Effect of changing climate on rice water requirement in Guilan, north of Iran
Hossein Hadinia, Nader Pirmoradian and Afshin Ashrafzadeh

ABSTRACT
In this study, the effectiveness of 15 global climate models (GCMs) for simulating weather data of Rasht synoptic station in the north of Iran was evaluated using a statistical downscaling approach. Downscaling of GCMs was performed using a stochastic weather generator model (LARS-WG5.5) and the best GCM (INCM3) was selected. The parameters such as precipitation, radiation, temperature and reference evapotranspiration were simulated using the selected GCMs for two periods of 2013–2042 and 2043–2072, and accordingly, the rice water requirement was estimated for the coming periods. Then, simulated results were compared with data in the baseline period (1981–2010). The results showed that reference evapotranspiration (ET0) for all the seasons will increase in the coming periods. The highest ET0 increase (18.5–23.7 mm month–1) will occur in the spring. Also, the average rice water requirement will increase between 178 and 572 m3 ha–1 depending on the emission scenarios and future studied periods. The incremental changes in ET0 and, consequently, in rice water requirement for the coming periods will occur as a result of the significant increase in temperature. The results of this study can be used by local planners as a correct view of water demand in the future.

Key words | changing climate, GCM, LARS-WG, Rasht

INTRODUCTION
Risks of climate change are not limited to a few fields and have undesired negative effects on many natural phenomena. To deal with the effects of climate change, researchers try to reduce its negative effects by predicting its effects over the coming years and decades. One of the major impacts of climate change is on water resources availability and water requirements in the future. The crop water requirements are changed by climate change with changing weather parameters.

One way to predict the changes of meteorological parameters due to climate change is to apply the global climate models (GCMs). The output of a GCM has a very low spatial resolution. The dynamic and statistical approaches are used for obtaining local-scale data from large-scale data that are provided by a GCM. Downscaling models based on dynamic approach are too expensive and time-consuming, while the statistical downscaling is faster and easier. LARS-WG is a statistical downscaling model which produces local-scale meteorological data from the output of GCMs. The Intergovernmental Panel on Climate Change (IPCC) developed long-term emissions scenarios that have been widely used in the analysis of possible climate change, its impacts, and options to mitigate climate change (IPCC 2000). Three scenarios of A1B, A2 and B1 were considered in LARS-WG model and are presented in Table 1.

Baguis et al. (2010) predicted that the crop evapotranspiration in the central region of Belgium would be increased during the coming periods by an increase in temperature. Harmsen et al. (2009), using the statistical downscaling method, examined the precipitation and reference evapotranspiration. The results showed that the evapotranspiration in dry months would be increased by
Table 1 | Definitions of the IPCC special report on emission scenarios (IPCC 4th Assessment Report) (IPCC 2007)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1B</td>
<td>Describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies</td>
</tr>
<tr>
<td>A2</td>
<td>Describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in a continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines</td>
</tr>
<tr>
<td>B1</td>
<td>Describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1B storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives</td>
</tr>
<tr>
<td>B2</td>
<td>Describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels</td>
</tr>
</tbody>
</table>

Rodriguez et al. (2007) estimated that the seasonal irrigation water requirement would be increased to between 15 and 20% by 2050 in the Guadalquivir River Basin in Spain. Thomas (2008) confirmed the effects of the changes on water balance components in China. Based on the outputs of the Model for Interdisciplinary Research on Climate, version 3.2, Yun et al. (2011) predicted increasing trends of the irrigation water requirement, mainly due to increased evapotranspiration and decreased effective rainfall.

The effect of climate change on rice water requirements have been studied in some regions in the world. Yoo et al. (2012) showed that the change rates of total paddy water demand as affected by climate change in South Korea ranged between −2.7 and 2.7% for the A1B scenario, −1.0 and 0.0% for the A2 scenario, and −1.5 and 2.4% for the B1 scenario. Based on the Hadley Centre Coupled Model, version 3 (HadCM3) output, De Silva et al. (2007) predicted an increase of 13–23% in paddy rice water requirement during the wet seasons. Shahid (2011) predicted an increase of the rice paddy water requirement during dry-seasons in northwest Bangladesh. Shrestha et al. (2014) studied the impacts of climate change on irrigation water requirements for rice at Ngamoeyek Irrigation Project in Myanmar. A decreasing trend of irrigation water requirement was observed for irrigated paddy under the three scenarios, indicating that small irrigation schemes are suitable to meet the requirements.

In some studies (such as Koocheki et al. 2007; Ashraf et al. 2011; Yoo et al. 2012; Shrestha et al. 2014; Deb et al. 2016), typically, a GCM has been selected and downscaled to predict the effects of climate change. Although using the outcomes of different GCMs leads to different results, in most cases there is no criterion for selecting the best GCM in a particular area and one model is chosen randomly. This causes the error and thereby lack of the accuracy of the predictions.

In Guilan province, which is located in the northern part of Iran (Figure 1), rice is the most important crop. The rice cultivated area is about 230,000 ha in Guilan (Ministry of Jahad-e-Keshvarzi 2015). Sefidrud Dam is located on Sefidrud River upstream of Guilan plain and it supplies irrigation water for 189,000 ha of rice cultivated area. The rest of the paddy fields are irrigated by the local river or groundwater resources. Therefore, rice production in Guilan province is dependent on a proper and efficient water supply from the reservoir of Sefidrud Dam. In recent years various water storage and adjustments dams have been made in upstream basins of Sefidrud Dam. These activities have led to a reduction in water resources entering into the reservoir of Sefidrud Dam and a water supply crisis in the Guilan province. Many studies relating to rice irrigation management in the Guilan plain and ways to improve it have been conducted. Any research and planning will not achieve the desired outcome without considering future environmental hazards and climate change. The irrigation water requirement for rice and other crops will change due to changes in meteorological parameters. To achieve
Effective water resources planning, the planners need to know about change in water demand as affected by climate change. In this way, it is necessary to study and analyze the irrigation water requirement of paddy fields as affected by changing climate. Therefore, this study was conducted to forecast the effect of changing climate on rice water requirement in Guilan province.

**METHODS**

**Meteorological data**

Required meteorological data were obtained from Rasht synoptic station with a latitude of 49° 37' east, longitude of 37° 19' north and altitude of -8.6 m + MSL. The annual average temperature is about 16.2 °C with a monthly average range of 6.6–25.1 °C. The annual average precipitation is 1,369 mm for a 40-year period. Precipitation is highest in September (226 mm) and lowest in July (42.6 mm). The annual average relative humidity is 81%. Mean monthly maximum and minimum relative humidity is 86 and 74%, respectively.

**LARS-WG model description and calibration**

LARS-WG as a stochastic weather generator was used as the downscaling method (Semenov & Barrow 2002). Semenov et al. (1998) applied representative stochastic weather generators, WGEN and the LARS-WG, for different climate zones in Europe, the United States, Asia and other areas, and evaluated the accuracy of simulated results. It was found that the LARS-WG was more accurate than the WGEN. In this study, the values of daily precipitation, minimum temperature, maximum temperature and sunshine hours of Rasht synoptic station for the 30-year period (1981–2010) were given to the model as the baseline period data. The model was calibrated using observed station data in Site Analysis process. Also, the QTest process, which represents a statistical comparison of synthetic weather data generated using LARS-WG with the parameters derived from observed weather data (Semenov & Barrow 2002), was carried out.
Comparing the performance of GCMs through LARS-WG model

In order to evaluate the effectiveness of different GCMs and select the best models, climatological data that are predicted by 15 GCMs were downscaled by LARS-WG5.5 model in daily time steps. This was followed by simulating the daily precipitation ($P$), minimum temperature ($T_{\text{min}}$), maximum temperature ($T_{\text{max}}$), solar radiation (RAD) and reference evapotranspiration ($E_{\text{T}_0}$) data for the period 2011–2012, and the parameters were compared with the observed data in monthly time steps.

Due to the fact that the LARS-WG model calculates $E_{\text{T}_0}$ based on the data generated and using the Priestley–Taylor equation (Priestley & Taylor 1972), this parameter was calculated based on the data from Rasht synoptic station using the Priestley–Taylor method and compared with the values generated by the model.

In the simulation process of $P$, $T_{\text{min}}$, $T_{\text{max}}$, RAD and $E_{\text{T}_0}$, 15 GCMs including CGMR, CSMK3, FGOALS, GFCM21, GIAOM, HADCM3, HADGEM, INCM3, IPCM4, MIHR, MPEH5, NCCCSM, NCPCM, BCM2 and CNCM3 (Table 2) were evaluated. Model assessment was performed based on the relative root mean square error (RRMSE) and best models were selected. RRMSE provides a measure (%) of relative difference of predicted versus observed data (Equation (1)). The simulation is considered excellent, good, fair and poor if NRMSE is less than 10, 10–20%, 20–30% and more than 30%, respectively (Jamieson et al. 1991):

$$RRMSE = \left( \frac{\sum_{i=1}^{n} (X_i - Y_i)^2}{n} \right)^{1/2} \left( \frac{100}{\bar{X}} \right)$$

where $X_i$ and $Y_i$ are the actual and simulated values, respectively, $i$ is the months of the year, and $\bar{X}$ is the mean of the observed data.

Forecasting meteorological parameters

Using the selected GCMs, the values of meteorological parameters were forecasted for two periods, 2013–2042 and 2043–2072, under three scenarios of A1B, A2 and B1. Then, the forecasted values were compared with the baseline period (1981–2010). The comparison was carried out with monthly, seasonal and annual scales.

### Table 2

<table>
<thead>
<tr>
<th>GCM</th>
<th>Research center</th>
<th>Country</th>
<th>Available emissions scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 CGMR</td>
<td>Canadian Centre for Climate Modelling and Analysis</td>
<td>Canada</td>
<td>A1B</td>
</tr>
<tr>
<td>2 CSMK3</td>
<td>Commonwealth Scientific and Industrial Research Organization</td>
<td>Australia</td>
<td>A1B, B1</td>
</tr>
<tr>
<td>3 FGOALS</td>
<td>Institute of Atmospheric Physics</td>
<td>China</td>
<td>A1B, B1</td>
</tr>
<tr>
<td>4 GFCM21</td>
<td>Geophysical Fluid Dynamics Lab</td>
<td>USA</td>
<td>A1B, A2, B1</td>
</tr>
<tr>
<td>5 GIAOM</td>
<td>Goddard Institute for Space Studies</td>
<td>USA</td>
<td>A1B, B1</td>
</tr>
<tr>
<td>6 HADCM3</td>
<td>UK Meteorological Office</td>
<td>UK</td>
<td>A1B, A2, B1</td>
</tr>
<tr>
<td>7 HADGEM</td>
<td>UK Meteorological Office</td>
<td>UK</td>
<td>A1B, A2</td>
</tr>
<tr>
<td>8 INCM3</td>
<td>Institute for Numerical Mathematics</td>
<td>Russia</td>
<td>A1B, A2, B1</td>
</tr>
<tr>
<td>9 IPCM4</td>
<td>Institute Pierre Simon Laplace</td>
<td>France</td>
<td>A1B, A2, B1</td>
</tr>
<tr>
<td>10 MIHR</td>
<td>National Institute for Environmental Studies</td>
<td>Japan</td>
<td>A1B, B1</td>
</tr>
<tr>
<td>11 MPEH5</td>
<td>Max-Planck Institute for Meteorology</td>
<td>Germany</td>
<td>A1B, A2, B1</td>
</tr>
<tr>
<td>12 NCCCSM</td>
<td>National Centre for Atmospheric Research</td>
<td>USA</td>
<td>A1B, A2, B1</td>
</tr>
<tr>
<td>13 NCPCM</td>
<td>National Centre for Atmospheric Research</td>
<td>USA</td>
<td>A1B, A2</td>
</tr>
<tr>
<td>14 BCM2</td>
<td>Bjerknes Centre for Climate Research</td>
<td>Norway</td>
<td>A1B, B1</td>
</tr>
<tr>
<td>15 CNCM3</td>
<td>Centre National de Recherches Meteorologiques</td>
<td>France</td>
<td>A1B, A2</td>
</tr>
</tbody>
</table>
**Evaluation of meteorological parameters changes**

In order to evaluate the trends in the studied parameters in the growing period of rice, the time series of each parameter during the years 1981–2072 was drawn for the rice growing period. Then, according to the slope of the line fitted to the points, increasing or decreasing trends of changes were identified. To verify the trends existence, the Mann–Kendall test (Mann 1945; Kendall 1975; Gilbert 1987) was used. The Mann–Kendall test is based on the statistic $S$. Each pair of observed values $y_i, y_j$ ($i > j$) of the random variable is inspected to find out whether $y_i > y_j$ or $y_i < y_j$. Let the number of the former type of pairs be $P$, and the number of the latter type of pairs be $M$. Then $S$ is defined as Equation (2) (Onoz & Bayazit 2002):

$$S = P - M$$  \hspace{1cm} (2)

where $n$ is the length of data time-series, for $n > 10$, the sampling distribution of $S$ is as Equation (3). $Z$ follows the standard normal distribution where:

$$Z = \begin{cases} 
+1 & \text{if } (x_i - x_k) > 0 \\
0 & \text{if } (x_i - x_k) = 0 \\
-1 & \text{if } (x_i - x_k) < 0 \\
\frac{S - 1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\
0 & \text{if } S = 0 \\
\frac{S + 1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 
\end{cases}$$

The variance of $S$ is obtained from Equation (4):

$$\text{Var}(S) = \frac{n(n - 1)(2n + 5)}{18}$$  \hspace{1cm} (4)

So, if $|Z| \leq Z_{0.025}$ is established at the 95% confidence level, the hypothesis $H_0$ (accepting the random data series) is assumed to be true, otherwise the hypothesis $H_1$ (trend existence) is assumed to be true.

**Rice water requirement changes in future decades**

The changes in $ET_0$ as affected by changing climate were obtained from Equation (5):

$$\Delta ET_0 = ET_{0f} - ET_{0p}$$  \hspace{1cm} (5)

where $\Delta ET_0$ is the difference between monthly $ET_0$ in the coming and baseline periods (mm/day), $ET_{0f}$ is monthly $ET_0$ in the coming period (mm/day) and $ET_{0p}$ is monthly $ET_0$ in the baseline period (mm/day).

To obtain rice evapotranspiration ($ET_0$), $ET_0$ values were multiplied by crop coefficient ($K_c$) of rice for the corresponding growth period. The cultivar of the rice cultivated in the region is Hashemi which grows during May, June, July and August. To convert $ET_0$ changes to rice evapotranspiration changes in each period, the values of $K_c$ were multiplied by $\Delta ET_0$ values for the same period (Equation (6)). Crop coefficients and growth stages for rice in the study area were obtained from Pirmoradian et al. (2013) (Table 3).

$$ET_c = K_c \times ET_0$$  \hspace{1cm} (6)

Finally, the changes in rice water requirement in the total period of growth were calculated using Equation (7):

$$DW(\text{mm}) = (\Delta ET_{0i} \times K_{c-in}) + (\Delta ET_{02} \times K_{c-dev}) + (\Delta ET_{03} \times K_{c-mid}) + (\Delta ET_{04} \times K_{c-late})$$  \hspace{1cm} (7)

where $DW$ is the change in rice water requirement in mm, $\Delta ET_{01}, \Delta ET_{02}, \Delta ET_{03}$ and $\Delta ET_{04}$ are the sum of monthly evapotranspiration differences for different coming periods, as compared to the baseline period, and $K_{c-in}$, $K_{c-dev}$, $K_{c-mid}$ and $K_{c-late}$ are the crop coefficients for the initial, developmental, middle and late stages, respectively. Also, changes in the volume of water requirement in $m^3 ha^{-1}$ ($DW_v$) were calculated (Equation (8)):

$$DW_v(\text{m}^3 \text{ha}^{-1}) = DW(\text{mm}) \times 10$$  \hspace{1cm} (8)

### Table 3 | Crop coefficients and growth stages for rice in study area (Pirmoradian et al. 2013)

<table>
<thead>
<tr>
<th>Growth stage</th>
<th>Time (day)</th>
<th>Crop coefficient ($K_c$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>20</td>
<td>0.99</td>
</tr>
<tr>
<td>Crop development</td>
<td>20</td>
<td>1.25</td>
</tr>
<tr>
<td>Mid-season</td>
<td>30</td>
<td>1.35</td>
</tr>
<tr>
<td>Late season</td>
<td>20</td>
<td>1.14</td>
</tr>
</tbody>
</table>

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*p * Effect of changing climate on rice water requirement

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* Gilbert | 1987 | A Reference Text Reference |
RESULTS AND DISCUSSION

Validation of LARS-WG model

The results of Q-test for daily precipitation, $T_{\text{min}}$, $T_{\text{max}}$ and RAD are shown in Table 4. The comparisons of the probability distributions for the synthetic and observed data using the Chi-square goodness-of-fit test and the means and standard deviations using the t and F tests, respectively, showed that the simulated data probability distribution is close to the true long-term observed distribution for the Rasht site.

Validation of GCMs in simulation of meteorological parameters

The values of RRMSE obtained from the comparison between the observed and simulated data for the period of 2011–2012 with running of various GCMs are presented in Table 5. As shown in the results, RRMSE for $T_{\text{min}}$, $T_{\text{max}}$, RAD, $P$ and $E_{To}$ ranged between 7.3 and 9.6%, 4.7 and 6.8%, 13.6 and 17.8%, 40.0 and 47.5%, and 8.7 and 13.8%, respectively. With respect to the results, the LARS model had a good performance in the prediction of $T_{\text{min}}$, $T_{\text{max}}$, RAD and $E_{To}$. However, in the case of precipitation, variability of precipitation when compared with other parameters and short duration of comparison period can lead to high values of RRMSE. The best GCM was gained as INCM3 due to the lowest average of RRMSE (16.6%) in simulating five meteorological parameters.
Forecasting under A1B scenario

Future changes in meteorological parameters as compared to the baseline period under A1B scenario are shown in Figure 2. Assuming A1B scenario, the average of $T_{\text{min}}$ would be increased during both coming periods and for all months. The increase would be higher for 2043–2072 than 2013–2042. It varies from 0.1 to 1.1 °C and from 0.5 to 2.3 °C for the first and second 30-year period as compared to the baseline period, respectively. The highest amount of increase will occur in April and July for 2043–2072 and 2013–2042, respectively. The changes of $T_{\text{max}}$ will also be increased in both periods for all the months. The increase in the first 30-year period ranges from 0.1 °C in December to 1.9 °C in May. For the second 30-year period, the highest and the lowest increase will occur in May with 3.2 °C and in February at a rate of 0.8 °C, respectively. The increase rate will also be higher in the second 30-year period than the first 50-year period.

RAD changes in the first 30-year period in all the months except May, July, September and November and in the second 30-year period in all the months except May, July, October and November will increase as compared to the baseline period. The maximum rate of decline for 2013–2042 and 2043–2072 will occur in May with amounts of 14.1 and 13.9 MJ m$^{-2}$, respectively. The total monthly precipitation would be reduced slightly in February, May, August and September and it will increase in other months as compared to the baseline period for the first 30-year period. For 2043–2072, there

![Figure 2](https://iwaponline.com/jwcc/article-pdf/8/1/177/373318/jwc0080177.pdf)
will be a decrease in all the monthly precipitation except in June, August, September and October. The highest increases in precipitation for 2013–2042 and 2043–2072 will occur in December and October with 28.4 and 22.4 mm, respectively. $ET_0$ will increase during both coming 30-year periods. The highest changes will occur in April for both periods with 18.5 and 22.3 mm for the periods of 2013–2042 and 2043–2072, respectively.

**Forecasting under A2 scenario**

The results of assuming the A2 scenario is shown in Figure 3. Under this scenario, $T_{min}$ changes would be increased for all the months and both 30-year periods. The highest increase will occur in July with a value of 0.9 °C for 2013–2042 and 2.0 °C for 2043–2072 as compared to the baseline period. The average of $T_{max}$ in the first 30-year period will increase for all the months as compared to the baseline period. The highest amounts of increases for 2013–2042 and 2043–2072 would occur in April with 2.0 and 2.5 °C, respectively.

RAD changes in the first 30-year period for all the months except July, September, November and December, and in the second 30-year period for all the months except April, May, July, October, November and December will increase. The highest increase for 2013–2042 and 2043–2072 will occur in June with 11.6 MJ m$^{-2}$ and in August with 22.7 MJ m$^{-2}$, respectively, as compared to the baseline period.

**Figure 3** | Prediction of monthly changes in the parameters, under the A2 scenario, for 2013–2042 and 2043–2072 periods compared to the baseline period.
Under A2 scenario, precipitation will reduce in the first 30-year period for January, February, March, April and October and for the rest of the months it will increase as compared to the baseline period. The highest increase will occur in December at a rate of 27.2 mm. In the second 30-year period, precipitation in the months of January, February, March, May, July and August will decrease and in the remaining months it will increase. The highest increase with 38.4 mm will occur in October. \(ET_o\) for both periods and all the months will increase relative to the baseline period. The highest changes will occur in May with amounts of 22.7 and 21.2 mm for 2013–2042 and 2043–2072, respectively, as compared to the baseline period.

**Forecasting under B1 scenario**

Assuming the occurrence of B1 scenario, the predicted results are shown in Figure 4. According to the results, the average of \(T_{\text{min}}\) will increase in both 30-year periods as compared to the baseline period and the highest increase for 2013–2042 (1.0 °C) and 2043–2072 (1.5 °C) will occur in July. Also, the average of \(T_{\text{max}}\) during 2013–2042 and 2043–2072 will increase in all months as

![Figure 4](https://iwaponline.com/jwcc/article-pdf/8/1/177/373318/jwc0080177.pdf)

**Figure 4** | Prediction of monthly changes in the parameters, under the B1 scenario, for 2013–2042 and 2043–2072 periods compared to the baseline period.
compared to the baseline period. The highest \( T_{\text{max}} \) increase for 2013–2042 and 2043–2072 would be in April with 1.8 and in May with 2.3 °C, respectively. The temperature changes under B1 scenario, like the other two scenarios, are more considerable in 2043–2072 as compared to 2013–2042.

RAD in the first 30-year periods and for all the months except May will increase as compared to the baseline period. The highest increase will occur in June at a rate of 21.9 MJ m\(^{-2}\). For 2043–2072, RAD will increase for all the months except April and July. The highest increase (10.9 MJ m\(^{-2}\)) relative to the baseline period will occur in August. Also, under B1 scenario, precipitation in the first 30-year period in January, February, March, May, June and November will decrease and in other months it will increase as compared to the baseline period. The highest increase (17.2 mm) would be in August. In the second 30-year period, precipitation in all the months except July, October, November and December will decrease. The highest increase will occur in November at a rate of 19.5 mm. \( ETo \) under the B1 scenario would increase for both coming 30-year periods as compared to the baseline period. The highest increase in 2013–2042 and 2043–2072 periods will occur in May with the amounts of 20.4 and 23.7 mm, respectively.

**Annual analysis**

The annual average of \( T_{\text{min}} \) during the 2013–2042 period as compared to the baseline period under the A1B, A2 and B1 scenarios will increase at the rate of 0.5, 0.7, and 0.5 °C, respectively. These values would be 1.3, 1.3 and 0.1 °C for 2043–2072, respectively. Also, the annual average of \( T_{\text{max}} \) for 2013–2042 under the A1B, A2 and B1 scenarios will increase at the rates of 0.4, 0.4 and 0.5 °C as compared to the baseline period, respectively. These values would be 2.0, 1.6 and 1.1 °C for 2043–2072, respectively.

The most seasonal decrease of RAD in both 30-year periods as compared to the baseline period will occur in the winter. The highest decrease will occur in the winter of 2013–2042 under the A2 scenario, with an average rate of 141.4 MJ m\(^{-2}\). The annual average of RAD during the first 30-year period under the A1B, A2 and B1 scenarios would be reduced at a rate of 315.5, 333.0 and 330.5 MJ m\(^{-2}\), respectively. These values would be 259.0, 274.70 and 292.7 for 2043–2072, respectively.

The average seasonal precipitation under the A1B scenario will increase for the 2013–2042 period as compared to the baseline period for all the seasons except winter. It will also increase during 2043–2072 and for all the seasons as compared to the baseline period. Under the A2 scenario, the increasing trend will occur in the first 30-year period for all the seasons except summer and in the second 30-year period for all seasons except spring. The average of seasonal precipitation under the B1 scenario in the first 30-year period for the spring (in trace amounts) and winter, would decrease and for the summer and autumn in the second 30-year period for all seasons, it would increase. The highest increase in precipitation over the baseline period will occur in the autumn of 2043–2072 under the B1 scenario at a rate of 55.5 mm. During the 2013–2042 period, the average annual precipitation under the A1B, A2 and B1 scenarios will increase at a rate of 68.2, 59.3 and 62.1 mm, respectively. These values would be 68.2, 19.5 and 108.9 mm for the 2043–2072 period, respectively. A decrease in RAD in the future is justified regarding the increased annual precipitation and cloudiness.

\( ETo \) for the 2013–2042 and 2042–2043 periods and under all three scenarios will increase as compared to the baseline period. The highest seasonal increase of \( ETo \) will occur under the A1B and B1 scenarios in both coming periods in the spring. Under the A2 scenario, the highest increase will occur in the autumn and spring of 2013–2042 and 2043–2072, respectively. The highest increase in \( ETo \) during 2043–2072 and under the A1B scenario will occur in spring at a rate of 44.4 mm. The average of annual \( ETo \) under the A1B, A2 and B1 scenarios during 2013–2042 will increase at a rate of 58.8, 47.8 and 61.7 mm, respectively. These values would be 104.0, 86.1 and 84.2 mm for 2043–2072, respectively.

**Changes in rice water requirement**

The changes in rice water requirements during the coming periods in the study area when compared with the baseline period of 1981–2010 are given in Table 6. According to the results, the highest increase in rice water requirement during the first 30-year period would be 273.1 m\(^3\) ha\(^{-1}\), considering the B1 scenario. This value would be 571.9 m\(^3\) ha\(^{-1}\) for the
the water demand in the region will increase over time and should be considered by planners. Considering the current cultivated area of Hashemi cultivar in the province of Guilan (178,502 ha), it seems that the water demand in the coming periods will increase considerably.

### The meteorological parameters changes in the growing season of rice

The changes in different meteorological parameters in the growing season of rice in the study area during 1981–2072 are shown in Figures 5–7. Due to the slope of fitted line on data, it seems that the temperature and \(ET_0\) in all

![Graphs showing changes in meteorological parameters](image-url)

<table>
<thead>
<tr>
<th>Period</th>
<th>Scenario</th>
<th>DW (mm)</th>
<th>DW_{v} (m^3 ha(^{-1}))</th>
<th>Changes (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013–2042</td>
<td>A1B</td>
<td>24.2</td>
<td>242.3</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td>A2</td>
<td>17.8</td>
<td>178.3</td>
<td>4.1</td>
</tr>
<tr>
<td></td>
<td>B1</td>
<td>27.3</td>
<td>273.1</td>
<td>6.1</td>
</tr>
<tr>
<td>2043–2072</td>
<td>A1B</td>
<td>57.2</td>
<td>571.9</td>
<td>12.0</td>
</tr>
<tr>
<td></td>
<td>A2</td>
<td>49.6</td>
<td>496.2</td>
<td>10.5</td>
</tr>
<tr>
<td></td>
<td>B1</td>
<td>46.1</td>
<td>461.0</td>
<td>9.9</td>
</tr>
</tbody>
</table>

**Table 6**: The changes of rice water requirement for 2013–2042 and 2043–2072 periods compared to the baseline period, under changing climate scenarios (DW: water requirement in mm, DW_{v}: water requirement in m^3 ha\(^{-1}\))

### References

scenarios will increase. Also, the changes in precipitation and RAD are increasing and decreasing, respectively, for all the scenarios except A2. The Mann–Kendall test was used to evaluate the significance of the changes.

The results of the Mann–Kendall test showed that the values of $T_{\text{min}}$, $T_{\text{max}}$ and $ET_o$ for the rice growing season during 1981–2072 have a significant trend under the three studied scenarios, while the changes in RAD and precipitation during the mentioned period are not significant. Therefore, the incremental changes in $ET_o$ and, consequently, in rice water requirement for the coming periods will occur as a result of the significant increase in temperature.

**CONCLUSIONS**

The results of this study showed that the rice water requirement is affected by changing climate in Guilan province for 2013–2042 and 2043–2072 periods. The irrigated paddy fields (189,000 ha) by Sefidrud reservoir in Guilan province consumes about 74% of agricultural irrigation water and 62% of total available water.

Based on the results, an increase in rice water requirement was identified for the three different climate change scenarios (A1B, A2 and B1). For the rice growing season, the average of $T_{\text{min}}$, $T_{\text{max}}$ and total $ET_o$ showed significant increasing trends for both future periods, while the temporal
variations of RAD and precipitation over time are not significant. The average rice water requirement in the 2013–2042 period under A1B, A2 and B1 scenarios will increase, amounting to 5.4, 4.1 and 6.1% mm, respectively as compared to the baseline period. These values would be 12.0, 10.5 and 9.9%, for the 2043–2072 period, respectively. The highest amount of the increased water requirement would be equivalent to 571.9 m³ ha⁻¹, assuming the A1B scenario.

Due to a decrease in available water from upstream basin resources in recent years, it is necessary to adapt water supply and demand based on water resources of Guilan province internal basins. Also, the development of some management strategies such as water saving irrigation, reuse of drainage water and conjunctive use of surface and groundwater resources can reduce risk in rice production in the future. In this way, to achieve sustainable rice production in the future, a correct view of water demand should be considered in water resources planning. Therefore, the results of this study can be used in water allocation and management in the future.

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