order to investigate the trends of annual mean temperature in Qazvin, the Mann-Kendall test and Sen's slope were used, as shown in *Table 4*. It can be seen from the results that there is a significant increasing trend in annual mean temperature during the period 1993–2060 in all three SSP scenarios, namely SSP126, SSP245, and SSP585. The slope was found to be steeper under SSP585, reflecting strong warming under high greenhouse gas emission conditions. This indicates that, over time and with increased greenhouse gas concentrations, the mean temperature is projected to increase gradually and at significant rates. During the baseline period, from 1993 to 2014, there was a slight increase in temperature; however, it was not significant because of the relatively short period and thus smaller natural variability. In general, these results clearly confirm the warming trend in Qazvin for the future climate scenarios and emphasize the fact that the magnitude of temperature increases would be more pronounced under higher emission pathways.

These findings are consistent with numerous studies conducted in semi-arid and arid regions, which have reported significant upward trends in annual mean temperature using non-parametric trend detection methods such as the Mann–Kendall test and Sen's slope estimator. For example, *Ahmadalipour et al*. (2017)1 identified significant warming trends across dry regions using climate model projections, with stronger slopes under high-emission scenarios. Similarly, *Manohar et al.* (2018) reported increasing temperature trends in semi-arid regions, emphasizing that temperature rise intensifies hydrological stress and alters water balance components. Overall, the agreement between the present results and previous studies confirms the robustness of the detected warming trend in Qazvin and reinforces the conclusion that future temperature increases will be more pronounced under higher emission scenarios, with important implications for evapotranspiration enhancement and drought intensification.

Table 4. Mann-Kendall test results and Sen's slope for the annual mean temperature of Qazvin

Statistical period	Scenario	P-value	Z	Trend slope
1993–2060	SSP126	*0.0001	3.7	0.008
	SSP245	*0.0001	3.6	0.008
	SSP585	*0.0000	4.5	0.009
1993–2014	baseline period	0.0900	1.2	0.030

* Significant at the 5% level

Fig. 4. illustrates the modeled monthly average temperatures under the considered scenarios for 2015–2060 with respect to the baseline period, which is representing the available data from 1993 to 2014 for each station. All the modelled scenarios indicated that the minimum temperature increase among the study stations will be about 0.5 °C until 2060. The greatest rises in temperature will occur during the warm months, and the maximum increase concerning the baseline will happen in August and will be over 1.2 °C.

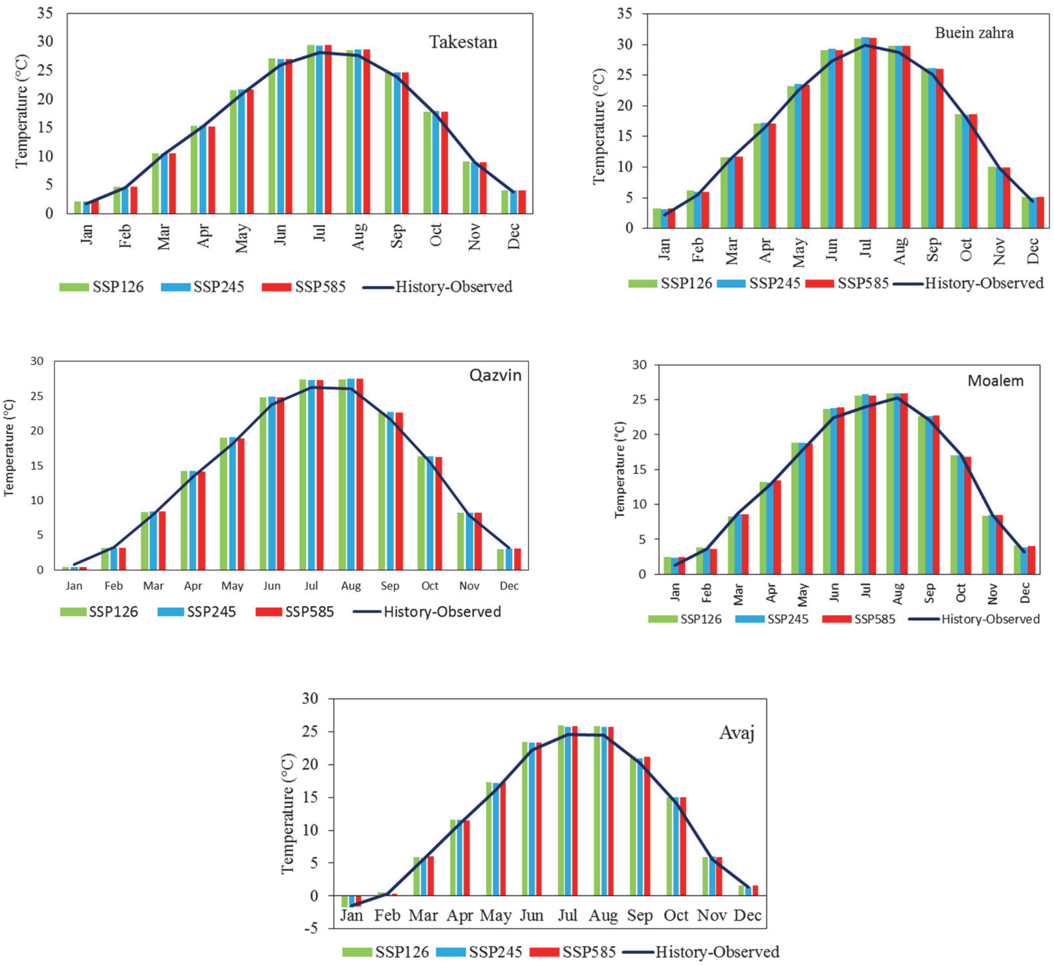

Fig. 4. Trends of monthly mean temperature under the studied scenarios in the future climate compared to the baseline period.

3.4.2. Precipitation

The results show that in all three scenarios, SSP126, SSP245, and SSP585, there is no statistically significant trend at the 5% level of significance during the period 2015–2062. In other words, the future annual precipitation under these scenarios does not appear to increase or decrease clearly, with no definite projection of precipitation change available. Similarly to this, precipitation also varies insignificantly during the baseline period, thus depicting that on a shorter timescale, annual precipitation remained fairly stable, and natural interannual variability may be more dominant than the long-term trend. Therefore, unlike mean temperature showing a clear upward trend, annual precipitation does not exhibit substantial or consistent changes in the future. This may impose potential risks for water resource management due to the fact that random fluctuations in precipitation could impact agriculture and water availability without providing any reliable long-term trend. The results are presented in *Table 5*.

Table 5. Mann-Kendall test results for annual mean precipitation data

Statistical period	Scenario	P-value	Z
	SSP126	0.7	-0.60
2015–2062	SSP245	0.1	0.90
	SSP585	0.5	-0.02
1993–2014	baseline period	0.7	-0.50

* Significant at the 5% level

Fig. 5 presents the projected change in precipitation values for the three scenarios (SSP126, SSP245, and SSP585) with respect to the baseline period. Overall, all three scenarios show a general expected decrease in mean precipitation when compared to the baseline; however, as indicated above, this decrease is not statistically significant. More importantly, the projected increase in precipitation over February and March from the baseline indicates that during these months (late winter), most crops within the region may have their requirements substantially satisfied with the present precipitation levels.

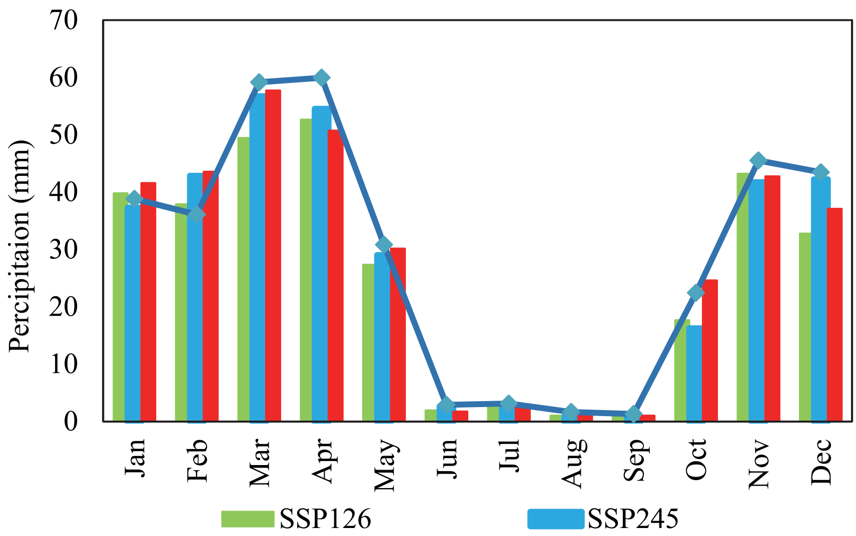

Fig. 5. Trends of mean monthly total precipitation at Qazvin station for 2015–2062 under the studied scenarios compared to the baseline period (1993–2014).

The simulated annual precipitation based on the outputs of the studied scenarios for the years 2020 to 2062 is presented in *Fig. 6*.

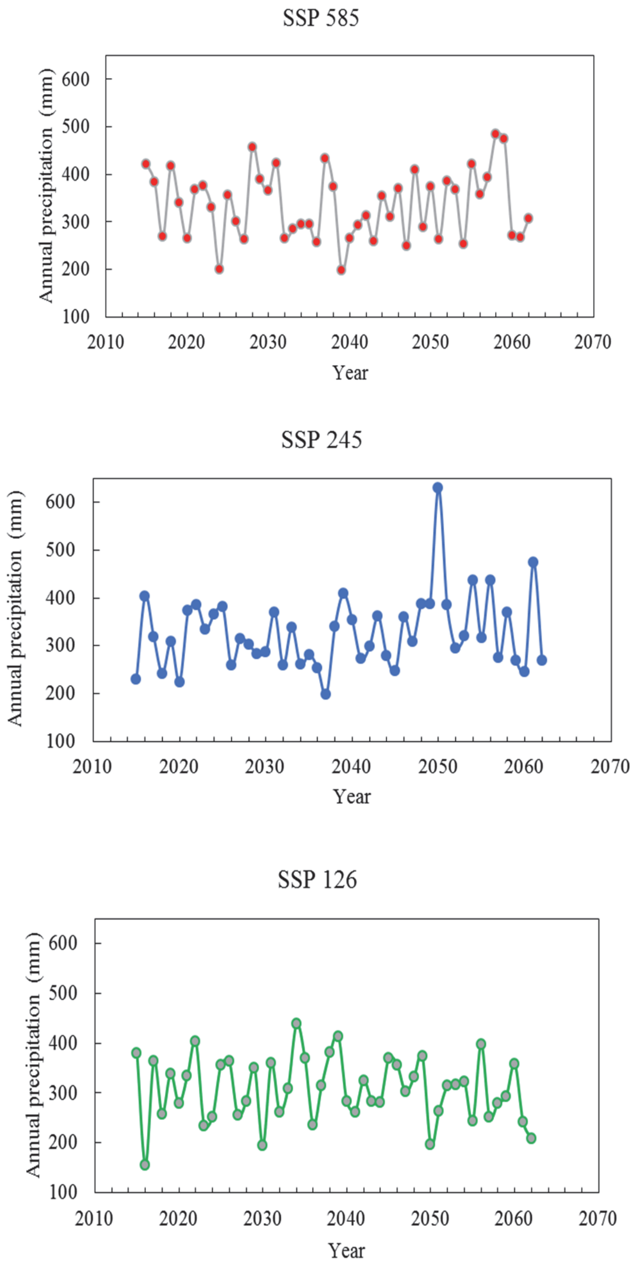

Fig. 6. Simulated annual total precipitation for the period 2015–2062 based on the Sixth Assessment Report climate scenarios.

3.5. Comparison of SSP scenario predictions with observed temperature and precipitation in Qazvin (2015–2020)

As the simulation of climate model scenarios started in 2015, the simulated results were compared with observational data for the period 2015–2020 when both datasets were available to examine the accuracy of models. Based on the different statistical indicators provided in *Table 6*, the temperature simulations with the highest accordance are with the predictions of the SSP245 scenario. The SSP245 is a moderate-to-high radiative forcing pathway with medium future CO_2 emissions, and based on that pathway, the temperature is expected to increase by about 4°C by 2100. According to error and performance indices, MAE, RMSE, NSE, and R^2 for SSP245 are better than for the other scenarios. Also, according to the P-value of the Wilcoxon test, which is close to 1 (0.96), there is no significant difference between simulated and observed data in this short period. The results of the Kolmogorov-Smirnov test are below the critical value for all three scenarios and confirm that the distribution of simulated data does not significantly deviate from the observed one. Accordingly, this analysis shows that for the short-term period 2015–2020, the SSP245 climate scenario has given the best temperature prediction. The model has been able to reproduce annual temperature variability in Qazvin. Thus, this confirms that it is suitable for long-term temperature trend analysis and for the evaluation of different future climate scenarios.

Table 6. Comparison of simulated temperature values under the studied scenarios with observed temperatures for the period 2015–2020

Temperature	SSP126	SSP245	SSP585
MAE	0.92	0.81	0.98
RMSE	1.08	1.02	1.11
NSE	0.99	0.99	0.98
R^2	0.98	0.99	0.98
Wilcoxon (P-value)	0.74	0.96	0.50
Kolmogorov-Smirnov	< critical value	< critical value	< critical value

Previous studies consistently highlight the suitability of intermediate emission scenarios such as SSP245 (or RCP4.5) for long-term temperature analysis. In Morocco, RCP4.5 projections for 2025–2100 indicated an average warming of about 1.78 °C, with short-term validation confirming model reliability for climate adaptation planning (*Kalita et al.*, 2023). In the Himalayan region, RCP4.5 successfully captured pronounced winter warming (~2.47 °C) with high validation performance, supporting its use in long-term hydrological impact assessments (*Munawar et al.*, 2022). Similarly, studies in India reported that SSP4.5-based simulations reproduced temperature-driven runoff reductions up to 2050 with high agreement to observations, demonstrating its robustness for evaluating future water-stress conditions. Collectively, these findings suggest that

SSP245 provides a balanced and realistic framework for climate impact assessments in semi-arid regions such as Qazvin (*Abed*, 2021).

Amongst the statistical indicators in *Table 7*, the observed precipitation in the period of 2015–2020 had the highest agreement with simulated values of the SSP126 scenario. The SSP126 pathway includes a low radiative forcing pathway that is supposed to provide an approximate value of radiative forcing at 2.6 W/m² by 2100. The projections under this pathway showed that the mean annual precipitation in the Qazvin province might decrease by at least 10% at the end of 2062 compared to the base period. Further confirmation of the model accuracy indices shows that SSP126 has lower MAE and RMSE values than the other scenarios. Its R2 and NSE values also stand at 0.90, showing the high accuracy of the model in reproducing precipitation data. The results of the Wilcoxon and Kolmogorov-Smirnov tests do not indicate a statistically significant difference between simulated and observed values. Therefore, such results confirm that for the short-term period of 2015–2020, the SSP126 scenario can provide the most reliable precipitation predictions, and the model will be able to reproduce the annual variations in Qazvin precipitation in an acceptable mode. Such findings also highlight a probable reduction in the mean precipitation in the future and emphasize the need to apply proactive water resources planning in response to climate change.

Table 7. Comparison of simulated precipitation values under the studied scenarios with observed precipitation for the period 2015–2020

Precipitation	SSP126	SSP245	SSP585
MAE	4.80	9.52	10.22
RMSE	6.39	13.77	15.91
NSE	0.90	0.52	0.36
R^2	0.90	0.59	0.62
Wilcoxon (P-value)	0.30	0.72	0.50
Kolmogorov-Smirnov	< critical value	< critical value	< critical value

3.6. Spatial analysis of climate change scenarios

In this section, precipitation and temperature changes of the studied future period, 2020–2060, relative to the baseline period, 1993–2020, were estimated and analyzed using spatial interpolation methods. The maps were prepared according to the annual averages of the statistical periods to illustrate clearly the spatial variability of precipitation and temperature. The results showed that under future climate conditions, the minimum precipitation across the province will be reduced. As discussed in the previous section, Qazvin's precipitation pattern is in the best agreement with the SSP126 scenario predictions. Therefore, the spatial mapping of precipitation changes was performed based on SSP126 with respect to the baseline period. It was observed that precipitation will be reduced over most areas of the province. The reduction is at its maximum in the southeastern area. This region will also witness more intensive drought conditions (*Fig. 7*).

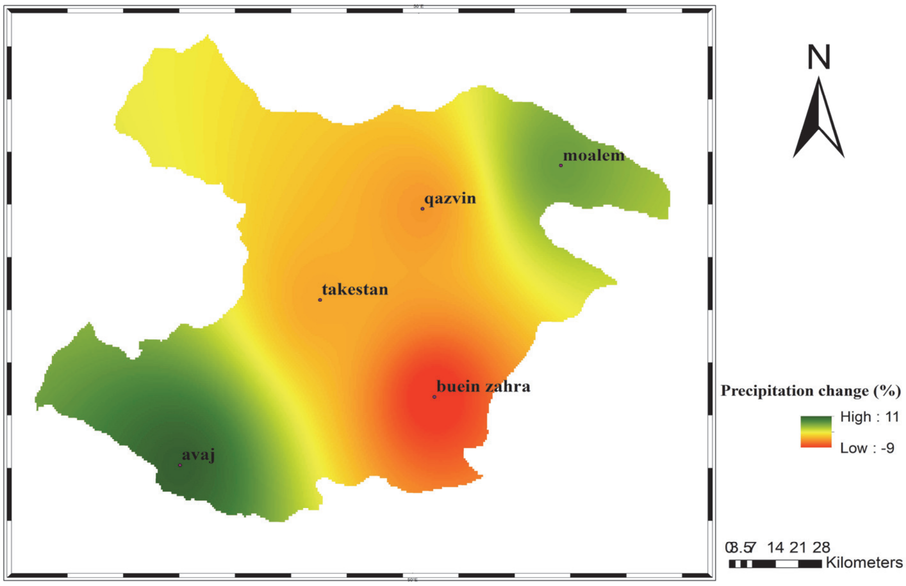

Fig. 7. Predicted precipitation changes under the SSP126 scenario for the future climate compared to the baseline period.

Spatial analysis of annual average temperature also shows that in both the baseline period and future climate conditions, the maximum temperatures occur in the Bouin-Zahra area. Moreover, the higher projected temperature rise in future climate conditions relative to other parts of the province underlines the fact that this area will be a focal point of warming. In general, the spatial analysis results imply that the climate of Qazvin Province in the future will be characterized by lower precipitation and higher temperatures. The identified point confirms that water resources management and climate change adaptation plans are required to focus with more attention and emphasis on the southeastern parts of the province and on the Bouin-Zahra area, due to the intensity of changes over these areas. *Fig. 8* presents the spatial distribution of annual average temperatures corresponding to the baseline period and to the studied scenarios for the future climate conditions. From this figure, it is clear that the highest temperatures for Qazvin Province occur over the Bouin-Zahra area during both the base period and under future climate conditions, with the highest rate of warming projected over this area.

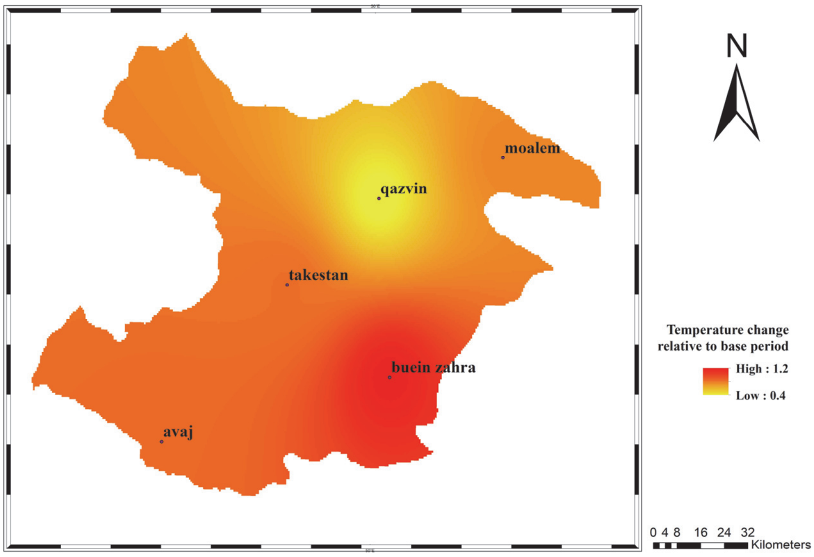

Fig. 8. Changes in annual mean temperature under the SSP245 scenario for the future climate compared to the baseline period mean temperature.

The spatial distribution of daily reference evapotranspiration (ET_0) during the baseline period and the future period under SSP126, SSP245, and SSP585 scenarios is presented in *Fig. 9*. The highest ET_0 values during the baseline period were observed in Bouin-Zahra and Takestan, and this pattern persists under future climate conditions. However, reference evapotranspiration also increases in other regions of the province, which can be attributed to the projected rise in temperature.

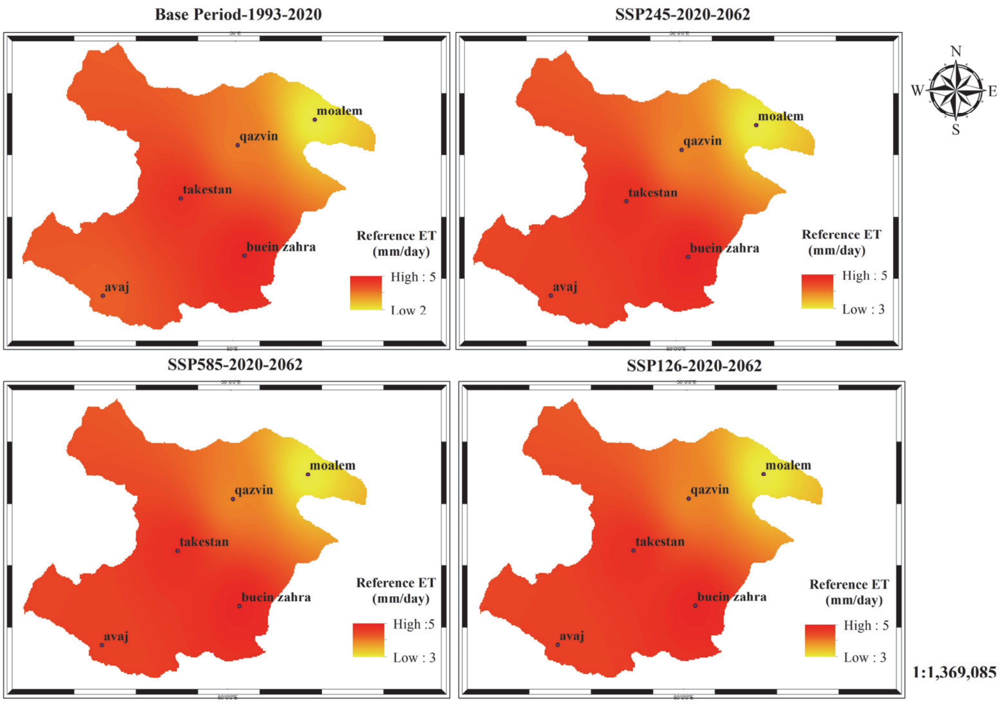

Fig. 9. Spatial distribution of daily mean reference evapotranspiration for the baseline period and future climate (2020–2062) under the studied scenarios.

3.7. Assessment of uncertainty in climate models

The analysis of the simulation results showed that temperature projections under the SSP245 scenario have the lowest uncertainty compared with other scenarios. As noted earlier, the statistical indices also confirmed that this scenario has the least error in the estimation of temperature, meaning it will provide more reliable temperature predictions. Contrarily, the simulated precipitation under the SSP126 scenario has the least uncertainty among all scenarios, and statistical indices confirm this scenario produces the most accurate precipitation estimates. Overall, the comparison indicates that uncertainty in precipitation projections is higher than for temperature, probably due to the more stochastic nature and higher variability over both short and long timescales.

3.8. Spatial analysis of drought under climate change conditions

Previous studies conducted in Qazvin Province have indicated that SPI has better spatial correlation compared to other indices for drought mapping. *Moradi* (2012) and *Naserzadeh et al.* (2012) had focused on this issue. Thus, SPI was adopted for the purpose of drought analysis in this study. It is worth stating here that the SPI at 12 months is quite appropriate for reflecting groundwater storage and river flows and is actually an effective indicator for hydrological drought. SPI analysis in recent years (from 2021 onward) indicates severe drought in this region. According to model outputs, the water resources in the province face critical conditions. Since meteorological and agricultural droughts usually precede hydrological droughts, a notable reduction in soil moisture has been recorded, raising vulnerability for rainfed agriculture. This accentuates the urgent need for sustainable water resource management policies and sharpened sensitivity in the implementation of land development projects. *Table 8* shows the drought and wet year frequency of each station for the study period. On average, the frequency of dry and wet years is almost equal (44.5% and 45.8%, respectively). In other words, hydrological drought and wet situations are almost in balance, but this condition reflects the vulnerability of the province's water resources because the natural system has limited capability for recovery against water scarcity. These results again highlight the necessity of implementing strict and sustainable policies to conserve and develop both surface and groundwater resources within Qazvin Province. Previous studies in Qazvin Province have shown that the standardized precipitation index (SPI) provides stronger spatial coherence for drought mapping compared to other indices, supporting its selection in this study (*Asgari et al.*, 2014). In particular, SPI at a 12-month time scale is widely recognized as an effective indicator of hydrological drought, as it reflects long-term precipitation deficits affecting groundwater storage and river flows. Similar applications of SPI-12 in semi-arid regions have demonstrated its reliability for identifying hydrological drought dynamics.

Table 8. Frequency (%) of drought and wet years at the stations during the study period based on the 12-month SPI (SPI-12)

Station	Statistical Period	Drought frequency (%)	Wet period frequency (%)
		SPI>0	SPI<0
Avaj	1997-2022	46.1	45.8
Buin Zahra	2006-2022	40.5	46.8
Moallem Kalaye	2002-2022	41.6	48.8
Qazvin	1993-2022	46.9	45.0
Takestan	2004-2022	47.3	43.0

The SPI for 2023–2062, according to the outputs of the AR6 climate scenarios, is shown for Qazvin Station (as an example) in *Fig. 10*. It shows that, under the SSP126 scenario, drought conditions remain until the end of 2025, followed by a period of moderate wet conditions. For the SSP585 scenario, the recent drought has continued until the end of 2027 and is then followed by a normal period. Under the SSP245 scenario, a normal period starts at the end of 2023 and continues until early 2026; after this, a moderate drought occurs until 2027. Spatially summarizing these results, *Fig. 11* presents the mapping of the 12-month average SPI under the studied scenarios for the next decade (2024-2034). This map outlines the expected spatial patterns of drought and wet conditions across the province.

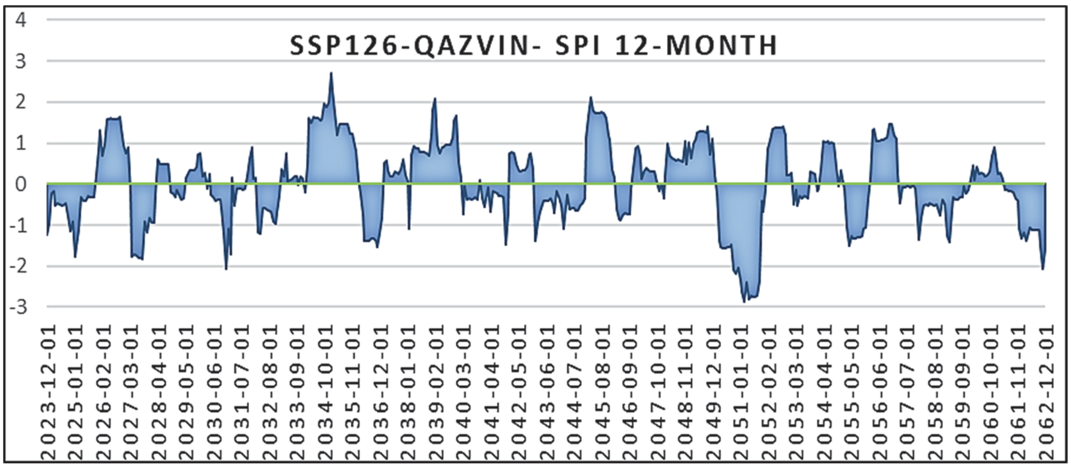

Fig.10. SPI-12 values for Qazvin station for the future period 2024–2062, based on CMIP6 scenario outputs.

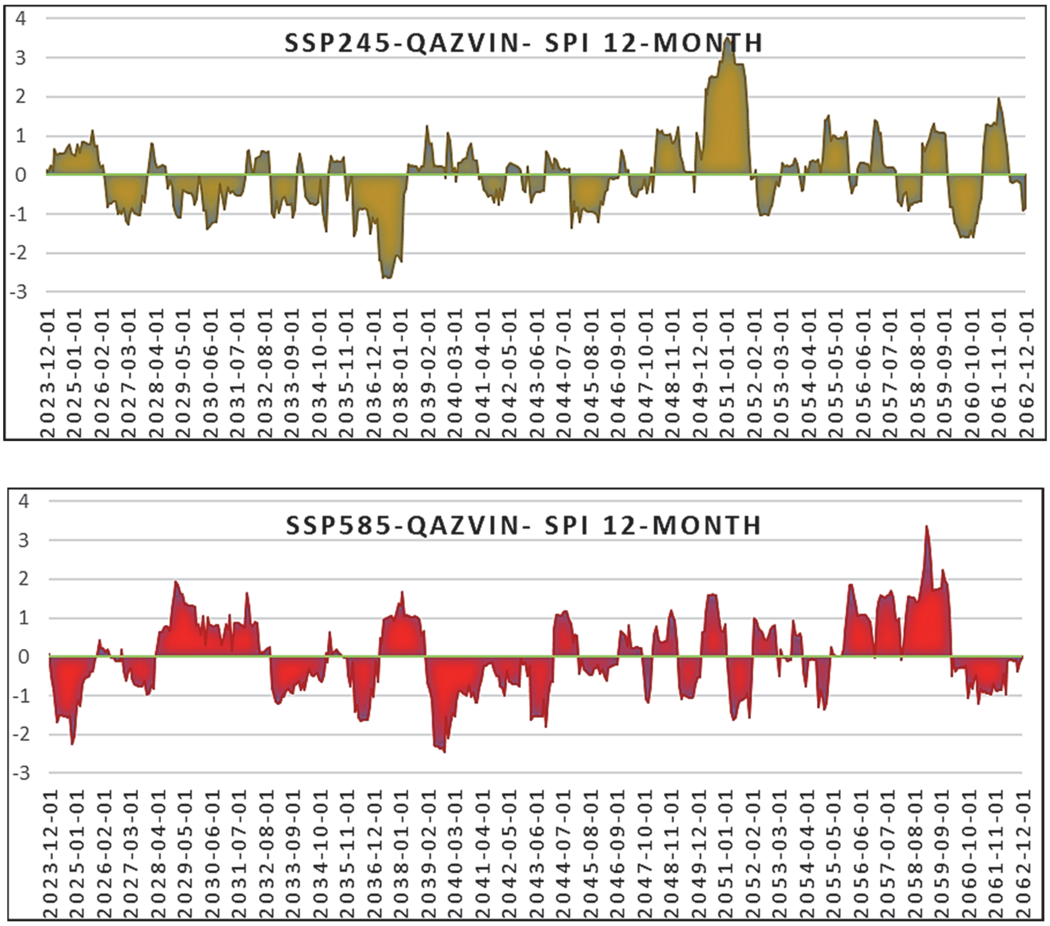

Fig. 10. Continued

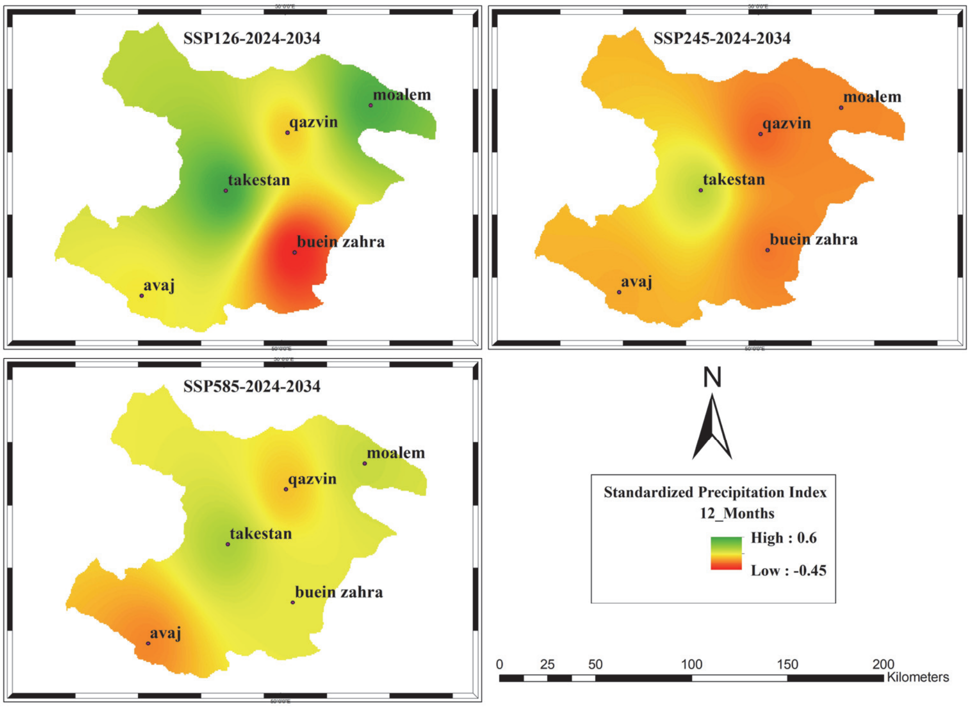

Fig. 11. Spatial distribution of the annual average SPI-12 values in Qazvin Province for the future climate based on SSP126, SSP245, and SSP585 scenario outputs (2024–2034)

4. Conclusion

According to the findings of this study, Qazvin Province is likely to experience a gradual and significant increase in temperature, along with a relative decrease in precipitation during the course of future climate change. Across all SSP scenarios (SSP126, SSP245, and SSP585), annual mean temperatures are trending upwards, especially under SSP585, which reflects a stronger warming under high greenhouse gas emissions. In contrast, changes in annual precipitation are not statistically significant, although it is possible to experience a reduction of approximately 10% in average precipitation. Based on a spatial analysis of the changes, it appears that the southeastern sector of the province and the Bou'in-Zahra region will be most affected by the reduced precipitation and the concentrated warming. Evapotranspiration is anticipated to increase across all areas, increasing the demands on water resources. Rainfed agriculture is at risk due to the 12-month standardized precipitation index's (SPI) severe drought events and alternating periods of drought and wet conditions, highlighting the vulnerability of surface and groundwater resources. In light of hydrological variability, forecasting precipitation is more uncertain than forecasting temperature, which highlights the importance of flexible planning and risk management.

These findings suggest the following measures for reducing vulnerability and enhancing resilience:

- Manage water resources sustainably by increasing the storage capacity of surface and groundwater, reducing water losses, and allocating water efficiently for agricultural and domestic uses.
- Promote climate-smart agriculture, cultivate low-water-use crops, and reduce the reliance on rainfed agriculture in vulnerable areas.
- Planning focused on adaptation and water resource management for the southeastern region and Bou'in-Zahra, which are expected to be most impacted by climate change.
- Maintain continuous monitoring and assessment by utilizing climate prediction models and drought indices for the purpose of periodically updating policies and programs related to water and agriculture.
- To enhance socioeconomic resilience, farmers and water users need to be trained in order to mitigate the economic and social impacts of droughts and climate change.

By implementing these measures, the province can increase its resilience to future droughts, increase its sustainability in agricultural production, alleviate pressure on water resources, and enhance its ability to adapt to climate change.

References

Abed, S. S., 2021: Future climate projections in Algeria using statistical downscaling model. *Research Square 1-29*. https://doi.org/10.21203/rs.3.rs-627355/v1

Ahmadalipour, A., Moradkhani, H., and *Svoboda, M.,* 2017: Centennial drought outlook over the CONUS using NASA-NEX downscaled climate ensemble. *International Journal of Climatology 37(5),* 2477-2491. https://doi.org/10.1002/joc.4859

Asgari, H., Mohsenipour, M., Shahid, S., Hadipour, S., Shafieifar, M., and *Roushenas, P.,* 2014: Spatio-temporal characteristics of droughts and drought trends in Qazvin Province of Iran. *Research Journal of Applied Sciences, Engineering and Technology 8(11),*1299-1311. https://doi.org/10.19026/rjaset.8.1100

Dafouf, S., Lahrach, A., Tabyaoui, H., and *Benaabidate, L.,* 2025: Future Evolutions of Precipitation and Temperature Using the Statistical Downscaling Model (SDSM), Case of the Guir and the Ziz Watershed, Morocco. *Earth. 6(1),*4. https://doi.org/10.3390/earth6010004

Dai, A., 2011: Characteristics and trends in various forms of the Palmer Drought Severity Index during 1900–2008. *Journal of Geophysical Research: Atmospheres. 116(12)* https://doi.org/10.1029/2010JD015541

Daneshvar, M. R. M., Ebrahimi, M., and *Nejadsoleymani, H.,* 2019: An overview of climate change in Iran: Facts and statistics. *Environmental Systems Research, 8(1),* 1–10. https://doi.org/10.1186/s40068-019-0135-3

Dehghanisanij, H., Kanani, E., and *Akhavan, S.,* 2020: Evapotranspiration and components of corn (Zea mays L.) under micro-irrigation systems in a semi-arid environment. *Spanish Journal of Agricultural Research, 18,* e1202. https://doi.org/10.5424/sjar/2020182-16814

Gholami, V., Jolandan, M. A., and *Torkaman, J.,* 2017: Evaluation of climate change in northern Iran during the last four centuries using dendroclimatology. *Natural Hazards 85(3),* 1835–1850. https://doi.org/10.1007/s11069-016-2667-4

Ghorbani, K., and *Valizadeh, E.* 2014: Studying frost and chilling dates affecting agriculture under climate change (Case study: Mashhad, Tabriz, Qazvin). *Journal of Water and Soil Conservation 21(4),* 197–211. (In Persian)

Kalita, R., Kalita, D., and *Saxena, A.,* 2024: Future projections of precipitation and temperature extremes at Sohra (Cherrapunji) using Statistical Downscaling Model. *Mausam 75(1),* 181-190. https://doi.org/10.54302/mausam.v75i1.6081

Kanani, E., Dehghanisanij, H., and *Akhavan, S.,* 2022: Variation in actual corn (Zea mays L.) evapotranspiration and crop coefficients under different point-source irrigation systems in a semiarid region. *Theoretical and Applied Climatology 148(1),* 303–315. https://doi.org/10.1007/s00704-022-03932-w

Kanani, E., Nazari, B., and *Dehghanisanij, H.,* 2025: A holistic assessment of water resources and management in the Zarrineh River sub-basin using *Water Accounting Plus. Scientific Reports 15,* 11725. https://doi.org/10.1038/s41598-025-XXXX-X

Karimi, V., Karami, E., and *Keshavarz, M.,* 2018: Climate change and agriculture: Impacts and adaptive responses in Iran. *Journal of Integrative Agriculture 17(1),* 1–15. https://doi.org/10.1016/S2095-3119(17)61794-5

Lhotka, O., Kyselý, J., and *Farda, A.,* 2018: Climate change scenarios of heat waves in Central Europe and their uncertainties. *Theoretical and Applied Climatology 131(3),* 1043–1054 https://doi.org/10.1007/s00704-016-2031-3.

Manohar, M. L., Sau, B. L., Jitendra Patidar, J.P., and *Abhishek Patidar, A.,P.,* 2018: Climate change and groundwater: impact, adaptation and sustainable. *International Journal of Bio-resource and Stress Management 9(3):* 408-415. https://doi.org/10.23910/IJBSM/2018.9.3.3C0671b

Mirsane, M., Sohrabi-Molayousef, T., Massah-Bavani, A., and *Bazrafshan, J.,* 2011: Assessment of uncertainties in AOGCM models and climate downscaling methods for simulating crop water requirements: Case study of Qazvin Plain. *In Proceedings of the 4th Iranian Water Resources Management Conference. Tehran.* https://civilica.com/doc/116974

Moradi, S., 2012: Drought monitoring based on precipitation-based indices in Qazvin Province (Master's thesis). *Faculty of Humanities, University of Zanjan, Zanjan, Iran.* (In Persian)

Munawar, S., Rahman, G., Moazzam, M. F. U., Miandad, M., Ullah, K., Al-Ansari, N., and *Linh, N. T. T.,* 2022: Future climate projections using SDSM and LARS-WG downscaling methods for CMIP5 GCMs over the transboundary Jhelum River Basin of the Himalayas Region. *Atmosphere 13(6),* 898. *https://doi.org/10.3390/atmos13060898*

Naserzadeh, M. H., and *Ahmadi, A.,* 2012: Evaluation of meteorological drought indices for drought assessment and spatial zoning in Qazvin Province. *Applied Researches in Geographical Sciences 12(27),* 141–162. (In Persian)

Nazari, B., Kanani, E., and *Sepehri, S.,* 2023: Assessment of water productivity improvement strategies using a system dynamics approach. *Applied Water Science 13(12),* 240. https://doi.org/10.1007/s13201-023-02044-8
Nazari, B., Kanani, E., and *Sepehri, S.,* 2024: A new perspective in assessing real water saving resulting from irrigation technology interventions. *Journal of Water Resources Planning and Management 150(9),* 04024033. https://doi.org/10.1061/JWRMD5.WRENG-6479.
Phuong, D. N. D., Duong, T. Q., Liem, N. D., Tram, V. N. Q., Cuong, D. K., and *Loi, N. K.,* 2020: Projections of future climate change in the Vu Gia Thu Bon River Basin, Vietnam by using statistical downscaling model (SDSM). *Water 12(3),* 755. https://doi.org/10.3390/w12030755
Rajsekhar, D., Singh,V. P., and *Mishra, A. K.,* 2015:Integrated drought causality, hazard, and vulnerability assessment for future socioeconomic scenarios: An information theory perspective. *J. Geophys. Res. Atmos. 120,* 6346–6378. https://doi.org/10.1002/2014JD022670.
Rasmussen, R., Ikeda, K., Liu, C., Gochis, G., Clark, M., Dai, A., Gutmann, E., Dudhia, J., Chen, F., Barlage, M., Yates, D., and *Zhang, G.,* 2014: Climate change impacts on the water balance of the Colorado headwaters: High-resolution regional climate model simulations. *Journal of Hydrometeorology (13),* 1091-1116. https://doi.org/10.1175/JHM-D-13-0118.1
Rezaei, M., Nohtani, M., Moghaddamnia, A., Abkar, A., and *Rezaei, M.,* 2014: Performance Evaluation of Statistical Downscaling Model (SDSM) in Forecasting Precipitation in two Arid and Hyper arid Regions. *Water and Soil 28(4),* 836-845. https://doi.org/10.22067/jsw.v0i0.23119
Ruíz Álvarez, M., Gomáriz Castillo, F., and *Alonso Sarría, F*., 2021: Evapotranspiration response to climate change in semi-arid areas: Using random forest as a multi-model ensemble method. *Water 13(2)*, 222. https://doi.org/10.3390/w13020222
Sami, S. S., Ali, A. A., and *Jalal, A. D. J.,* 2024: An application of the statistical downscaling model (SDSM) to simulate precipitation data in the Iraqi Western Desert*. AIP Conference Proceedings 3009, No. 1,* 030113. *AIP Publishing LLC*. https://doi.org/10.1063/5.0197996
Tabari, H., Paz, S. M., Buekenhout, D., and *Willems, P.,* 2021: Comparison of statistical downscaling methods for climate change impact analysis on precipitation-driven drought*. Hydrology and Earth System Sciences 25(6),* 3493-3517. https://doi.org/10.5194/hess-25-3493-2021
Terink, W., Immerzeel, W. W., and *Droogers, P.,* 2013: Climate change projections of precipitation and reference evapotranspiration for the Middle East and North Africa until 2050. *International Journal of Climatology 33(14),* 3055-3072. https://doi.org/10.1002/joc.3650
Wilby, R. L., Dawson, C. W., and *Barrow, E. M.,* 2002: SDSM—A decision support tool for the assessment of regional climate change impacts. *Environmental Modelling and Software 17(2),* 147–159. https://doi.org/10.1016/S1364-8152(01)00060-3
Woyessa, Y. E. 2024: Assessment of climate change impact and comparison of downscaling approaches: a case study in a semi-arid river basin*. Proceedings of International Association of Hydrological Sciences 385,* 97-102. https://doi.org/10.5194/piahs-385-97-2024
Xu, Y. P., Pan, S., Fu, G., Tian, Y., and *Zhang, X.,* 2014: Future potential evapotranspiration changes and contribution analysis in Zhejiang Province, East China. *Journal of Geophysical Research: Atmospheres 119(5),* 2174-2192. https://doi.org/10.1002/2013JD021245
Yousefi-Ramandi, R., 2012: Analysis of wet and dry periods in Qazvin Province using drought indices to determine the most appropriate drought indicator (Master's thesis). *Faculty of Geographical Sciences, Kharazmi University, Tehran, Iran.* (In Persian)
Zarrin, A. and *Dadashi-Roudbari, A.,* 2023: Evaluation of CMIP6 models in estimating temperature in Iran with emphasis on equilibrium climate sensitivity (ECS) and transient climate response (TCR). *Iranian Journal of Geophysics 17(1),* 39–56. https://doi.org/10.30499/ijg.2022.344862.1430