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Original Article:

The Effect of Past Climate Change on the Water Footprint Trend in Saffron at Homogeneous Agroclimatic Regions of Khorasan

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Extended abstract

Introduction: Climate change and global warming have increased the intensity of droughts and their continuation. This phenomenon causes improper distribution of precipitation and the available water sources. Temperature and precipitation change under climate change and the agricultural products is affected by these two factors. Iran is the largest producer and exporter of saffron in the world, so that about 90% of the production and cultivated area of saffron in the world belongs to Iran. Meanwhile, 96% of Iran's saffron is produced in Khorasan. Saffron is one of the most efficient agricultural products in terms of water consumption, and it is considered an under-expected plant in terms of the need for nutrients. The aim of this research is investigating the changes in the water footprint of saffron under the past climate changes during the 2006 to 2017 in Khorasan region.

Materials and Methods: In this study, Fuzzy Clustering Method (FCM) was used for clustering homogeneous agroclimatic regions of saffron production using precipitation data (p), minimum and maximum temperature (Tmax, Tmin), humidity, (RH%) count of sunny hours (SH) and wind speed (WS). Then the water footprint components, including green, blue and gray water footprints and the economic value of the water footprint components in the production of saffron during the 2006-2017 were estimated using Hoekstra and Chapagain concept. Finally, the trends of water footprint components and climatic factors were investigated using Man-Kendall trend analysis test and regression analysis.

Results and Discussion: Saffron production regions in Khorasan were divided into three homogenous agroclimatic regions with the help of FCM. Based on the results, the weighted average water footprint of saffron in Khorasan is 2833 M^3/kg, respectively, the share of blue, green and 89.81, 18.11. The share of gray water footprint is very small and around 0.005%; The highest water footprint is related to Bejestan county (cluster 2) (4176.8 M^3/kg) and the lowest water footprint is related to Beshrouye county (cluster 3) (1609.5 M^3/kg). The average economic value of saffron is 0.61 $/$M^3$, the highest and lowest of which belong to Beshrouye and Bejestan counties, respectively (1.03 and 0.40 $/$M^3$). The results of the analysis of the saffron yield trend and water footprint showed that the saffron water footprint components during the studied period have a significant decreasing trend and the saffron yield also has an increasing trend during this period. The results of regression analysis showed that in all clusters, performance has a negative coefficient and a significant value. This means that more than anything, increasing the yield will reduce the water footprint. Also, the trend of climatic variables showed that temperature is increasing and humidity and precipitation are decreasing, but this trend is statistically no significance and weak.

Conclusion: The three provinces of North, Razavi and South Khorasan have the highest level of cultivation and production of saffron in Iran. Based on the results, the average annual production of saffron in three clusters is equal to 157.8 tons/year during the studied period. The highest yield of saffron is related to cluster 3 and Faruj county (4.3 kg/ha) and the lowest yield is related to cluster 1 and Bejestan county (2.5 kg/ha). The weighted average of the total water footprint of saffron is 2833 M^3/kg, the largest share of water footprint is related to cluster 1 and Bejestan county (3884.8 M^3/kg), which according to the results has the lowest yield, and the lowest share of water footprint is related to Cluster 2 and Torbat Heydarieh county (1331.1 M^3/kg). According to the results, the highest and lowest economic value of the total water footprint of saffron in the study area is related to cluster 1 in Beshroieh (1.03 $/$M^3$) and Bejestan (0.40 $/$M^3$), respectively. The trend analysis of water footprint components showed that during the studied period, the water footprint components in all three clusters had a significant decreasing trend, and the yield of saffron also had an increasing trend. The trend of climatic variables confirms the increase in temperature and decrease in precipitation, therefore, climate change has occurred in the region, and according to the change of climatic variables and the impact of water footprint on climate change, it is possible to adapt this species to the change by changing the cultivation period or changing the genotype.

Conflict of Interest: The authors declare no potential conflict of interest related to the work.

Keywords: Climate change, water footprint, saffron, multivariate regression test, Mann-Kendall test.

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Table 1. Average components of water footprint in saffron in three clusters by city

WF_{Total} (m^3/kg)	WF_{Gray} (m^3/kg)	WF_{Blue} (m^3/kg)	WF_{Green} (m^3/kg)		
4176.8	0.19	3884.8	291.9	Bajestan	Cluster 1
2411.4	0.17	1960.8	450.4	Bardaskan	
3357.9	0.14	2606.3	751.5	Taybad	
2353.3	0.17	1803.9	549.3	Khaf	
3178.0	0.14	2726.0	451.8	Kashmar	
3373.2	0.14	2971.0	402.1	Gonabad	
3484.0	0.18	3052.3	431.6	Birjand	
2888.1	0.13	2599.0	288.9	Ferdows	
1609.5	0.15	1421.3	188.0	Boshruyeh	
3126.7	0.16	2756.4	370.1	Sarayan	
3216.0	0.17	2693.7	522.1	Sarbishe	
2926.4	0.15	2556.7	369.5	Ghayenat	
2429.4	0.21	2075.4	353.8	Nehbandan	
2411.3	0.16	1784.3	626.9	Sabzevar	Cluster 2
3019.3	0.13	2344.7	674.5	Mashhad	
2141.8	0.15	1331.1	810.5	T.Heydariyeh	
3070.5	0.13	2287.2	783.2	Neyshabur	
2830.3	0.13	2125.4	704.7	Quchan	Cluster 3
2692.8	0.11	2215.1	477.6	Sarakhs	
2174.6	0.15	1573.8	600.7	T.Jam	
2873.3	0.13	2192.1	681.1	Dargaz	
3829.5	0.17	3081.8	747.5	Fariman	
2613.4	0.08	2079.9	533.4	Faruj	
2389.5	0.07	1933.8	455.6	Esfarayen	
1713.5	0.07	1395.3	318.1	Jajrom	
3381.9	0.09	2876.7	505.1	Shirvan	
2833.6	0.14	2320	513.1	Average	Total
4176.8	0.21	3885	810.5	Max	
1609.5	0.07	1331	188	Min	

Table 2. The trend of climatic factors using the Mann-Kendall test in the statistical period of 2006-2017

Sunshine hours	Perecipition (mm)	relative humidity (%)	Tmin (°C)	Tmax (°C)	Description Statistics	
9.1	125	35.6	10.4	24.4	Average	**Cluster1**
0.03	0.23	0.07	0.05	0.03	CV	
0.71	-0.48	-1.67*	0.89	+1.73*	Z value	
8.6	216.1	44	9	22.1	Average	**Cluster 2**
0.02	0.30	0.06	0.05	0.03	CV	
0.75	0.75	-1.03	0.89	+1.78*	Z value	
8.3	185.9	52.4	8.3	21.8	Average	**Cluster 3**
0.03	0.21	0.05	0.06	0.03	CV	
0.21	-1.03	-1.44	1.58	+1.71*	Z value	

***Significance at 90% confidence level, ** at 95% confidence level and *** at 99% confidence level, No sign: no significance**

Table 3. The trend of water footprint components in Khorasan region using the Mann-Kendall test in the statistical period of 2006-2017

	Water Footprint (m3/kg)					
Yeild (kg/ha)	Total	Gray	Green	Blue	Description statisctics	
3.1	2963.3	0.2	417	2546.7	Average	**Cluster 1**
0.14	0.24	0.27	0.34	0.23	CV	
1.71	-2.13**	-1.99**	-1.99**	-2.13***	Z value	
3.2	2647	0.1	720.3	1926.6	Average	**Cluster 2**
0.19	0.41	0.50	0.62	0.35	CV	
3.09***	-2.81***	-2.81**	-2.26***	-2.67**	Z value	
3.5	2702.3	0.1	547.7	2154.5	Average	**Cluster 3**
0.12	0.19	0.17	0.22	0.20	CV	
2.81***	-3.22***	-2.95**	-2.40***	-3.36***	Z value	

***Significance at 90% confidence level, ** at 95% confidence level and *** at 99% confidence level, No sign: no significance**

Table 4. Regression relationship of climatic and plant variables on water footprint

Cluster number	Variable	Coefficince	SE Coef	T-Value	P-Value	VIF	Model
I	Rh (%)	-0.0075	0.00445	-1.65	0.127	8.29	WFT = 2.425 + 0.000438 IWR - 0.00751 Rh - 0.1292 Yield
	Yield ($kg\ ha^{-1}$)	-0.1292	0.0433	-2.98	0.012	10.12	
	IWR (mm)	0.000438	0.00028	1.57	0.146	2.01	R-Sq=81.88%
II	T_{max}	0.000304	0.00011	-2.59	0.027	1.27	WFT = 0.33496 - 0.000304 T_{max} + 0.000176 Rh - 0.015028 Yeild
	Rh (%)	0.000176	0.00005	3.53	0.005	10.35	
	Yield ($kg\ ha^{-1}$)	-0.15	000041	- 3657	000	945	R-sq=99.94%
III	T_{min}	-0.00403	-0.00132	-3.05	0.012	3.00	WFT = 0.2525 - 0.000081 ET_c + 0.001030 P - 0.00403 T_{min} - 0.130 Yield
	P_{eff} (mm)	0.00103	0.000025	41.28	0.000	1.67	
	ETc (mm)	-0.00008	0.000036	-2.23	0.05	6.58	R-Sq=99.6%
	Yield ($kg\ ha^{-1}$)	-0.13	0.0021	-3.01	0.013	3.41	

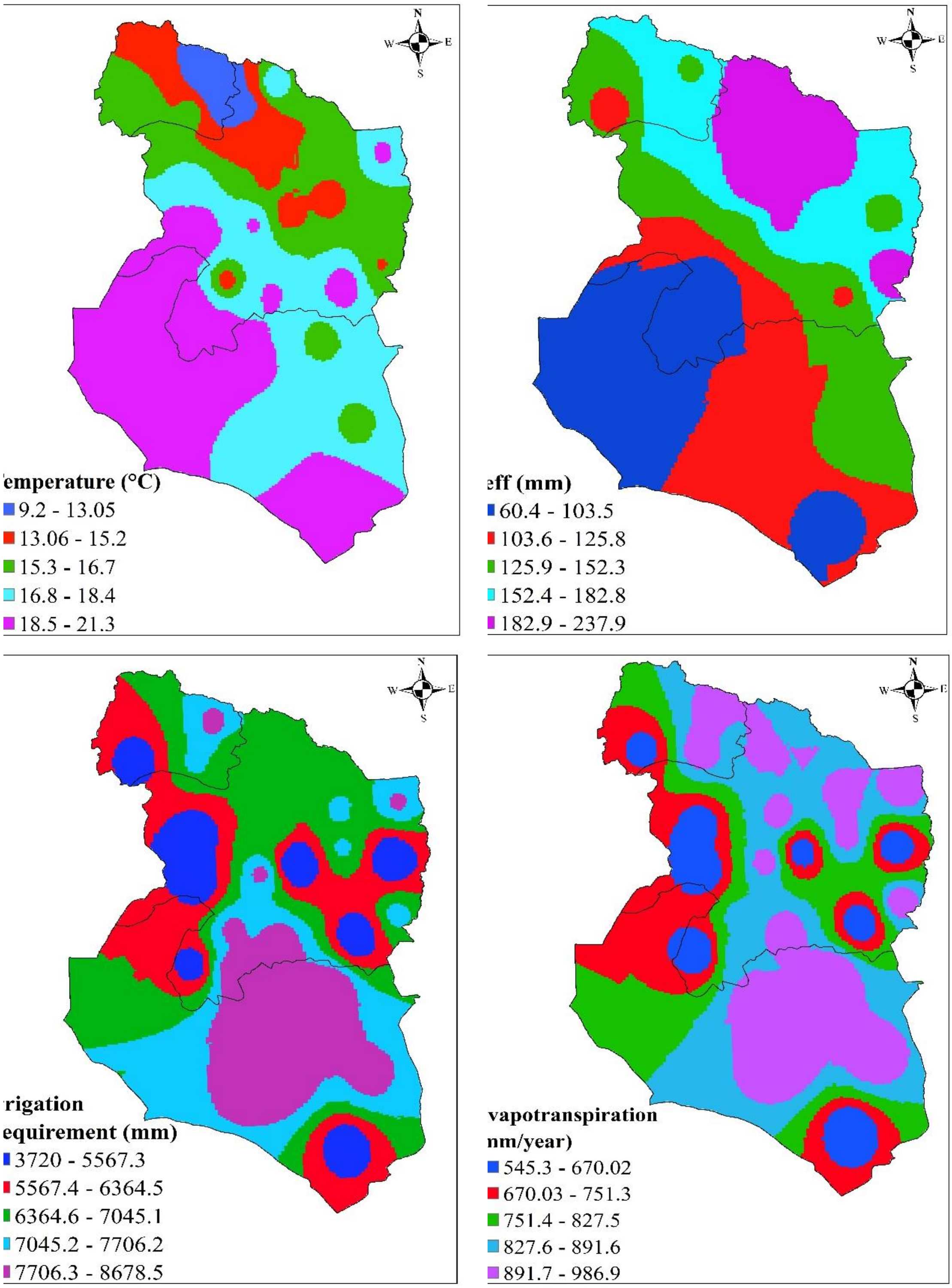

Fig 1. Spatial changes of average temperature, effective precipitation, water demand and evaporation and transpiration in Khorasan region

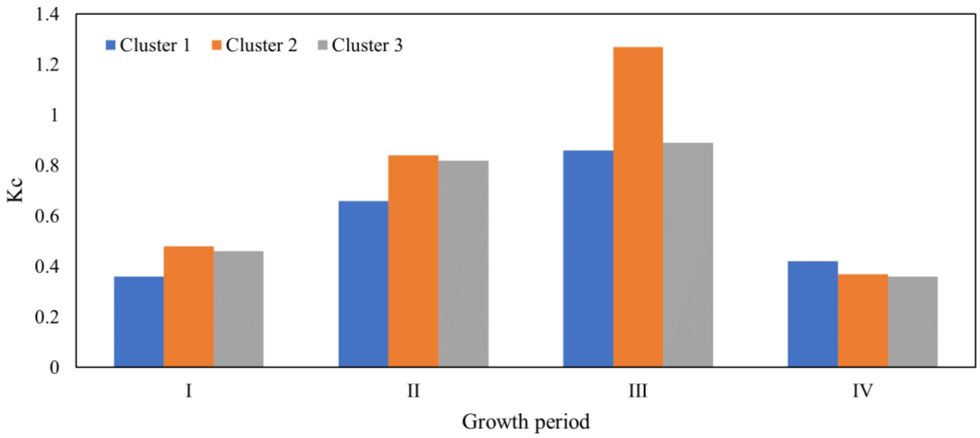

Fig 2. The Kc of saffron in Khorasan region

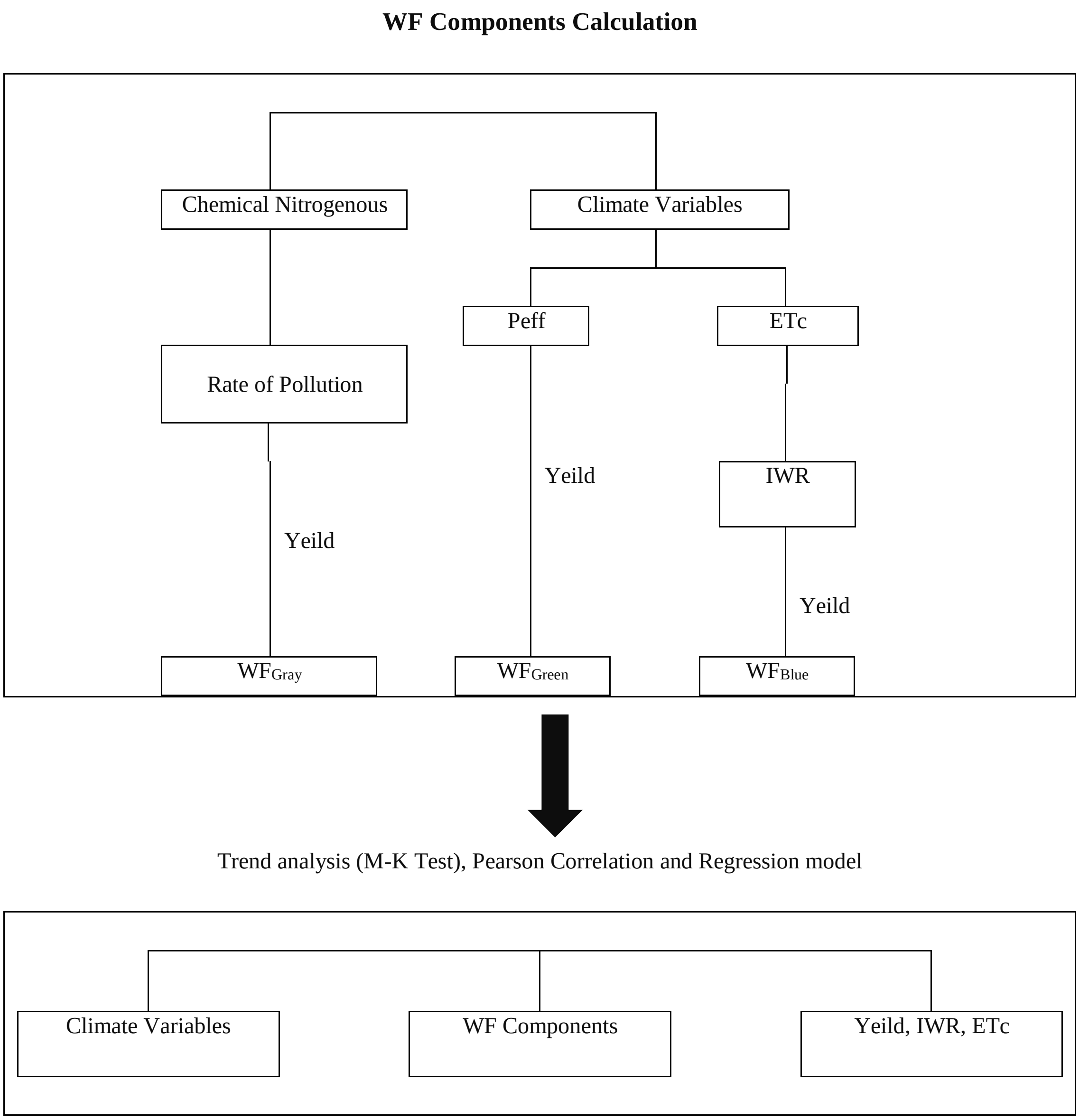

Fig 3. Research flowchart

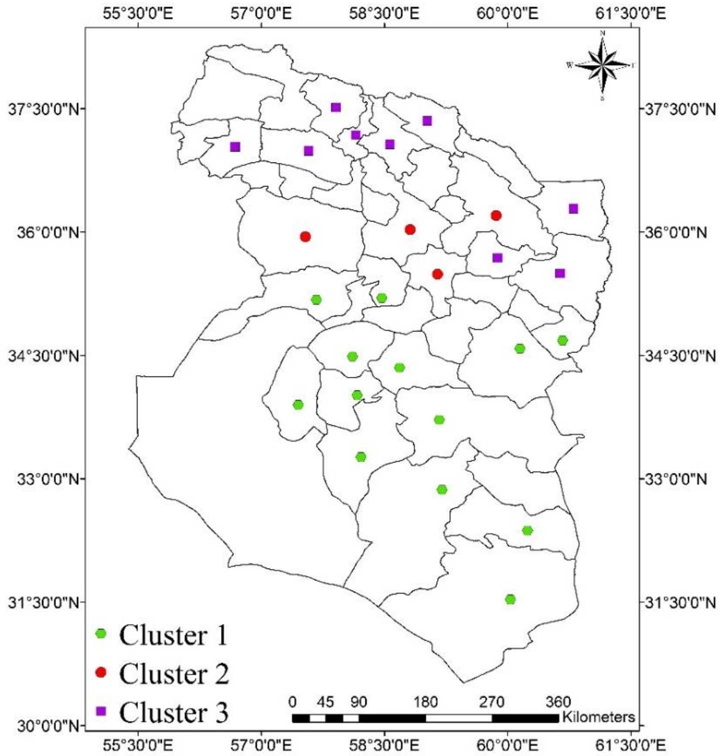

Fig 4. Homogeneous agroclimatic regions of saffron production in Khorasan region

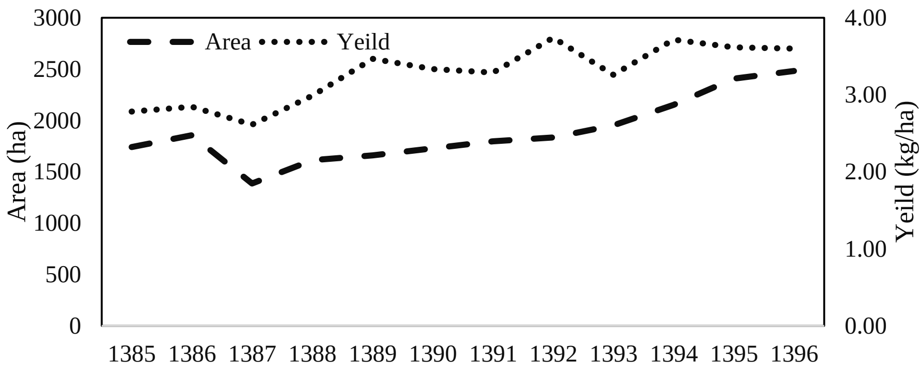

Fig 5. Changes in the cultivated area and yield of saffron in the study area during the statistical period of 2006-2017

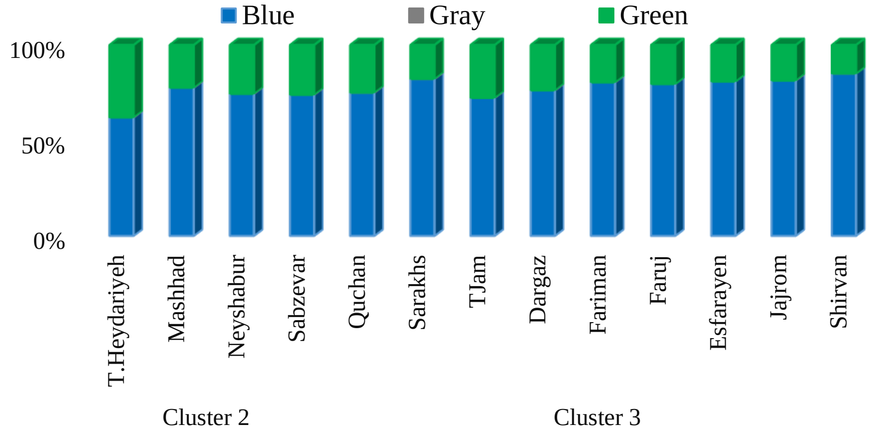

Fig 6. Shares of Saffron water footprint components in the major Saffron producing cities

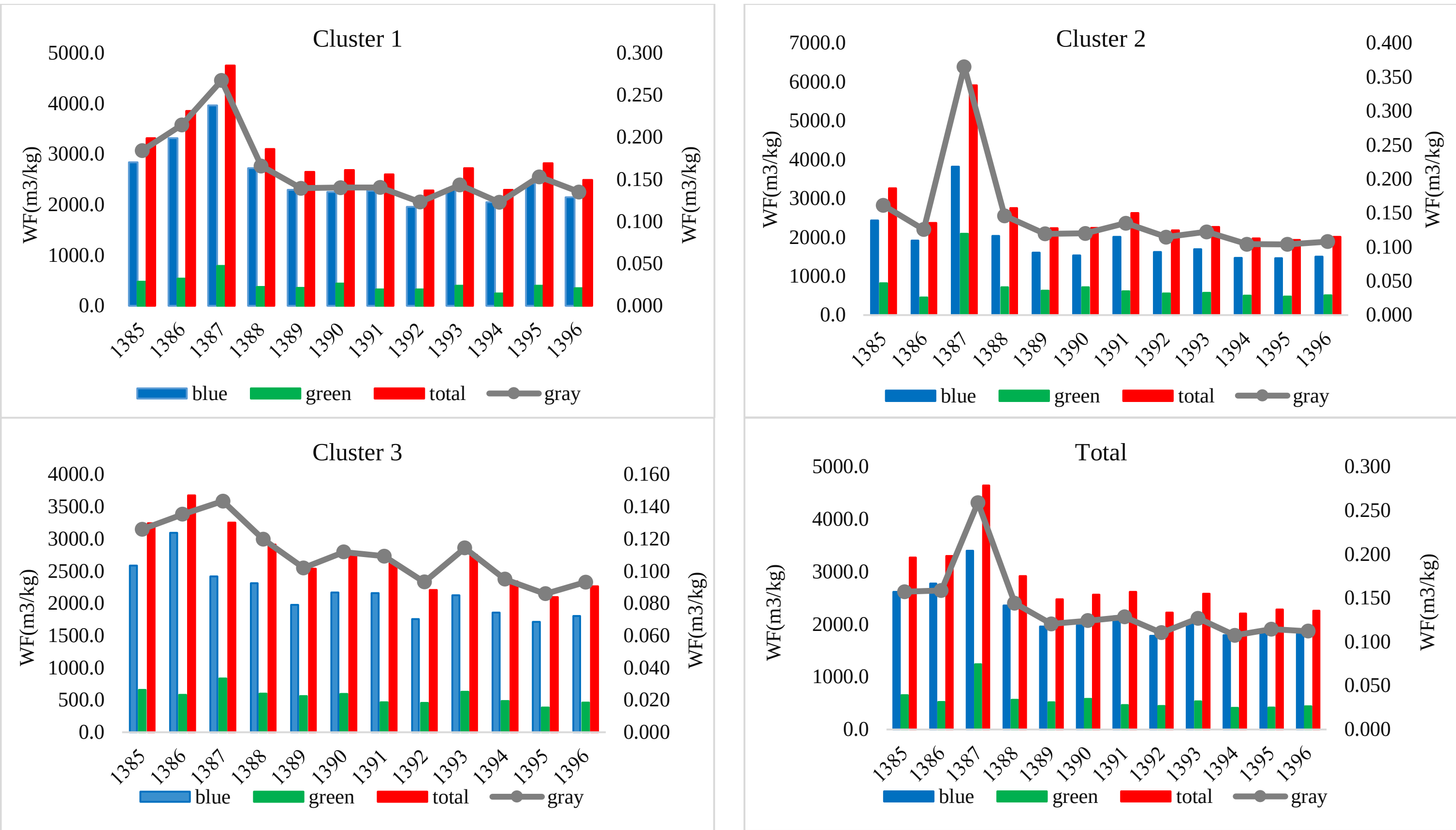

Fig 7. Temporal changes of water footprint in saffron product in clusters and the whole region during the study period (blue color: blue water footprint, green color: green water footprint, red color: total water footprint, gray color: gray water footprint)

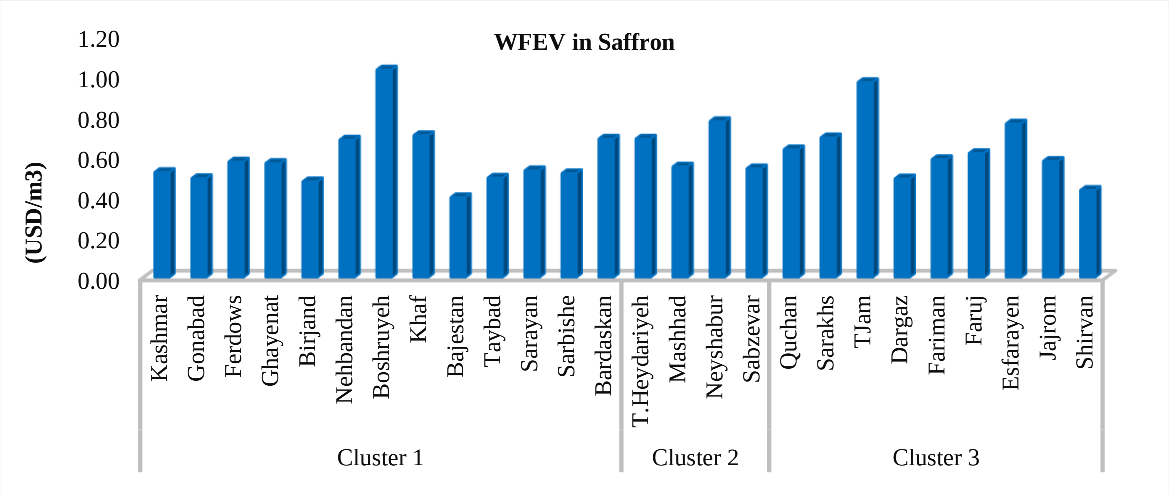

Fig 8. The average economic value of saffron water footprint in Khorasan region in each cluster by city