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The effects of climate change on the water requirement of potato plants (Case study: south of Kerman province)

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ABSTRACT

Potato is considered a strategic product in providing food security in the future. Considering the phenomenon of global warming and affecting the production of agricultural products, it is necessary to evaluate its effects on potato production in the country. For this purpose, CanESM2 climate model data were used under RCP4.5, RCP2.6 and RCP8.5 release scenarios in the south of Kerman province. The SDSM statistical model was used for exponential microscaling of CanESM2 model output, and the Cowpat model was used to estimate the water requirement of potato plants. The results of the statistical indicators showed the high accuracy of the SDSM model and the conformity of the calibration and validation results with observational data. The mean square error of the SDSM model did not exceed 0.8% in the calibration and verification stages and was in the excellent range. The simulation results in the studied areas under RCP scenarios show an increase in the minimum temperature in the range of 0.3 to 1.3 °C, a maximum temperature in the range of 0.3 to 1.2 °C, and a decrease in precipitation in the range of -6.4 to -37.6 It will be mm. The net irrigation requirement increased in all the regions under study. The greatest increase occurred in the third period (2100-2070). On average, Kohnuj station with an average increase of 18.3% shows the highest increase, and Manujan station with 12.02% of the net irrigation requirement. Jiroft station showed the highest water demand with a 17.3% increase after Kohnuj.

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1. Introduction

Climate change and rising temperature increase the amount of evaporation and transpiration of plant potential, the result of which is an increase in water demand of plants. (Zamani et al., 2022). Considering the population growth and the increase in the need for food and on the other hand the change of water and soil resources as a result of climate change, it is very important to evaluate the effects of climate change on agricultural water consumption (Sheidaeian et al., 2013). In agriculture, the first impact of climate change, directly or indirectly, is on changes in the water needs of plants and water resources in agriculture, thus it is expected that in the future, the area under cultivation and the yield of crops will undergo significant changes. It endangers food security in the world. Temperature is one of the important environmental parameters that photosynthesis, respiration, growth, performance, and all vital activities of agricultural plants depend on. An increase in temperature due to an increase in greenhouse gases may cause a decrease in the amount of rainfall and an increase in evaporation and transpiration, causing a decrease in the proper humidity of the plant in the soil and leading to an increase in the water requirement of the plants, drought stress and ultimately a decrease in their yield (Ahadi et al., 2023). Different agricultural products need a certain amount of water during their growth period, and part of this need is provided through rainfall and ultimately effective rainfall, and another part is provided through underground water absorbed by plant roots. If the amounts of effective precipitation and the underground water absorbed by the plant roots are insufficient for the growth of the crop, which is often the case, the remaining water consumption requirement, which is referred to as the net irrigation requirement, is provided through irrigation. The World Food and Agriculture Organization has introduced potatoes as a product that provides future food security in the world, and the country of Iran, having a diverse climate and with an annual production of five million tons of potatoes, ranks thirteenth in the production of this product in the world (FAO, 2019). Considering the importance of potatoes in the diet and the necessity of its availability in different seasons of the year, its cultivation is of special importance. Therefore, considering the population growth and the increasing demand for food, and on the other hand, the change in water and soil resources as a result of climate change, it is very important to evaluate the effects of climate change on agricultural water consumption (Bayatani, 2018). Yarahamdi Kharajo and Saghafian (2005), with the aim of presenting the water balance model of Selmas and Tsouj plains located in the north and northwest of Lake Urmia, used the CROPWAT model to calculate the evaporation and transpiration and the water requirements of the plants in the area. Finally, the water balance model for the irrigation areas was presented and the results showed that the balance trend in both plains, especially in the Tusuj region, was completely negative and there is no logical relationship between the potential of the available water resources and the amount of its use. Najafi and Sattar (2005), in a study, evaluated the accuracy of CROPWAT software in the Isfahan region. For this purpose, they used the lysimeter data of the reference grass plant in the Kabutrabad district of Isfahan for the years 1372 to 1377. The research results showed that the average values of MARE, RMSE, and R2 were estimated as 21%, 1.4%, and 81% respectively. The sensitivity analysis of the model also shows that, except in the case where the wind speed is more than one meter per second and the reference evaporation and transpiration is less than 6 mm per day, the estimated error did not decrease in the rest of the cases. Mojarad et al. (2005) calculated the water consumption requirement (ETC) of rice by separating early and late varieties based on the values of potential evaporation and transpiration (ETO) and plant growth coefficients (KC) in ten stations of Mazandaran Plain. Also, the amount of effective precipitation was calculated using the most appropriate method (reliable precipitation method) in the CROPWAT model and the amounts of underground water absorbed by plant roots (GWC). The results of the study showed that the consumption water requirement and the net irrigation requirement in the east of the Mazandaran plain are more than in the west. While the effective rainfall is more in the west of Jalga. They also concluded that effective rainfall provides a greater share of the consumption water needs in the west of the Jalga, while this share is less in the east of the Jalga. The amount of effective precipitation in the region is much lower than the net irrigation requirement. Lashkari et al. (2009), in a study, investigated the efficiency of the CROPWAT model in estimating the water requirement of the wheat crop in the west of Kermanshah. By specifying the length of the dry season, they stated that the length of the dry season in this region, which lasts from early spring to mid-autumn, coincides with the time of crop ripening and its sensitivity to water shortage. Therefore, by using the crop watt model, they calculated the actual evaporation and transpiration of the wheat crop and the water and irrigation needs for the cities of Islamabad Gharb, Sarpol Zahab and Ravansar during a statistical period of 18 years from 1988-2005. The results showed that due to the dominance of drought and the soil facing a moisture deficit, two to three supplementary irrigations are needed to prepare the crop for harvesting. In research, Ehsani et al. (2012) estimated the potential, and actual evapotranspiration using climate information, plant (pasture) and soil characteristics with the help of CROPWAT software in the steppe region of Central Province (Shor station). In this study, the values of potential and actual evaporation and transpiration have been calculated using the FAO Penman-Monteith method. The results showed that the rate of potential evaporation and transpiration during the growing season in the region was 6.16 times the average of the actual evaporation and transpiration, and the actual evaporation and transpiration was 1.18 times the average rainfall of the statistical period of the growing season. Its meaning is that the plant has used the stored moisture for actual evaporation and transpiration. Then they estimated the average pasture fodder production to be 257 kg/hectare. They stated that real evaporation and transpiration as a climate index is one of the basic factors in improving the efficiency of water consumption. Understanding the future changes in plant water needs due to climate change is essential for water resource management and agricultural planning. Nkomozepi and Chung (2012), in a study, predicted net irrigation needs using the CROPWAT model for the country of Zimbabwe. The results showed that the predicted temperature, evaporation and transpiration increase, while the calculated precipitation decreases in the future period. The predicted irrigation requirement will increase by 33%, 66% and 99% in the 2020s, 2050s, and 2090s, respectively, compared to the base period by 67 mm. Ashofteh (2013), evaluated the impact of the climate change phenomenon on the water demand of major agricultural crops in the Aydoghmush irrigation network (including wheat, barley, alfalfa, potatoes, etc.), using the HADCM3 model. The results indicate an increase of 1.8 to 1 degree in temperature and 28-33% changes in precipitation in the future period compared to the base period. In order to estimate the water requirement, potential evaporation and transpiration were calculated using the FAO Penman Mantis method, and plant evaporation and transpiration were calculated using the FAO 24 method. The results of the increase in risk show the amount of water needed by crops, so that this increase reaches about 10 and 13% for the risk of 50 and 25%, respectively. Liu et al. (2013) analyzed the long-term trends of reference evaporation and transpiration and agricultural water demand in different areas. The results showed that the precipitation process in the growth stages is not beneficial for the growth of spring mountain air. The crop coefficient (spring mountain barley) in Tibet was 0.87 and the water requirement was 389 mm. The greatest water deficit was in the ripening and full maturity stages, which are the most important growth stages for barley. Weiguang Wang et al. (2014), in a study of changes in rice yield, potential evapotranspiration (ET), irrigation water requirement (IWR), and irrigation water efficiency (IWUE) in the Yangtze and Kaifeng River basins. Pulu River in China was evaluated. In this study, the output of the HADCM3 atmospheric general circulation model was used under the release scenarios A2 and B2 with the SDSM statistical microscale method. ORYZA2000 rice crop model was used in the growth period evaluation. According to the results obtained from this study, the yield of rice decreases, the amount of (ET) and (IWUE) increases significantly and the growth period of rice becomes shorter. The possible effects of climate change on olive growth in the Mediterranean region were investigated by Lazar et al. (2015). In this research, ECHAM5 regional climate models and A1B scenario were used, and the evaporation and transpiration and the water required by the crop were measured and calculated according to the standard method described in the FAO Irrigation and Drainage Publication 56. The results of this research indicate the potential expansion of olive cultivation to the north and higher altitudes of the region in the next 50 years. Due to the increase in evaporation and transpiration (by 8%) and the required irrigation water (with an increase of 18.5%) and the decrease in rainfall, it will no longer be possible to grow olives in the rainfed manner that is currently being produced. Using the output of climate models, the effects of climate change on the water requirements of winter wheat and tomatoes in the Mediterranean region have been simulated. According to the results, precipitation decreases, temperature (1.5±0.27), and annual reference evaporation and transpiration increase by 6.7%. The average length of the growing season until 2050 for wheat and tomato is estimated to be 15 and 12 days shorter, respectively (Sameh Saadi et al., 2015). Naresh Kumar et al. (2015) evaluated the effects of climate change on potatoes in the Indo-Gangetic region of India using two atmospheric general circulation models MIROCHI.3.2 and PRECIS. The results showed that the period of crop growth and the efficiency of irrigable water will decrease, evaporation and transpiration will increase, and will cause an 11% decrease in potato yield in the period of 2020, 2050 and 2080.

2. Material and Methods

The study area in this research includes stations with a statistical period of 17 years (1989 to 2005) including Jiroft, Kohnuj and Manujan. In this study, the data of maximum temperature, minimum temperature, precipitation, average relative humidity, average wind speed, and sunny hours on a daily time scale were used for exponential micro-scale. The output of the general circulation models of the atmosphere is large-scale, so the SDSM microscaling model was used to exponentially scale the output of the general circulation model. In the SDSM model, in order to exponentially scale the data of climatic parameters from three types of data: a-large-scale variables in the future period (2011-2100) CanEMS2 general circulation model, b-NCEP large-scale variables in the period (1989-2005) and c-Observational data (maximum temperature, minimum temperature, precipitation, average relative humidity, average wind speed and sunny hours) have been used daily (Bayatani, 2018). The WOFOST model was used to simulate potato plant performance. In this study, the data of the research projects of Jiroft Agricultural Research Center during 2011-2015 were used as a base or observation period. The net irrigation requirement during the growing season based on the simulated data of the CanESM2 model under the RCP scenarios in the conditions of the future climate period (2011-2040-2041-2070, 2071 and 2100) using the CropWat model in the studied areas was made. To estimate the net irrigation requirement, it is necessary to first calculate the reference plant evaporation and transpiration (ETo) using meteorological data including minimum and maximum temperature, average relative humidity, average wind speed, and sunny hours. In this study, the FAO Penman-Mantith method was used to calculate reference evapotranspiration (ETo). It is worth mentioning that before entering the data of sunshine hours into the model, unit conversion must be done. Then the effective rainfall was calculated using the USDA method and finally, the net irrigation requirement was calculated.

2.1. SDSM data generation model

One of the most important statistical exponential microscale models is the SDSM model, which is an artificial generator of meteorological data. The SDSM model was developed in England in 2002. The SDSM model calculates statistical relationships based on the multiple linear regression method between large-scale (predictors) and local (predictors) climate variables (Wilby and Dawson, 2004). In this model, the local climate is expressed by the large-scale climate of the region in the form R=F(X). where R represents the local variable that has been scaled down, X is a set of large-scale climatic variables, and F is a function of determination conditional on X, which is obtained based on training and validation of historical data (Bayatani, 2018). In this research, from the output data of the atmospheric general circulation model (CanESM2), the CanESM2 model is a comprehensive coupled CGCM model and is a part of the CMIP5 model series of the fifth report (AR5) and the IPCC International Panel on Climate Change (Arora et al., 2011). Table 1 shows the characteristics of this model, even though three scenarios RCP2.6, RCP4.5 and RCP8.5 have been used. In this research, in order to validate and verify the SDSM model, the large-scale observational variables of the study area on a daily scale in the period of 1989-2005 (variables extracted from NCEP) as independent variables, and the data of maximum temperature, minimum temperature, Precipitation, average relative humidity, average wind speed and observed daily sunshine hours of the region during the same period were entered into the model separately as dependent variables. After recalibrating the SDSM model, in order to check the ability of the CanESM2 general circulation model to simulate the climatic variables of the region, the large-scale variables of the CanESM2 model in the period of 1981-2005 were entered into the SDSM model (recalibrated in the previous step) and the maximum temperature variables, Minimum temperature, precipitation, average relative humidity, average wind speed and sunshine hours of the region were scaled for this period. Finally, the small-scaled variables of the region are compared with the observational variables and after gaining confidence in the ability of the CanESM2 model to scale the climatic variables of the region, the time series of the variables by introducing the large-scale variables of the CanEMS2 model in the periods of (2011-2040), (2070-2041, 2071-2100) were simulated to the SDSM model (recalibrated from the previous step) for future periods.

Table 1. Model Specifications CanESM2 (Arora et al., 2011)

Model Name	**CanESM2**
Atmospheric Resolution (degree) (length x width)	°8/2×°2/8
Ocean Resolution (degree) (length x width)	°94/0×°41/1
Founding Group	(CCCMA) Canada
Simulation Period (historical/future)	1850-2005/2011-2100
Simulation Scenarios	RCP2.6, RCP4.5, RCP6 and RCP8.5

2.2. CROPWAT model

The CROPWAT model was designed by the Water and Land Development Division of the Food and Agriculture Organization of the FAO. In the CropWatt software, to calculate the evaporation and transpiration of the ETO reference plant, the value of which is calculated by the Penman-Mantith-FAO equation based on the minimum and maximum climatic data of air temperature, relative humidity, radiation duration, and wind speed. In this model, the evaporation and transpiration of the reference plant are calculated monthly. By using this model, the water requirement of 30 different crops (latest version) can be assessed in a combined manner and an irrigation program can be presented for each crop. Also, by entering soil moisture data, this model will be a useful tool for managing moisture deficiency (Najafi and Sattar, 2005). Model performance evaluation criteria To evaluate the capability and accuracy of the SDSM model in simulating observational data (1989-2005) and also to determine the validity and evaluation of the WOFOST model in simulating different phenological stages of potato plant and potato tuber performance from statistical criteria. such as the square root of the mean squared error (RMSE), root mean squared normalized error (RMSEn), maximum error (ME), coefficient of explanation (R2), and Nash coefficient (Ens) were used.

$$\mathrm{RMSEn} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - M_i)^2} \quad (1)$$

$$\mathrm{ME} = \mathrm{Max}|S_i - M_i|.\frac{100}{\bar{M}} \quad (2)$$

$$\mathrm{RMSEn} = 100\frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - M_i)^2}}{\bar{M}} \quad (3)$$

In equations (1-3), Si and M_i are simulated and measured values respectively, $\bar{M}$ is the average of M_i values and n are the number of observations. The values of the root mean square error and the root mean square normalized error in the optimum state or the state where the simulated and measured values are equal to zero and the model efficiency value in this state is equal to one.

3. Results and discussion

3.1. Production of climate change scenarios in future periods

The performance of the SDSM model in micro-scale climate data was evaluated by statistical indices (Table 2). The results show that the value of the explanation coefficient R2 has a significant value in all cases (above 0.99). The maximum error (ME) for the simulation of minimum temperature, maximum temperature and precipitation was obtained on average for all three studied stations as 0.17, 0.15 and 19.9, respectively. Which shows the greater error of precipitation simulation compared to the temperature parameter. is. The root mean square error (RMSE) index in rainfall simulation is also much higher than other parameters (2.2) and shows more error. Therefore, according to the results of Table 2, the ability of the SDSM model to simulate meteorological parameters has been confirmed, but nevertheless, the model shows less accuracy in simulating precipitation, which is consistent with the findings of (Nazari et al., 2014; Taei Semiromi et al., 2014; Jafarpur, 2015) corresponds. In the following, the results obtained from the evaluation of the SDSM model are presented in Table 5.

Table 2. Efficiency of SDSM model in simulating precipitation and average minimum temperature and maximum temperature in observation period with NCEP data

		Accuracy criterion				**Variable**	**Station**
R^2	ME	RMSEn (%)	RMSE	E_{ns}	percentage error		
1	0.21	0.1	0.02	0.99	=0.02	Minimum temperature	
1	0.24	0.1	0.03	0.99	=0.02	Maximum temperature	**Jiroft**
0.99	21	0.7	1.2	0.99	-4.5	Rain	
1	0.2	0.1	0.02	0.99	=0.03	Minimum temperature	
1	0.1	0.05	0.02	0.99	0.004	Maximum temperature	**Kohnuj**
0.99	10.8	0.4	0.7	0.99	-1.7	Rain	
1	0.1	0.07	0.01	0.99	=0.04	Minimum temperature	**Manujan**

1	0.1	0.1	0.03	0.99	-0.04	Maximum temperature
0.99	28	0.8	1.6	0.99	-1.8	Rain

Table 3 shows the results of the simulation of the minimum, maximum and precipitation temperatures in the next three periods under the RCP4.5, RCP2.6 and RCP8.5 emission scenarios. According to Table 3, the maximum and minimum temperature simulated for the future period (2011-2100) under RCP scenarios shows an increase compared to the monitoring period in all three RCP scenarios. Rainfall has also changed in all three scenarios in the future periods and shows a decreasing trend. The average annual increase of minimum and maximum temperature in the study areas was observed from 0.4 °C in the RCP2.6 scenario to 0.7 °C in the RCP8.5 scenario. The highest increase in maximum and minimum temperature by 1 and 1.3 °C respectively was observed in Kohnuj and Jiroft stations in the RCP8.5 scenario. The average decrease in precipitation by 1.2 mm in the RCP2.6 scenario to 1.7 mm in the RCP8.5 scenario was also observed. The highest decrease in rainfall was observed in the amount of 38 mm in Jiroft station.

Table 3. Average changes in minimum and maximum temperature and annual precipitation in selected stations in three periods of 2011-2040, 2041-2070 and 2071-20100 compared to the observation period under the three emission scenarios RCP2.6, RCP4.5, and RCP8.5

Rain						**Maximum temperature**						**Minimum temperature**						**Station**	
Manujan		Kahnuj		Jiroft		Manujan		Kohnuj		Jiroft		Manujan		Kohnuj		Jiroft			
203.8		185.9		175.8		34.2		33.7		32.8		18.8		19.7		17		**Observation**	
mm	%	mm	%	mm	%	C°	%	C°	%	C°	%	C°	%	C°	%	C°	%		
-16	-8	-15	-8	-13	-8	0.3	1	0.4	1	0.5	2	0.4	2	0.4	2	0.4	2	Rcp2.6	2011-2040
-12	6	-12	-7	-10	-6	0.3	1	0.3	1	0.4	1	0.5	2	0.4	2	0.3	2	Rcp4.5	
-18	-9	-14	-7	-14	-8	0.3	1	0.4	1	0.5	2	0.4	2	0.4	2	0.4	2	Rcp8.5	
-12	-6	-16	-9	-12	-7	0.4	1	0.5	1	0.6	2	0.4	2	0.5	3	0.5	3	Rcp2.6	2041-2070
-12	-6	-22	-12	-19	-11	0.5	2	0.6	2	0.7	2	0.6	3	0.6	3	0.6	4	Rcp4.5	
-10	-5	-24	-13	-31	-18	0.7	2	0.8	2	1	3	0.7	4	0.9	4	0.8	5	Rcp8.5	
-15	-7.5	-13	-7	-12	-7	0.4	1	0.4	1	0.6	2	0.4	2	0.4	2	0.4	3	Rcp2.6	2071-2100
-6	-3	-27	-14	-25	-14	0.6	2	0.7	2	1	3	0.8	4	0.8	4	0.7	4	Rcp4.5	
-9	-5	-20	-11	-38	-21	0.4	1	1	4	1	3	0.5	3	1.3	7	1.2	7	Rcp8.5	

3.2. Changes in reference evapotranspiration (ETO) in the observation period and in the future

The amount of reference evaporation and transpiration (ETO) was calculated using the FAO Penman-Monteith formula and based on the data of the observation period and the future period. The simulated annual ETO values for the future climatic period compared to the reference average evaporation and transpiration in the monitoring period for the studied areas are presented in Table 4. According to Table 4, as can be seen, reference evaporation and transpiration values in the future climatic conditions show different results compared to the monitoring period in the studied stations. Manujan stations show a reduction in their reference evaporation and transpiration in all three future climate periods. Kohnuj station of the third period, the RCP8.5 scenario, is the reduction reference rate of evaporation and transpiration. The highest rate of increase of reference evaporation and transpiration related to the Jiroft station occurred in the third period (2100-2071) and RCP8.5 scenario.

Table 4. The number of changes in reference average evaporation and transpiration (mm per day) in the selected stations in the three periods of 2011-2040, 2041-2070 and 2071-20100 compared to the monitoring period under the three emission scenarios RCP2.6, RCP4.5 and RCP8. 5

2071-2100			**2041-2070**			**2011-2040**			**Observation**		**Station**
RCP8.5	RCP4.5	RCP 2.6	RCP8.5	RCP4.5	RCP 2.6	RCP8.5	RCP4.5	RCP 2.6			
3.7	2.9	2.2	3	2.6	2.5	2.1	2.1	2.3	%	48.3	**Jiroft**
0.2	0.1	0.09	0.1	0.1	0.1	0.08	0.08	0.09	ΔET_c		
-1.8	1.9	1.1	1.7	1.7	1.4	1.3	1.06	3.1	%	76.39	**Kahnuj**
-0.1	0.1	0.7	0.1	0.1	0.09	0.08	0.07	0.2	ΔET_c		
-6.5	-3	-2.3	-3.3	-2.3	-2.1	-1.8	-1.5	-1.5	%	73.4	**Manujan**
-0.4	-0.2	-0.1	-0.2	-0.1	-0.1	-0.1	-0.09	-0.09	ΔET_c		

3.3. Changes in actual evapotranspiration and transpiration (ETc) of potato plants in the observation period and in the future

Actual evapotranspiration (ETc) of potato plants based on the CanESM2 model under RCP scenarios, using plant coefficients (Kc) and reference evapotranspiration (ETo) in the conditions of the future climate period (2011-2040, 2041-2070 and 2100) 2071-2071) was simulated in the study areas (Table 5). The simulation results of actual evaporation and transpiration of potatoes show an increase in the consumption of water in all the studied stations (Table 5). According to the obtained results, the highest rate of increase in the actual evaporation and transpiration was observed in the second period (2041-2070). It should be noted that in the study areas (Jiroft, Kohnuj and Manujan stations) in the third period in the RCP8.5 scenario, the increase in actual evaporation and transpiration slightly improved. According to Table 5, it can be concluded that the results obtained from the simulation of the actual evaporation and transpiration of potatoes in the study areas indicate a lower increase in the actual plant evaporation and transpiration (ETc) in the study areas.

Table 5. Actual evapotranspiration (ETc) changes (mm) in selected stations in three periods of 2011-2040, 2041-2070 and 2071-20100 compared to the monitoring period under three emission scenarios RCP2.6, RCP4.5, and RCP8. 5

2071-2100			**2041-2070**			**2011-2040**					
RCP8.5	RCP4.5	RCP 2.6	RCP8.5	RCP4.5	RCP 2.6	RCP8.5	RCP4.5	RCP 2.6	**Observation**		**Station**
6.6	8.3	7.5	8.5	7.8	7.3	7.3	6.6	6.7	%	48.3	**Jiroft**
16.4	20.7	18.6	21.1	19.5	18.3	18.2	16.5	16.6	ΔET_c		
13.3	17.6	15.2	18	16.3	15.3	15.05	13.6	14.6	%	76.39	**Kohnuj**
46.6	61.4	53	62.8	57	53.4	52.6	47.4	51	ΔET_c		
6	16.2	14.3	16.2	15.3	14.5	13.8	13.2	13.8	%	73.4	**Manujan**
23.4	63	55.5	63	59.7	56.5	53.8	51.4	53.7	ΔET_c		

3.4. Effective precipitation changes (PEff rain) in the observation period and in the future

Effective precipitation (PEff rain) based on the CanESM2 model under RCP scenarios was simulated using the USDA method in the conditions of the future climate period (2011-2040, 2041-2070 and 2071-2100) in the study areas (Table 6). The simulation results of effective rainfall show the reduction of effective rainfall in all studied stations (Table 6). According to the obtained results, the highest decrease in effective precipitation was observed in the third period (2100-2071). So that the effective rainfall reduction percentage was calculated in the range of 23.5 (Kahnuj) to 46.7 (Jiroft) percent in all stations and scenarios investigated (Table 6).

Table 6. Number of changes in effective precipitation (PEff rain) (mm) in selected stations in three periods 2011-2040, 2041-2070 and 2071-20100 compared to the monitoring period under three release scenarios RCP2.6, RCP4.5 and RCP8.5

2071-2100			**2041-2070**			**2011-2040**					
RCP8.5	RCP4.5	RCP 2.6	RCP8.5	RCP4.5	RCP 2.6	RCP8.5	RCP4.5	RCP 2.6	**Observation**		**Station**
-46.7	-41.8	-32.5	-43.2	-38.6	-38.3	-37.7	-34	-35.8	%	94.5	**Jiroft**
-44.2	-39.5	-30.7	-40.8	-36.5	-36.2	-35.6	-32.1	-33.8	ΔP_{Eff}		
-44.2	-40.3	-25.9	-41.5	-31.6	-29.7	-25.2	-23.8	-23.5	%	79.56	**Kohnuj**
-35.1	-32	-20.6	-33	-25.1	-23.6	-20	-18.9	-18.7	ΔP_{Eff}		
-32.1	-33.2	-32.8	-30.8	-32.4	-32.02	-32.6	-31.5	-33.4	%	114.54	**Manujan**
-36.8	-38	-37.6	-35.2	-37.1	-36.7	-37.4	-36	-38.2	ΔP_{Eff}		

3.5. Simulation of net irrigation requirement (In) during the growing season of potato plant

The net irrigation requirement during the growing season was simulated based on the simulated data of the CanESM2 model under RCP scenarios in the conditions of the future climate period (2011-2040, 2041-2070 and 2071-2100) in the study areas (Table 7). The percentage of changes and increases in net irrigation requirement (Table 8) was calculated for three climate periods based on RCP scenarios. The results of the simulation of the net need for potato irrigation showed an increase in the need for irrigation in the Jiroft, Kohnuj and Manujan stations (Table 8). According to the obtained results, the highest amount of increase in net irrigation requirement was observed in the second period (2041-2070). So, with the increase of radiative forcing in RCP2.6, RCP4.5 and RCP8.5 scenarios, the percentage of increase in net irrigation requirement increased significantly. The percentage of increase in net irrigation requirement was calculated between 4 and 24% in all stations and scenarios investigated (Table 8). The results of the increase in irrigation demand and the comparison of three climatic periods showed an increase in irrigation demand in the range of 11.1% (Manujan station) to 16.6% (Jiroft station) in the period of 2011-2040 (Table 8). It should be noted that in the second period (2041-2070), the percentage of decrease is between 12.8% (Manujan) and 24% (Kahnuj). In the third period (2100-2071), the percentage of decrease is between 4.05 (Manujan) and 23.2 percent (Kahnuj). Therefore, the results show the variability of the potato plant's irrigation needs due to the phenomenon of climate change in the study areas. The results of the Mann-Kendall test also show this well (Table 9). In the RCP2.6 scenario, the decreasing trend for potato irrigation requirement was not significant in any of the studied stations (Table 9). In the RCP4.5 scenario, the increasing trend of the net need of potato irrigation in all stations was significant at the 99% level. In the RCP8.5 scenario, in two stations, Jiroft and Kohnuj, it was significant at the 99% level, but in Manujan station, the decreasing trend of the net irrigation requirement was significant at the 99% level (Table 9).

Table 7. Simulation of potato net irrigation requirement (mm) based on CanESM2 model under RCP scenarios in the study areas in the periods of 2011-2040, 2041-2070 and 2071-2100

2071-2100			**2041-2070**			**2011-2040**			**Water requirement of observation period**	**Station**
RCP8.5	RCP4.5	RCP2.6	RCP8.5	RCP4.5	RCP2.6	RCP8.5	RCP4.5	RCP2.6		
214.5	231.57	202.63	215.2	209.42	208.02	207.1	202.08	203.88	177.66	**Jiroft**
350.3	362.04	342.26	364.33	350.68	345.72	341.28	335	338.34	293.82	**Kohnuj**
338.06	373.96	365.92	371.44	369.79	366.32	364.15	360.87	364.94	324.9	**Manujan**

Table 8. Coefficient of changes in net irrigation needs during the potato growing season based on CanESM2 model under RCP scenarios in the study areas in the periods of 2011-2040, 2041-2070 and 2071-2100.

2071-2100			**241-2070**			**2011-2040**				**Station**
RCP8.5	RCP4.5	RCP2.6	RCP8.5	RCP4.5	RCP2.6	RCP8.5	RCP4.5	RCP2.6		
20.5	20.2	14.1	21.1	17.9	17.1	16.6	13.8	14.8	%	**Jiroft**
36.4	36	25	37.5	31.8	30.4	29.5	24.4	26.2	ΔI_n	
19.2	23.2	16.5	24	19.4	17.7	16.2	14	15.2	%	**Kohnuj**
56.5	68.2	48.4	70.5	57	52	47.5	41.2	44.5	ΔI_n	
40.5	15.1	12.6	14.3	13.8	12.8	12.1	11.1	12.3	%	**Manujan**
13.2	49	41	46.5	45	41.4	39.3	36	40	ΔI_n	

Table 9. The results of the Man-Kendall test of the net need of potato irrigation at the probability level of 0.05 in the selected stations

	2011-2100		
RCP8.5	RCP4.5	RCP2.6	**Station**
Z	Z	Z	
**4.6	**4.3	-0.003	**Jiroft**
**3.7	**7.1	1.3	**Kohnuj**
**-3.9	**4.06	0.8	**Manujan**

4. Conclusion

One of the obvious examples of climate change is the increase in temperature and decrease in precipitation in the future climate. Therefore, any change in the global climate has a direct impact on the production of agricultural products in different regions of the world and as a result, on the issue of providing food security at the global level. In this regard, in this study, the effects of climate change on the yield and length of potato phenological stages in three stations of Jiroft, Kohnuj and Manujan, which are considered to be the main centers of potato production in the country, were discussed in the future. In this study, in order to simulate the future climate, the CanESM2 general circulation model data were used under RCP4.5, RCP2.6 and RCP8.5 emission scenarios for the period of 2011-2100. The results of simulation of temperature parameters (minimum and maximum temperature) indicated an increase in the average minimum temperature and maximum temperature from 0.38 to 1 °C and 0.36 to 0.9 °C, respectively. At Manujan station, in the last period, the trend of temperature increases from the RCP4.5 scenario to the RCP8.5 scenario has been photographed, and the average minimum and maximum temperatures both decrease in this period, and this can indicate the increasing desertification. the climate of the region in the distant future. The average decrease in rainfall in the studied areas was calculated from 11 mm to 22 mm. In order to estimate the net irrigation requirement, the reference plant evaporation and transpiration (ETo) was calculated using meteorological data including minimum and maximum temperature, average relative humidity, average wind speed, and sunny hours. In this study, the FAO Penman-Mantis method was used to calculate reference evapotranspiration (ETo). In the study areas of Manujan station, the rate of potential evaporation and transpiration will decrease in the future period, and the rate of potential evaporation and transpiration has decreased in the last period of the RCP8.5 scenario at Kohnuj station. On average, the rate of potential evaporation and transpiration will decrease by 2.7% in Manujan station. These conditions are while in the rest of the study areas, we see an increase in evaporation and transpiration potential in these areas. The highest amount of potential evaporation and transpiration is related to Jiroft station by 2.6% and the lowest increase of potential evaporation and transpiration is related to Kohnuj station by 1.3%. The plant water requirement (ETc) has increased in all three studied stations. On average, the highest and lowest water consumption requirements of the plant are 15.4% and 6.6%, respectively, belonging to the two stations of Kohnuj and Jiroft. Effective precipitation decreased in the study areas. The highest decrease in average effective precipitation belonged to Jiroft station with 38.7% and the lowest decrease in effective precipitation belonged to Kohnuj station with 31.7%. The net irrigation requirement increased during the plant growth period in all studied areas. The greatest increase occurred in the third period (2100-2070). On average, Kohnuj station with an average increase of 18.3% shows the highest increase and Manujan station with 12.02% of the net irrigation requirement. Jiroft station showed the highest water demand with a 17.3% increase after Kohnuj.

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