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ORIGINAL ARTICLE

GIS Modeling of Climate Change Impact on Saffron Water Requirement (the case of Ardabil Province)

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In recent decades, climate change in Iran has led to the introduction of specific plants that have less water requirement than policymakers. Saffron cultivation has a long history in Iran and saffron was ranked as one of these figures on the agenda of policymakers. Here we presented the evaluation of Climate Change Impact on Saffron Water Requirement by GIS Modeling in Ardabil Provincel. We spot periods 1992-2017 and 2017-2040 as base and future period, respectively. For CCCSN, the data from five global climate models (GCMs) from the CGCM3T47 archive were selected that cover three 'Representative Concentration Pathways' (RCPs) scenarios. Potential evapotranspiration is estimated by Torrent White method. The accuracy of models at base period was determined by evaluation criteria, such as the RMSE, R2. Results showed that accuracy of CGCM3T47 model on A1B scenario was higher than other AOGCM models which used on base term. Also, it illustrated that water requirement will rise in all capable regions of state on 2040. In universal, average of addition of water requirement is 67, where in Germi, capital of state, we will have maximum variations by 95 mm ascension for the year 2040. Also, pole of production saffron in state, Bilasvar will have 40 mm ascension in saffron water requirement. Mean water requirement of saffron will be constantly increasing. In the meanwhile, the index of 425.52 mm for the year 2017 to 487.61 mm for the year 2040 were performed.

Keywords: Torrent White; Potential evaporation; Saffron crop coefficient; CCCMA

Introduction

It is necessary to grow sustainable crops in arid regions more than other places because water scarcity is higher in arid regions such as Southern Khorasan (decline in mean rainfall = 427 mm in aquifers) (www.skhrw.com). Growing sustainable crops adapted to climate conditions with high production and quality in this region can improve water productivity. On the other hand, the phenomenon of climate change causes variations in intensity and frequency of such climatic variables as mean rainfall and temperature.

The reports claim that land surface temperatures are rising. Unfortunately, this rising temperature has a negative effect on climate variables in Iran (Hadizadeh et al., 2011). It should be noted that these variables directly influence the yield of the strategic plant in this region (i.e. saffron). In fact, study of the effects of climate change on water requirement of saffron as the most important input can guide the policy-makers to adopt an effective policy for management of growing saffron in this region. Many studies have investigated the effects of climate change on important crops indigenous and exported to Iran. The Third Generation Coupled Global Climate Model (CGCM3) derived from Atmosphere-Ocean Global Circulation Models (AOGCMs) was used in order to study the effects of climate change on net irrigation requirement and yield of irrigated wheat (Soleymani *et al.*, 2011) in Behshahr town in Mazandaran. The climate parameters of temperature and precipitation were simulated using A2 emission scenario in 2011-2040, 2041-2070, and 2071-2100 periods.

The results showed that precipitation increases in autumn and decreases in the winter and spring although the temperature rises by 1-2ºC throughout a year by the end of 2100. The net irrigation requirement increased by replacing the planting date to winter. This increase will intensify in upcoming periods under the influence of climate change. No remarkable change was detected in relative crop yield loss in upcoming periods compared to the base period in a certain planting date. Luo *et al.* (2005) evaluated the yield of wheat under climate change in southern Australia with regard to the impacts of three factors of rainfall, temperature and increase in CO_2 concentration. The results showed that rainfall is the most effective factor in product yield in the regions with medium and low rainfall. Shrestha (2017) examined the impacts of climate change on water requirement and yield of rice in the irrigation network in Negamwick in Myanmar. They used two ECHAM5 and HadCM3 climate models under

A1B, B2, and A2 scenarios in 2020-2080 period. The results showed a decrease in maximum temperature under the three scenarios. The results also showed a decrease in water requirement of rice under all three scenarios in this region by the 2080s horizon. Riediger et al. (2017) investigated and simulated the impacts of climatic change on water requirement of agricultural products in central Europe. The results showed that maximum temperature rises by the end of this period. The results also showed that current reservoir of water in aquifer is not enough to maintain the current cropping pattern. The impacts of climate change on water requirement was studied in irrigation network of products in Baojiksia in China. They examined the mechanism of the effects of climate change and used dynamic thinking to form an equation between the effects of climate change, water requirement in the irrigation network, future adaptability facilities.

The results showed an increase in temperature. Increase in temperature by 1°C increased net water requirement by 120 million cubic meters and gross water requirement by 200 million cubic meters. Climate change had a significant impact on Haih River in China (Wang et al., 2017). They proposed some management policies for consumption and supply of water resources to overcome future problems and adapt to future conditions.

The results indicated emergence of climate change and its negative impacts on water resources that increase water requirements of crops. Given the importance of water requirement of plants, few studies were carried out on the effects of water requirement on various products in Southern Khorasan Province. Water requirement of saffron as a strategic product in this region was investigated in this study. Water requirement was modeled and zoned under the influence of outputs of four climate models by the 2040s horizon. Increase in saffron water requirement was estimated. The areas undergoing water scarcity crisis were introduced. In the end, those factors that increase water requirement in critical areas were studied and effective solutions were presented to solve these problems.

Materials and Methods

Location of study area

Southern Khorasan Province is located at the west of Iran on the common border with Azerbaijan with a surface area of more than 150797 square kilometers. This region has a dry climate. It consists of 11 towns, 22 districts and 51 villages. The density and focus of rural areas are mostly in the mountainous and the capital. Annual precipitation, average maximum and minimum temperature are 152 mm, 7 and 26°C respectively (http://skhmet.ir/).

The cities distributed across this region were selected in order to investigate the effects of climate change. This enhances zoning accuracy in the region. Of 29 cities in this region, 19 cities were selected (according to political divisions in 2013). Figures 1 and 2 show topography and location of the selected cities in this region.

Introduction of CCCSN Database

The CCCMA database complied in Canada was used in this study. A model called CGCMT47 was developed in this database according to such parameters as monthly rainfall, average monthly temperature, wind speed at two meters high, etc. Monthly data and daily data for 2001-2100 was collected from this database. The distance between ocean model networks was 192 x 96 meters (www.ipcc.com/, www.cccsn.ec.gc.ca/).

The CCCSN database is a subset of the CCCMAs that consists of climate parameters for all CGCMT47 output models. ECHO_G, HADGEM ECHAM50M models from CGCMT47 output models were used to extract monthly rainfall parameters under A1B, B1, and A2 scenarios. Land use change under scenario B1 was higher than the other two scenarios. Energy use and gross domestic production under A1B and A2 scenarios were greatly higher than B1 scenario. Parameters of average monthly precipitation and temperature for 1992-2017 period as the base period and 2017-2020 period as the upcoming period were extracted for selected cities in this region.

Long-term statistics in the selected stations were adapted to output of climate models based on R2 factor in this region to determine accuracy of climate models for estimating parameters of average monthly rainfall and temperature.

The nearest station to each city was considered as the base station. Further details in this equation are shown in Figure 1.

Calculation of potential evaporation rate

Torrent White method was used to calculate potential evaporation rate (Safavi et al., 2015). Average monthly temperature as input variable in this equation was extracted from outputs of climate models under various scenarios.

Evaporation was calculated for all months in a year using the Torrent White method. This method is based on average monthly temperature. Following steps were taken to calculate this parameter:

Annual thermal index (I) was calculated from sum of monthly thermal indices within a year.

$$i_m = \left(\frac{T_m}{5}\right)^{1.51}$$

In this equation, im represents monthly thermal index and Tm represents monthly average temperature. This was carried out for all 12 months within a year. If Tm was zero or negative, in will be zero for that month. Then, annual thermal index (I) will be calculated from monthly thermal indices throughout the year.

$$I = \sum_{n=1}^{12} i_m$$

a coefficient was calculated from the equation using the annual thermal index (I). Quantities of a and I coefficients were constant throughout a year but monthly thermal index and monthly temperature were calculated on a monthly basis.

$$a = (6.75 \times 10^{-7})\, I^3 - (7.71 \times 10^{-5})\, I^2 + (1.792 \times 10^{-2}) I + 0.492$$

Evaporation is calculated using the following formula for each month of the year.

$$ET_P = 16\left(\frac{10T_m}{I}\right)^a$$

In this equation, ETp represents evaporation rate for a month (mm).

ETp is calculated using the above equation assuming that every month has 30 days and 12 daylight hours. However, the number of days in each month and the number of daylight hours vary in different months in a year given different quantities of ETp. Therefore, the Nm coefficient should be modified. Modified ETp is obtained from Equation (5) (Alizadeh, 2006).

$$(ET_P)_a = 16N_m\left(\frac{10T_m}{I}\right)^a$$

Crop coefficient: this is a prerequisite for estimation of saffron water requirement. For this purpose, the results of studies on determining crop coefficient of saffron in Khorasan province were used. Table 2 shows saffron coefficient during growing season (Alizadeh *et al.*, 1999). Evapotranspiration of saffron during the growing period was calculated using equation (6), the crop coefficient and the reference evapotranspiration.

$$ET_C = ET_O \times K_C$$

After calculating evapotranspiration of saffron, effective rainfall on a monthly basis should be calculated in order to assess saffron water requirement. Equation (7) was used for this purpose.

$$P_{eff} = f\,(D)\left[\begin{matrix}\left(\left(1.25 \times (p_t)^{0.824}\right) - 2.93\right) \times \\ 10^{(0.000955 \times ET_C)}\end{matrix}\right]$$

In this formula, *Peff* represents effective rainfall (mm per month), *Pt* represents monthly rainfall (mm), ETC represents evapotranspiration per month (mm) and *f(D)* is the function of depth of discharge of moisture from the soil before irrigation. If the depth of discharge was considered as normal as 75 mm, the quantity of this function will be 1.

The net irrigation requirement of saffron is obtained from equation (8).

$$NIR = ET_C - P_{eff}$$

In this equation, NIR represents net irrigation requirement (mm per month).

Calculation of semivariogram function: selection of a standard experimental function is the first step to zoning. Semivariogram is the sum of squared difference of a pair of points separated by h distance. For this purpose, the + GS software was used to determine the best semivariogram. The software converts collected data to normal data. The best function fitted to the data was selected from the empirical functions based on RSS, R2 evaluation criteria.

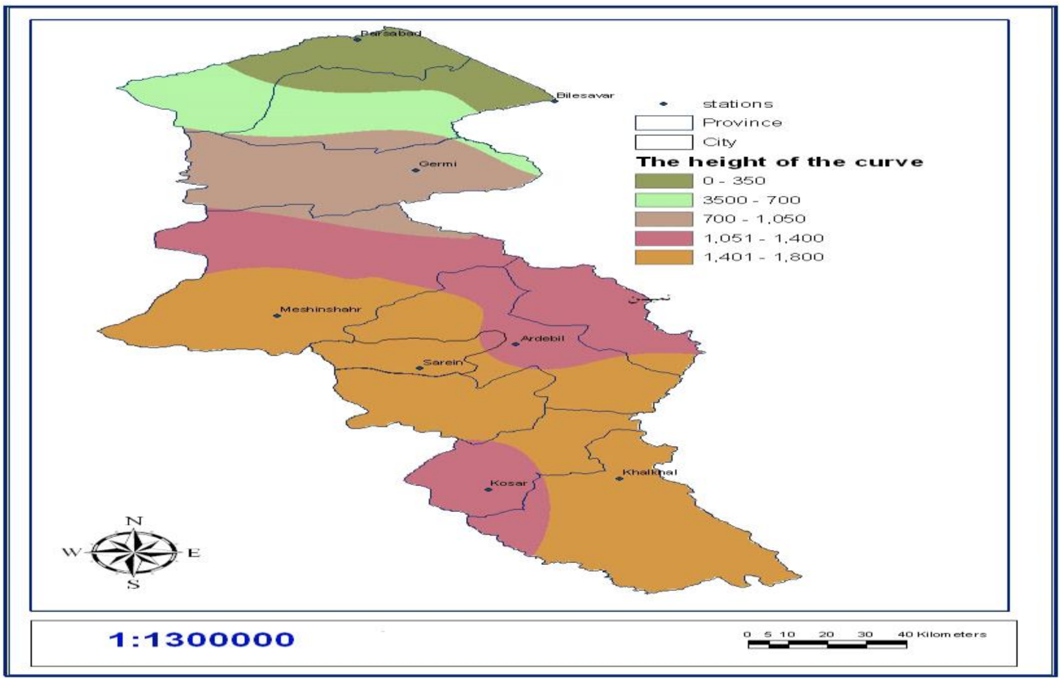

Fig .1. Topography of Ardabil State

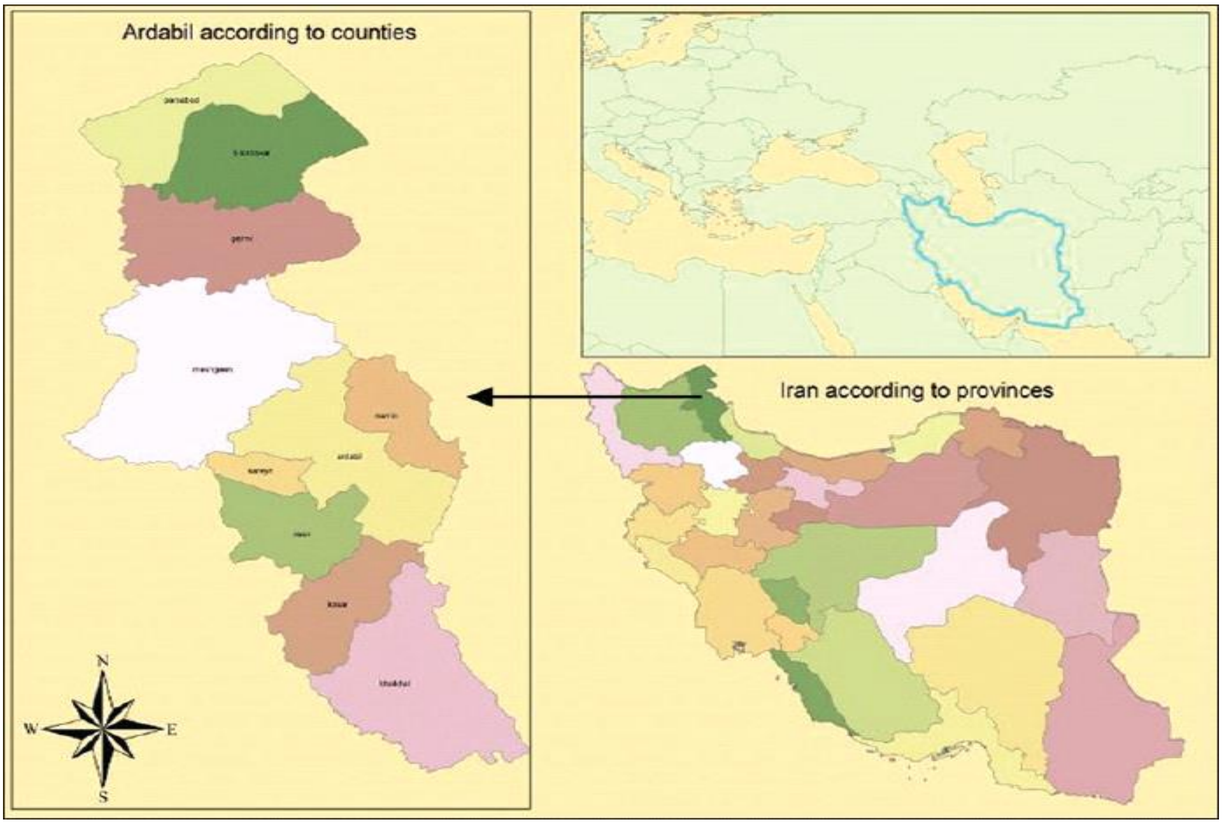

Fig. 2. Location of Selected Cites on Ardabil State

Precipitation model zoning

After determining the best semivariogram in the + GS environment, precipitation model was zoned in different periods using GeoStatistical Analysis feature in the GIS software. Inverse distance weighting was used for interpolation. The inverse distance weighting method as an interpolation methods is based on inverse distance between the weights where estimation is based on values of the points near the estimation point. The two-dimensional interpolation equation based on the above method is shown in equations (9) and (10).

$$W\ (x, y) = \sum_{i=1}^{n} \lambda_i w_i$$

$$\lambda_i = D_i^{-\alpha} \Big/ \sum_{i=1}^{n} D_i^{-\alpha}$$

where W (x, y) represents estimated values in the desired location, N (x, y) shows the number of the given adjacent points, (x,y.λi) represents the weight assigned to each given value, Wi represent location (xi, yi), Di represents the Euclidean distance between each point located at (x, y) and (xi, yi), α represents quantity of the power that is influenced by the weight of Wi on W. Finally, zoning map of saffron water requirement in this region by the 2017-2020 horizon was prepared and generalized to all agricultural areas in this region.

Results and Discussion

The results of determining the accuracy of climate models in estimating precipitation and temperature in each city in accordance with the station in that city are given in Table 3. Certainly, climate models have failed to determine the climate parameters independently and accurately for all cities. In some cities, the output of climate models did not have high correlation with long-term statistics. Although downscaling escalates accuracy of the data derived from climate models, simulation results of these models for climate parameters are identical in neighboring cities. In practice, long-term statistics of the stations for these cities contradict with simulation data. Difference in climate outputs results from two parameters of accuracy of models for estimating climate parameters and different distances between networking of these models. Details of clarity and distance of networking points are given in the CCCSN database (www.cccsn.ec.gc.ca).

Contents of Table 3 show that the CGCM3T47 model under A1B scenario is mostly adapted and the ECHO-G model is less adapted to long-term statistics. Accuracy of A1B scenario is higher than B1 and A2 among scenarios of the CGCM3T47 model. Increase in water requirement by the 2017-2040 horizon for selected cities in this region is shown in Table 1.

The largest increase in water requirement belongs to capital of Khorasan and the smallest increase belongs to northwestern areas of Khorasan according to the CGCM3T47 model under the A1B scenario. Bilesavar city as the center of saffron production in this region suffers from increase in water requirement by the 2040. Average effective rainfall in this period is 18135 mm, which followed a downtrend trend. Therefore, effective rainfall in the last five years was less than the average although potential evaporation followed an upward trend. Potential evapotranspiration for 2017-2040 period was calculated. The best experimental function for the most accurate climate model was determined. Table 2 show the output of the + GS software for this model.

Since the Software shows the most susceptible growing areas of saffron in the northeastern areas of this province, the study aimed to detect variations in water requirement in this region. Figures 3 and 4 show the results of simulation and zoning of increase in water requirement in 2017-2020 under A1B scenario. The CGCM3T47 model is given.

Table 1. Accuracy of AOGSM models (1992-2017)

HADGM1		ECHO-G				ECHAM60M			CGCM3T		Station
A	A1B	A2	B1	B1	A2	A1B	B1	A2	A1B		
0.44	0.63	0.48	0.46	0.65	0.49	0.47	0.67	0.51	0.49		Parsabad
0.81	0.87	0.82	0.84	0.90	0.85	0.87	0.93	0.88	0.90		Aslandoz
0.58	0.55	0.61	0.60	0.57	0.59	0.57	0.59	0.61	0.59		Jafarabad
0.66	0.56	0.52	0.68	0.58	0.54	0.71	0.60	0.56	0.73		Bileh savar
0.59	0.53	0.64	0.62	0.55	0.66	0.64	0.57	0.69	0.66		Angut
0.93	0.90	0.87	0.89	0.92	0.91	0.95	0.94	0.92	0.98		Adrabil
0.69	0.50	0.58	0.71	0.52	0.60	0.73	0.54	0.62	0.76		Nir
0.91	0.87	0.57	0.45	0.90	0.84	0.90	0.93	0.87	0.93		Khalkhal
0.69	0.71	0.62	0.72	0.73	0.64	0.74	0.74	0.66	0.77		Sareyn
0.68	0.54	0.74	0.71	0.56	0.76	0.73	0.73	0.79	0.92		Forodgah
0.83	0.81	0.84	0.86	0.84	0.87	0.89	0.89	0.90	0.92		Germi
0.74	0.67	0.49	0.40	0.44	0.50	0.42	0.42	0.52	0.43		Kivi
0.60	0.72	0.56	0.63	0.74	0.58	0.65	0.65	0.60	0.67		Lahrood
0.53	0.50	0.47	0.55	0.52	0.48	0.57	0.57	0.50	0.59		Razey
0.50	0.73	0.40	0.52	0.75	0.42	0.54	0.54	0.43	0.56		Sardabeh
0.73	0.77	0.87	0.89	0.87	0.90	0.88	0.88	0.93	0.91		Meshkin
0.76	0.69	0.79	0.71	0.84	0.70	0.73	0.73	0.72	0.76		Samian
0.55	0.59	0.50	0.57	0.61	0.52	0.59	0.59	0.54	0.61		moradlu

Table 2. Saffron water requirement variations in South Khorasan province during 2017 -2040

HADGM1		ECHO-G				ECHAM60M			CGCM3T		Name of city
A	A1B	A2	B1	B1	A2	A1B	B1	A2	A1B		
-2.48	121.75		89.25	64.66	27.69	56.15	34.26	2.27	71.39	39.89	Parsabad
4.78	133.94		96.24	58.08	27.69	56.15	34.26	8.44	78.17	32.26	Aslandoz
-2.48	121.75		89.25	64.66	27.69	56.15	34.26	2.27	71.39	39.89	Jafarabad
-2.48	121.75		89.25	64.66	21.03	41.59	18.49	2.27	71.39	39.89	Bileh savar
-2.48	121.75		89.25	64.66	27.69	56.15	34.26	2.27	71.39	39.89	Angut
-3.86	115.51		71.44	62.57	111.04	82.49	60.40	8.21	47.61	95.52	Adrabil
-3.86	115.51		71.44	62.57	111.04	82.49	60.40	8.21	47.61	95.52	Nir
-7.42	87.75		71.44	62.57	158.74	102.70	86.79	3.37	95.52	53.42	Khalkhal
-3.86	115.51		71.44	62.57	111.04	82.49	60.40	8.21	47.61	95.52	Sareyn
-3.86	115.51		71.44	62.57	89.14	72.91	49.47	8.21	47.61	95.52	Forodgah
-2.42	121.75		89.25	64.66	21.03	41.59	18.49	2.27	71.39	39.89	Germi
-7.42	87.75		71.44	62.57	111.04	82.49	60.40	8.21	47.61	95.52	Kivi
-3.86	115.51		71.44	62.57	111.04	82.49	60.40	8.21	47.61	95.52	Lahrood
-3.86	115.51		71.44	62.57	1110.4	82.49	60.40	8.21	47.61	95.52	Razey
-3.86	115.51		71.44	62.57	111.04	82.49	60.40	8.21	47.61	95.52	Sardabeh
4.78	133.94		83.81	59.73	89.14	72.91	49.47	-2.76	80.53	36.71	Meshkin
4.78	133.94		96.24	58.08	61.75	72.22	41.44	8.44	78.17	32.26	Samian
20.66	110.95		96.24	58.08	61.75	72.22	41.44	8.44	78.17	32.26	moradlu

Table 3. Details of tentative functions for best AOGCM model

Rss*	R^2	Imperials	scenario	AOGCM
4	0.55	Exponential		
38	0.67	Spherical		
2	0.68	Gaussian	A_1B	$CGCM_3T_{47}$
34	0.56	linear		

*Based on 10-5

Table 4. Statistical terms of zoning layers

Layer name		Parameter
2040	2017	(mm)
487.61	425.52	Mean
34	14.94	s.t.d
534.97	459.8	Max
416.424	379.7	min

According to the results of prominent cities in this province and standard deviation of saffron water requirement, the spatial variation rate was high in 2017-2040. In other words, there was a remarkable change in average water requirement in different cities in this province. The difference is clearly evident in maximum and minimum rainfall in these years. It should be noted that spatial variation rate of this parameter increases at the end of the study period that indicates heterogeneous distribution of saffron water requirement in the selected cities compared to previous periods. The difference in the extreme quantities in this period reflects this issue. Soleymani et al. (2011) studied net irrigation requirement of irrigated wheat under the influence of climate change. They showed that net irrigation requirement is greatly influenced by climate change. The trend of changes in saffron water requirement in this province shows 67mm-increase in water requirement by the end of planting season in 2040. This result is consistent with the results of the study conducted by Wang *et al.* (2017) who mentioned an increase in water requirement in irrigation network of rivers. Bilesavar city is the most suitable area for cultivation of saffron in the province. There will be 40mm- increase in water requirement in this city at the end of the growing season in 2040. Changes in water requirement of saffron in such cities as Jaffarabad, Garmi and Angoute are similar to Bilehadar city. Simulation results are still identical in neighboring nearby cities by taking into account downscaling of model outputs and high accuracy of the CGCM3T47 model in comparison to other models although different water requirement is expected in different cities.

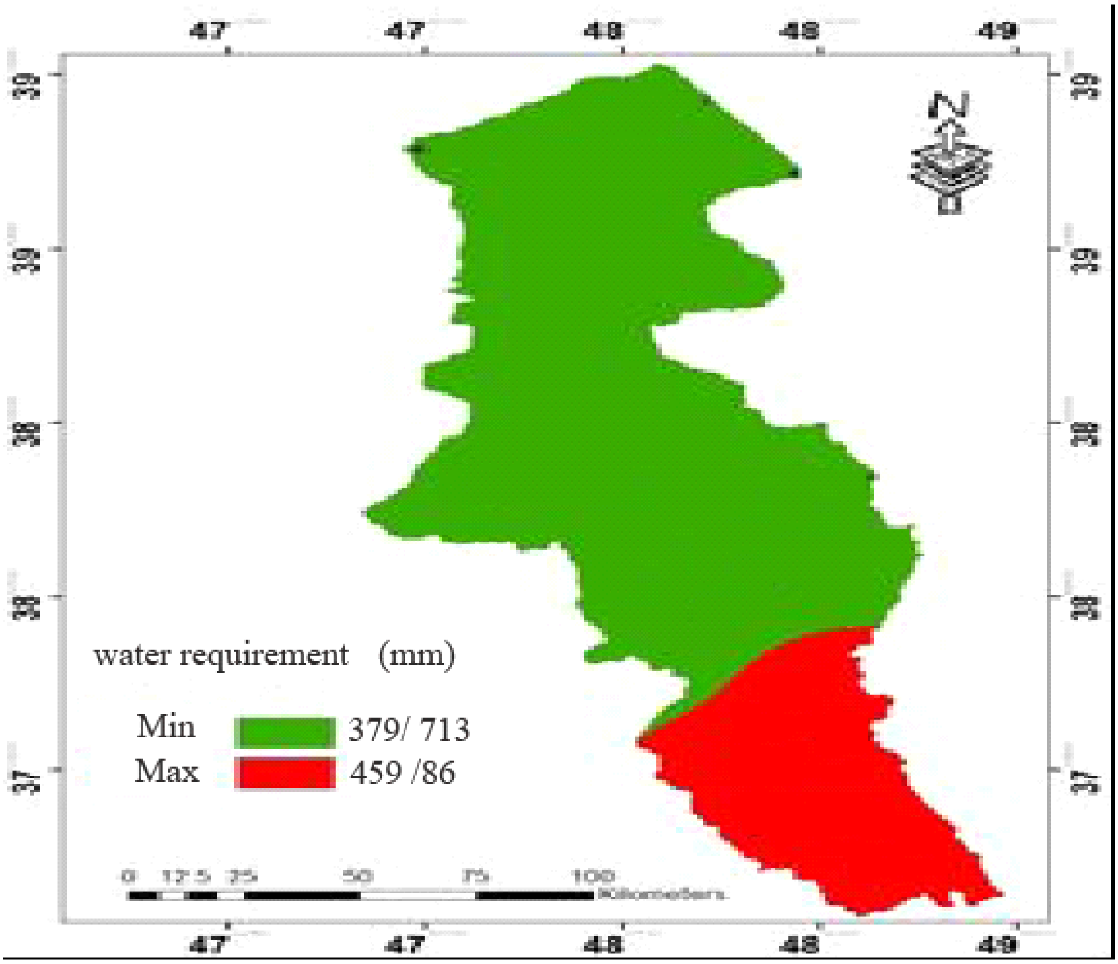

Fig 3. Zoning water requirement of saffron in Ardabil during 2017

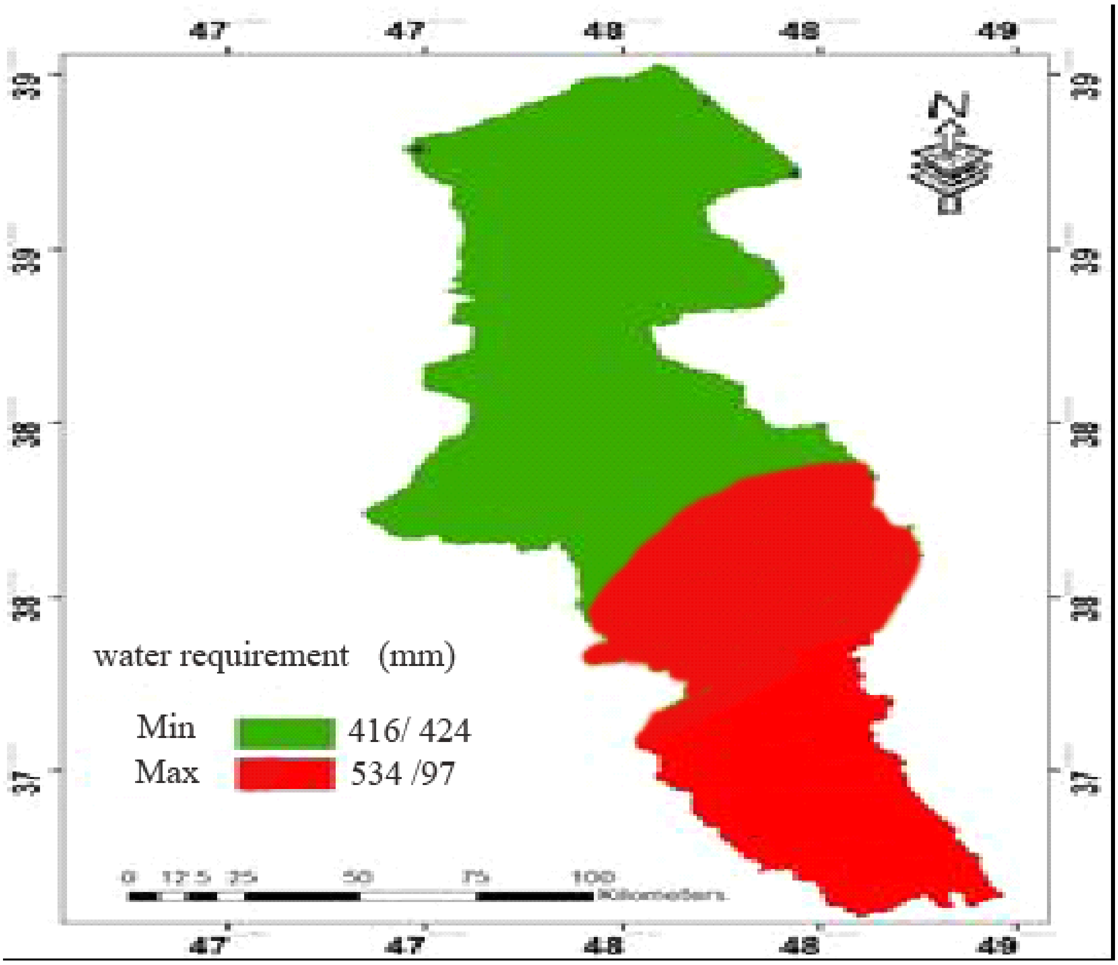

Fig 4. Zoning water requirement of saffron in Ardabil during 2040

Conclusion

Output of climate models was compared with 22-year-old statistics of meteorological stations in the vicinity of selected cities. The accuracy of these models was determined. CGCM3T47 model under the A1B scenario was the most fitted model to the data. Saffron water requirement in this province will increase by 67 millimeters in 2040. In addition, 40mm-increase was simulated in Bilehsavar city in 2040. Most changes occurred in the capital and in Ardebil. These results were not unexpected since this city is the capital of this province with larger industrial activities than other areas in this province. Saffron water requirement in Ardabil will increase by 95 mm at the end of the growing season in 2040. Since saffron is a strategic product in Ardabil province, it is necessary to pay attention to the policies that reduce the effects of climate change and adapt to existing climate conditions (the main strategy for controlling the effects of climate change). Optimal use of water resources, agricultural inputs, industrial development by taking into account the capacities of this province, determining the optimal cropping pattern, etc. should be considered in the 20-year development horizon in this province. Southern Khorasan Province had the first rank of saffron production in Iran in 2017 (kilogram per hectare saffron production).

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