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Virtual water trade and water footprint accounting of Saffron production in Iran

Ommolbanin Bazrafshan[a,*], Hadi Ramezani Etedali[b], Zahra Gerkani Nezhad Moshizi[c], Mansoureh Shamili[d]

[a] Department of Natural resources Engineering, University of Hormozgan, Iran
[b] Department of Water Engineering, Imam Khomeini International University, Iran
[c] Department of Natural resources Engineering, University of Hormozgan, Iran
[d] Department of Horticulture Science, University of Hormozgan, Iran

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ABSTRACT

The virtual water concept has a considerable potential to help improve the productivity of limited fresh water resources especially in the agriculture sector. Iran is the biggest producer and exporter of Saffron in the world. This research explores the average magnitude and share of water footprint components, including the green, blue, grey and white water footprints over the period of 2008–2014 in the provincial and national levels. The average water footprint of the Saffron production in Iran was 4659 m^3 kg^{-1}. The share of green, blue, white, and grey water footprints are estimated as 12, 42, 40, and 6 percent, respectively. The total water footprint of Saffron production was around 1541 MCM yr^{-1} that the share of exported virtual water was 1354.6 MCM yr^{-1}. The average economic water footprint of Saffron production is 3.1 m^3 per $. Lorestan, East Azerbaijan and Isfahan have the lowest economical water footprint while Chaharmahal and Bakhtiari, Semnan and Fars have the highest values. The results of this research provide valuable information for managers and policy makers to extend the cultivation area in regions with low economical water footprint and also the regions with rain-fed cropping and sufficient precipitation. In contrast, increasing yield and water use efficiency in regions with high economical water footprint is very necessary.

1. Introduction

Saffron is the most expensive spice in the world, with demands from pharmaceutical and dyeing industries (Hill, 2004). Production of Saffron in Iran has a long history (Khanali et al., 2017). With 90% of the production and cultivation area, Iran is the biggest producer and exporter of Saffron in the world (Baghalian et al., 2010). About 40% of the non-oil exports of the country belongs to saffron export (Amiri et al., 2012). The rising requirement for water in all dimensions of human life, agriculture, domestic, and industry sectors have posed extreme pressure on water resources (Arabi et al., 2014; Montaseri et al., 2016). Water resources deficit leads to reduce groundwater levels, gradual drying of rivers and water pollution (Makonnen and Hoekstra, 2010). Yang and Zehnder, (2007) described virtual water as the real water consumption in the agricultural sector with the integration of economic concepts. Virtual water concept, related to water resources management and development, is an illustrative image of the need for water to supply the food for the world's population (Turton, 2000).

Exporting water-intensive products will bring considerable economic profit to the countries with rich sources of fresh water (Ababaei and Ramezani, 2014; Chapagain et al., 2005; Makonnen and Hoekstra, 2010). Water footprint concept, firstly introduced by Hoekstra and Hung (2002), then revised by Hoekstra and Chapagain (2008), is defined as the total amount of fresh water used to produce a product (Hoekstra et al., 2011).

The water footprint of a product can be divided into four components, named as green water, blue water, grey water (Falkenmark, 1995) and white water (Ababaei and Ramezani, 2017). The green water footprint is related to the share of the required water supplied from (effective) precipitation. Blue water footprint refers to the volume of the irrigation water applied to produce the product. Grey water footprint is the volume of freshwater required to dilute fertilizers and pesticides used in the production process (Hoekstra and Chapagain, 2008; Hoekstra et al., 2009). The white water footprint is a new concept proposed by Ababaei and Ramezani, (2017) referring to the amount of irrigation water lost in a growing season.

* Corresponding author.
E-mail address: O.bazrafshan@hormozgan.ac.ir (O. Bazrafshan).

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In Iran, virtual water studies have been mostly focused on strategic crops carried out at regional scales (Ababaei and Ramezani, 2014, 2017; Montazar and Zadbagher, 2010 Dehghanpur and Bakhshoodeh, 2008; Babazadeh and Sarai, 2012 Pour jafari et al., 2013; Arabi et al., 2014 Zare et al., 2015 Safi and Mir-Lotfi, 2015; Aligholi et al., 2016; Montaseri et al., 2016). Considering the value of information on the magnitudes and shares of water footprint components in water resources management at the national level, and given the fact that no accurate estimation of water footprint in the production of Saffron at provincial and national levels are available, the goal of this research is the estimation of the water footprint components, water footprint accounting and virtual water trade in the Saffron production and Iran's exported Saffron.

2. Materials and methods

Iran, with the area of 1,648,195 km^2, is located between 25°03′ N and 39°47′ N, and 44°14′ E and 63°20′ E (Saeidkhani et al., 2017). The Saffron-producing provinces are located in very humid regions in northern Iran (with the annual precipitation of 590 mm), regions with the Mediterranean climate in the west (with the precipitation of 250 mm) and semi-arid climate in the center of the country (with the precipitation of 50 mm) (Zarch et al., 2011) (Fig. 1). On average, 86,000 ha of farmlands in the country is dedicated to the cultivation of Saffron (Ministry of Agriculture- Jihad (MAJ), 2017). The organization of agriculture and water is self-governing in any province of Iran, so this study was conducted at the provincial level.

The magnitudes of water footprint components in the production of Saffron are estimated as average values over the period of 2008–2014 using the calculation framework proposed by Ababaei and Ramezani (2017), which includes modifications to the original framework of Hoekstra and Chapagain (2008). CROPWAT (Smith, 1992) and the FAO Penman-Monteith equation were used as the standard methods to estimate the water requirement of Saffron (Eq. (1)). The below equations are used for WF component calculations.

$$WF_{Green} = \frac{(P_e) \times 10}{Y} \quad (1)$$

$$WF_{Blue} = \frac{(ET_c - P_e) \times 10}{Y} \quad (2)$$

$$WF_{Gray} = \frac{\alpha \times NAR}{C_{Max} - C_{Nat}} \times \frac{1}{Y} \quad (3)$$

$$WF_{White} = \max\left(0, \frac{10 \times (GI - IR)}{Yield} - WF_{Gray}\right) \quad (4)$$

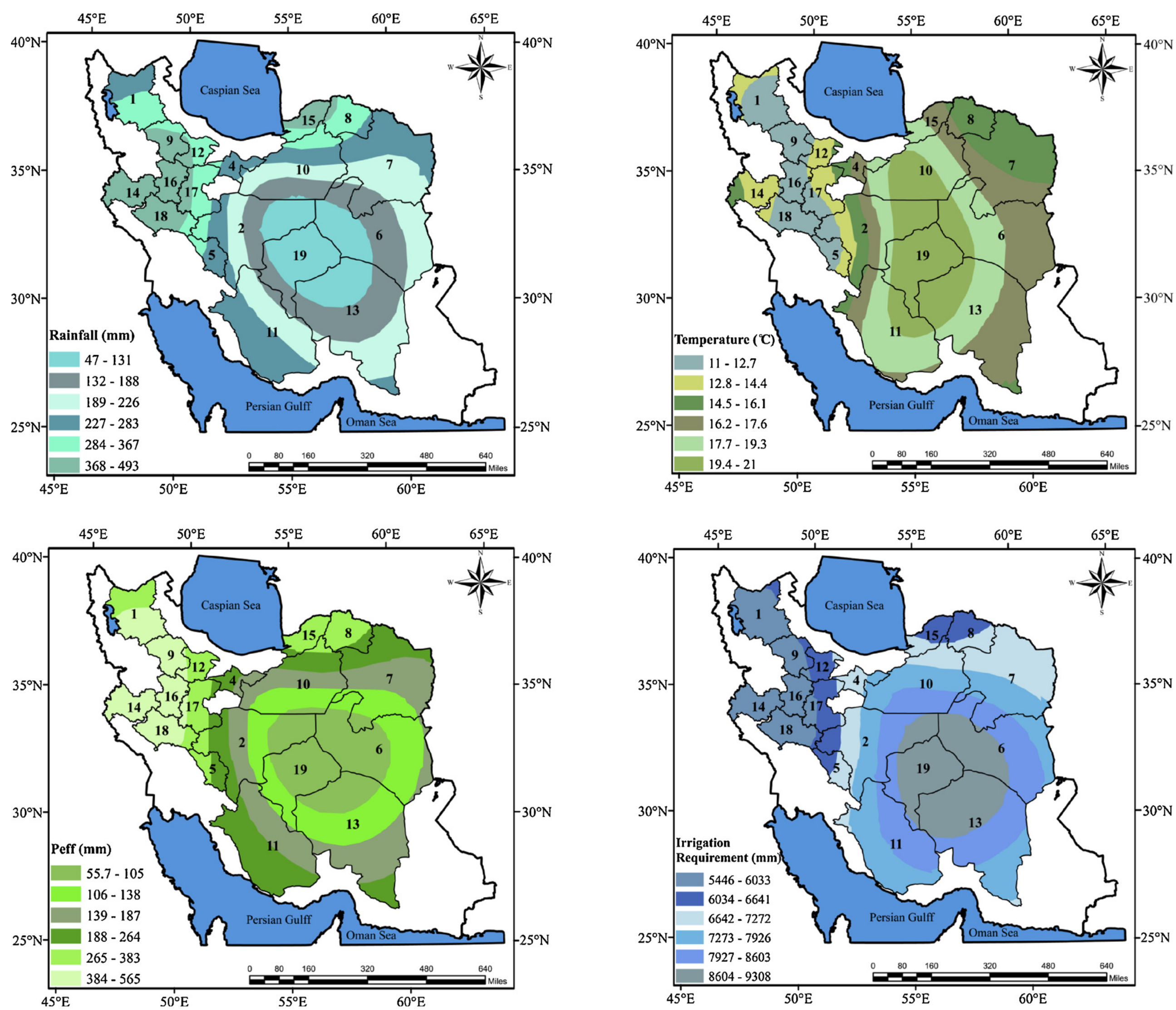

Fig. 1. Spatial distribution of effective precipitation (P_{ef}); net irrigation requirement (IR); temperature and rainfall in the Saffron producing provinces of Iran. The names of the 19 Saffron producing provinces are provided in Table 1.

In the following equations, WF_{Green}, WF_{Blue}, WF_{grey}, and WF_{White} are green, blue, grey, and white water footprints (m^3/kg), respectively, P_e is the seasonal effective precipitation (estimated with the USDA method) over growing season (mm), ET_c is crop evapotranspiration (mm), Y is crop yield (ton/ha), α is percentage of nitrogen fertilizer waste, NAR is fertilizer consumption rate (kg ha^{-1}), C_{max} is the critical concentration of nitrogen in the receiving water bodies (kg m^{-3}), C_{Nat} is the real concentration of nitrogen in the receiving water bodies (kg m^{-3}), D_t is the seasonal net irrigation (mm), and 10 is the factor for unit change from mm to m^3/ha. The value of α for water deficit conditions usually set at 10% (Chapagain et al., 2006). In this study, WF_{Grey} has been estimated only for nitrogen fertilizers, as the main source of pollution in the country (Ababaei and Ramezani, 2017). Maximum concentration of nitrogen in the receiving water bodies was considered 10 mg/l, based on the US-EPA standard (Chapagain et al., 2006). The real nitrogen concentrating was assumed zero (a conservative choice) due to the lack of measured values in receiving water bodies (Chapagain et al., 2006). Total water footprint in each province was calculated as follows:

$$WFV_{i,x} = \text{Prod}_{i,x} WF_{i,x} \quad i = 1, 2, .., 19 \tag{5}$$

$$AWF_{i,x} = \frac{\sum WFV_{i,x}}{\sum \text{Prod}_{i,x}} \tag{6}$$

in which *i* is production index, *x* is WF component (blue, green, grey, or white), *Prod* is the Saffron production (kg), *WFV* is the total volume of each WF component (m^3) in each province, and *AWF* is the average of each WF component (m^3 kg^{-1}). Saffron yield and source of N fertilizer data (2008–2014) were obtained from the Iranian Ministry of Agricultural-Jihad (MAJ) at the provincial scale.

The economic WF calculated by the following equations (Mojtabavi et al., 2017):

$$WF_{E(Green)} = \frac{WF_{Green}}{NB} \tag{7}$$

$$WF_{E(Grey)} = \frac{WF_{Grey}}{NB} \tag{8}$$

$$WF_{E(Grey)} = \frac{WF_{Grey}}{NB} \tag{9}$$

$$WF_{E(White)} = \frac{WF_{White}}{NB} \tag{10}$$

In which $WF_{E(Green,\ Blue,\ Grey\ and\ white)}$ is the economic WF of green, blue, grey and white respectively, and NB is the net benefit according to US $\$^{-1}$. The average net benefit of saffron production is 6250 US$ ha $Year^{-1}$ (Ministry of Agriculture- Jihad (MAJ), 2017).

3. Results and discussion

Total Saffron production, yield, area and nitrogen fertilizer application in each province are presented in Table 1. Saffron is produced under irrigated conditions in the whole country. On average, annual Saffron production in the country is around 228.5 ton, with an average yield of 4.14 kg ha^{-1}, and the total utilization of nitrogen fertilizers is 105.8 kg ha^{-1}. The highest Saffron yield is obtained in Isfahan and Lorestan provinces, i.e., 6.19 and 5.45 kg ha^{-1}, respectively. Although the largest Saffron-cultivated lands are located in Razavi Khorasan and South Khorasan provinces, both of the provinces have the smallest Saffron yield due to severe water stress.

According to the reports of Ministry of Agriculture Jihad (Ministry of Agriculture- Jihad (MAJ), 2017), although the Saffron sowing area increased whose yield decreased in Iran. Comparing the Saffron yield (4.14 kg ha^{-1}) during 2008–2014 with the former period (2000–2007) shows a 24% yield decrease. Saffron yield is considerably higher in other countries, like Italy (8.3 kg ha^{-1}) and Spain (7.94 kg ha^{-1}) (FAO, 2014). Based on the results of Koocheki (2013), low knowledge and technology of planting and harvesting, low fertility of Saffron farms, low thickness of the soil layer and the lack of using chemical and organic fertilizers are the crucial reasons of low yield.

Fig. 1 shows the spatial distribution of average precipitation, net irrigation requirement, temperature and precipitation in the major saffron producing provinces in Iran. Net irrigation requirement is high in the central (Yazd and Kerman), eastern and southeastern (Razavi Khorasan and South Khorasan) parts of the country while effective precipitation and total precipitation are higher in the west (Lorestan and Kermanshah), north (Golestan) and north-west (East Azerbaijan). Effective precipitation provides greater share of water requirement in the west and north provinces of Iran while this share is lower in southern and central regions.

The components of Saffron WF are summarized in Table 2. The green, blue, grey and white WF ranged 127-1510 m^3 kg^{-1}, 999-3499 m^3 kg^{-1}, 162-510 m^3 kg^{-1} and 8898-2875 m^3 kg^{-1}, respectively. The total average WF in Saffron production in the selected provinces is 4659 m^3 kg^{-1} with 12% WF_{Green}, 42% WF_{Blue}, 40% WF_{White}, and 6% WF_{Grey}. Three provinces with high shares of WF_{Green} are Golestan (29%), Lorestan (27%) and Kermanshah (21%), and the smallest are Yazd (3%), Southern Khorasan (4%), and Semnan (5%), respectively. The WF_{Blue}, with a share of 42%, constitutes the largest part of WF in Saffron production. Yazd (46%), Semnan (45%), and South Khorasan (45%) have the largest shares of the WF_{Blue}. In contrast, Golestan (33%), Lorestan (35%), and Kermanshah (37%) have the smallest shares of the WF_{Blue}. The green + blue WF indicates that Chaharmahal and Bakhtiari, Golestan, Fars, and Razavi Khorasan provinces have the largest shares. Considering the considerable amounts of precipitation in these provinces, strategies such as cultivation of new genotypes more adapted to the wet periods, shortening the flowering period of Saffron with the aim of avoiding the dry period at the end of the growing season can be considered to reduce the share of the WF_{Blue} and reduce the share of the green + blue WF.

Around 6% of total WF in Saffron production is contributed by the WF_{Grey}. Chaharmahal and Bakhtiari (6.1%) has the highest share of WF_{Grey} and the smallest share is related to Yazd (4.9%). The average of WF_{Grey} in Saffron production in the study period of 2008–2014 is estimated to 260 m^3/kg and the highest share is for Chaharmahal and Bakhtiari province (510 m^3/kg). The main reasons for the considerable value of WF_{Grey} in this province are low yield of Saffron, high consumption of chemical fertilizer, and high leaching of fertilizer in this region (Ministry of Agriculture- Jihad (MAJ), 2017).

The WF_{White} constitutes 40% of the total WF of Saffron production in the country. Three provinces with high shares of WF_{White} are Golestan (29%), Lorestan (27%) and Kermanshah (21%) provinces, and Yazd (46%), Semnan and Southern Khorasan (45%) have the largest shares. However, the declinnig groundwater is so serious in more than 400 plains in Iran, including Yazd, Ardakan, Mashhad, Neyshabur, and Birjand (Madani, 2014). These provinces have low precipitation and a high crop water requirement. On the other hand, inappropriate irrigation management (number of events and the volume of irrigation) has led to decreased Saffron yield in these regions and larger WF (Shirzadi et al., 2017). Three provinces with high shares of WF_{White} are Lorestan (32%), Golestan (32%) and Kermanshah (38%), due to the high yield of Saffron. In addition, the distribution of the WF_{Green} in these three provinces indicates that a larger amount of precipitation in these regions has led to higher soil moisture and supplying a considerable part of water demand.

Table 3 presents the average annual volume of each WF component, averaged over the period of 2008–2014. The total volume of the WF of Saffron production in the country is 1541 MCM per year. Razavi Khorasan (1204 MCM $year^{-1}$) and South Khorasan (278 MCM $year^{-1}$) have the largest WF of Saffron production, while Zanjan (0.36 MCM $year^{-1}$) and Alborz (0.44 MCM $year^{-1}$) have the smallest WF.

The largest volumes of WF were observed in Razavi Khorasan (78%)

Table 1
The 15-year average of Saffron production data for the main producing provinces.

Province	Code (Fig. 1)	Production (ton)	National Share (%)	Yield (kg/ha)	Area (ha)	N Fertilizer* (kg/ha)
East Azerbaijan	1	0.60	0.21	5.14	116.7	100
Isfahan	2	3.31	1.18	6.19	533	100
Alborz	3	0.10	0.04	4.02	24.9	100
Tehran	4	0.22	0.07	4.45	44.9	100
Chaharmahal and Bakhtiari	5	0.10	0.04	1.96	51.0	150
South Khorasan	6	48.10	17.09	3.41	14091.5	100
Razavi Khorasan	7	218.41	77.78	3.15	69406.5	80
North Khorasan	8	2.61	0.93	5.15	504.5	50
Zanjan	9	0.10	0.04	4.63	21.6	100
Semnan	10	0.31	0.11	2.80	107.1	120
Fars	11	1.60	0.57	3.24	494.5	100
Qazvin	12	0.10	0.04	3.45	29.0	100
Kerman	13	2.61	0.93	5.10	509.5	100
Kermanshah	14	0.20	0.07	4.58	43.7	100
Golestan	15	0.30	0.11	3.95	76.0	200
Lorestan	16	0.31	0.11	5.45	55.0	90
Markazi	17	0.30	0.11	3.27	91.7	120
Hamadan	18	0.30	0.07	4.35	46.0	100
Yazd	19	1.51	0.53	4.39	342.0	100
Total	–	**228.5**	**100**	**4.14**	86589	**105.8**

* Source: Ministry of Agriculture- Jihad (MAJ, 2017.

Table 2
Water footprint components for the main Saffron producing provinces (values in parentheses refers to share of WF components).

Povince	Water (mm)			WF ($m^3\,kg^{-1}$)				
	ET_c	IR	P_{eff}	Green (%share)	Blue(%share)	Gray(%share)	White(%share)	Total
East Azerbaijan	897.4	609.8	287.6	559 (18%)	1186 (39%)	194 (6%)	1123 (37%)	3063
Isfahan	990.8	832.4	158.4	256 (8%)	1344 (43%)	161 (5%)	1332 (43%)	3094
Alborz	949.5	751.9	197.6	492 (11%)	1872 (42%)	249 (6%)	1831 (41%)	4445
Tehran	889.4	777.1	112.3	252 (6%)	1745 (44%)	224 (6%)	1714 (44%)	3935
Chaharmahal and Bakhtiari	982.3	686.2	296.1	1510 (17%)	3499 (39%)	510 (6.1%)	3378 (38%)	8898
South Khorasan	982.5	894.2	88.3	259 (5%)	2625 (45%)	293 (5%)	2623 (45%)	5801
Razavi Khorasan	902.1	749.8	152.3	484 (9%)	2383 (43%)	317 (6%)	2330 (42%)	5515
North Khorasan	946.4	751.6	194.8	378 (11%)	1458 (42%)	194 (6%)	1426 (41%)	3457
Zanjan	945.8	661.6	284.2	614 (17%)	1429 (39%)	216 (6%)	1372 (38%)	3631
Semnan	942.0	852.4	89.6	320 (5%)	3040 (45%)	356 (5%)	3021 (45%)	6738
Fars	1064.5	839.0	225.5	697 (11%)	2593 (42%)	309 (5%)	2572 (42%)	6171
Qazvin	978.3	788.7	189.6	550 (10%)	2287 (43%)	290 (5%)	2251 (42%)	5378
Kerman	1014.4	880.9	133.5	262 (7%)	1726 (44%)	196 (5%)	1722 (44%)	3906
Kermanshah	903.1	577.7	325.4	711 (21%)	1262 (37%)	218 (6%)	1184 (35%)	3376
Golestan	939.5	642.9	296.6	1432 (29%)	1629 (33%)	253 (5%)	1556 (32%)	4870
Lorestan	962.8	544.7	418.1	767 (27%)	999 (35%)	183 (6%)	926 (32%)	2875
Markazi	957.5	664.6	292.9	569 (12%)	2031 (35%)	305 (6%)	1951 (40%)	4857
Hamedan	922.7	697.2	225.5	519 (13%)	1604 (41%)	230 (6%)	1552 (40%)	3904
Yazd	986.4	930.7	55.7	127 (3%)	2122 (46%)	228 (4.9%)	2130 (46%)	4607
Average	**955.6**	**743.8**	**211.8**	**566 (12%)**	**1939(42%)**	**260(6%)**	**1895(40%)**	**4659**
Max	**889.4**	**544.7**	**55.7**	**1510(29%)**	**3499(46%)**	**510(6.1%)**	**3378(46%)**	**8898**
Min	**1064.5**	**930.7**	**418.1**	**127(3%)**	**999(33%)**	**162(4.9%)**	**926(32%)**	**2875**

and Southern Khorasan (18%). The sum of the volume WF in these two provinces is 1483 MCM, which is more than 96% of the total WF (1541 MCM) in the whole country. In Chaharmahal and Bakhtiari, Golestan, Lorestan, and Kermanshah, a large share of WF is related to the WF_{Blue} despite having considerable amount of seasonal precipitation.

The largest share of the total WF in Saffron related to the blue + white WFs would be 82%, while the average share of blue + white WFs was estimated by Ababaei and Ramezani, (2017) to be 37% for cereals in Iran. Although WF_{White} eventually returns to the water cycle, there are opportunities for effective irrigation management to reduce the WF. More than 96% of Saffron cultivated lands are located in central parts of Iran with arid and semi-arid climates, the share of WF_{Blue} was considerably large (greater than 42%). Most of the required water supplied from groundwater resources, which led to the groundwater depletion (Sepaskhah and Yarami, 2010). Changing cultivation calendar and using genotypes more adapted to the wet season can result in a considerable decrease in WF_{Blue} and an increase in the contribution of the WF_{Green} (Koocheki, 2013).

The relation between the provinces obtained through hierarchical cluster analyses (linkage between groups). Euclidian distance has been used for similarity measures of dendrograms. This method classified the provinces in three groups in terms of WF_{Green} (Fig. 2a). Each group has similar characteristics in the yield and effective precipitation. The ranges of WF_{Green} are as follows: 127-378 $m^3\,kg^{-1}$ in the first group, 379-767 $m^3\,kg^{-1}$ in the second and 768-1510 $m^3\,kg^{-1}$ in the third group. The group-1 contains the provinces with low effective precipitation, while the group-3 includes those with high effective precipitation and low yield.

There are four major groups obtained from $WF_{Blue.}$ The amounts of WF_{Blue} in the four groups are as follows, group-1: 999-1458 $m^3\,kg^{-1}$, group-2: 1604 to 1872 $m^3\,kg^{-1}$, group-3: 2122-2625 $m^3\,kg^{-1}$ and group-4: 3040-3499 $m^3\,kg^{-1}$. The provinces of each group are given in details

Table 3
The total volume of WF each component and the economic WF in the main Saffron-producing provinces.

Province	Total volume of WF (MCM yr^{-1})					WF_E (m^3 $\$^{-1}$)
	Green	Blue	Gray	White	Total	
East Azerbaijan	0.34	0.71	0.12	0.67	1.84	2.04
Isfahan	0.84	4.44	0.53	4.40	10.21	2.06
Alborz	0.05	0.19	0.02	0.18	0.44	2.96
Tehran	0.05	0.35	0.04	0.34	0.79	2.62
Chaharmahal and Bakhtiari	0.15	0.35	0.05	0.34	0.89	5.93
South Khorasan	12.4	126	14.1	125.9	278.5	3.87
Razavi Khorasan	105.7	520.4	69.4	508.8	1204.4	3.68
North Khorasan	0.98	3.79	0.50	3.71	8.99	2.30
Zanjan	0.06	0.14	0.02	0.14	0.36	2.42
Semnan	0.10	0.91	0.11	0.91	2.02	4.49
Fars	1.12	4.15	0.49	4.12	9.87	4.11
Qazvin	0.05	0.23	0.03	0.23	0.54	3.59
Kerman	0.68	4.49	0.51	4.48	10.15	2.60
Kermanshah	0.14	0.25	0.04	0.24	0.68	2.25
Golestan	0.23	0.49	0.08	0.47	1.26	2.79
Lorestan	0.23	0.30	0.06	0.28	0.86	1.92
Markazi	0.27	0.61	0.09	0.59	1.56	3.46
Hamedan	0.10	0.32	0.05	0.31	0.78	2.60
Yazd	0.19	3.18	0.34	3.19	6.91	3.07
Total	**123.7**	**671.3**	**86.6**	**659.3**	**1541**	–
Average	**6.5**	**35.3**	**4.6**	**34.7**	**81.1**	**3.1**
Max	**105.7**	**520.4**	**69.4**	**508.8**	**1204.4**	**5.93**
Min	**0.05**	**0.14**	**0.03**	**0.14**	**0.36**	**1.92**

in the dendrogram of Fig. 2b.The WF_{Grey} classified to three groups (Fig. 2c). The ranges of WF_{Grey} are as follows: 161-253 $m^3\,kg^{-1}$ in the first group, 290-356 $m^3\,kg^{-1}$ in the second and 510 $m^3\,kg^{-1}$ in the third group. In case of WF_{Grey}, the group-1 is regarded as provinces with lower nutrient consumption, whereas group-3 is as higher consumption.

There are six groups obtained from WF_{Blue}. The provinces of each group are shown in Fig. 2d. In this case, the first group is regarded as provinces with lower irrigation water requirement, whereas the sixth group is cherechterized as higher requirement. The amounts of WF_{White} in six groups are as follows, group-1: 926-1184 $m^3\,kg^{-1}$, group-2: 1332–1556 1872 $m^3\,kg^{-1}$, group-3: 1714-1951 $m^3\,kg^{-1}$, group-4: 2130-2251 m^3kg-1, group-5: 2321–2330 and group-6: 3021–3378.

Finally, provinces are classified in four groups based on total WF (Fig. 2e). The group-1 consist of Kerman, Hamedan, Tehran, North Khorasan, Kermanshah, Lorestan, Zanjan, East Azerbaijan and Isfahan provinces whose total WF range is 2875-3935 $m^3\,kg^{-1}$. The associated range for group-2 is 3906-5801 $m^3\,kg^{-1}$. This cluster includes Golestan, Markazi, Alborza, Qazvin, South Khorasan, Yazd and Razavi Khorasan provinces. Semnan and Fars provinces are in cluster-3 with 61-71-6738 $m^3\,kg^{-1}$ of total WF. Chaharmahal and Bakhtiari is the only member of cluster-4, with total WF of 8898 $m^3\,kg^{-1}$. As mentioned above, cluster-1 can be classified as low-total WF, cluster-2 as middle-total WF, cluster-3 as high- total WF and cluster-4 as very high-total WF.

The Saffron consumption is 0.5 g per capita in each year with the estimated volumes of consumed VW 186.4 MCM yr^{-1} based on the population of about 80 million in Iran (Ministry of Agriculture- Jihad (MAJ), 2017; Statistical Centre of Iran (Statistical Centre of Iran (SCI), 2017). The total volume of the WF of Saffron production is 1541 MCM per year that 186.4 MCM will be used yearly in the country and 1354.6 MCM exported per year to other countries. The 162.5 MCM $yr^{-1}$of exported VW is the share of WF_{Green} and 1192.1 MCM yr^{-1} of total WF includes of blue, grey and white. Hence considerable volume of the region's groundwater resources was exported annually from Iran through exporting Saffron production.

Based on the WF_E listed in Table 3, Lorestan and Chaharmahal and Bakhtiari provinces has the lowest (1.92 m^3 US$$^{-1}$) and the highest (5.93 m^3 US$$^{-1}$) WF_E of Saffron production in Iran, respectively. It means, Lorestan province can earn 1 $ by consuming 1.92 m^3 (1.93 m^3 per US$) water while Chaharmahal and Bakhtiari province consumes 5.93 m^3 water to earn 1 $ (i.e. 3.1 times more consumption than Lorestan). The other provinces in WF_E ascending are Semnan (4.49 m^3 US$$^{-1}$), Fars (4.11 m^3 US$$^{-1}$), South Khorasan (3.87 m^3 US$$^{-1}$) and Razavi Khorasan (3.68 m^3 US$$^{-1}$), respectively. These provinces have low yield per ha. More than 94% of Saffron is produced in the Razavi Khorasan and South Khorasan with a low yield (3.3 kg ha^{-1}). The average of exported WF_E for Saffron production is 3.1 m^3 US$$^{-1}$ in Iran that the shares of green, blue, white, and grey WF are estimated as 0.36, 1.29, 1.26, and 0.17 m^3 US$$^{-1}$, respectively.

Arabi-Yazi et al (2009) classified the WF_E in the exported agricultural products to six groups, including very low, low, middle, high, very high and extreme. In this category, the Saffron is placed in the middle group in regards of WF_E. Also, the majority of exported products include pistachios, almond, apple, plumes, and watermelons are in the middle group (Ministry of Agriculture- Jihad (MAJ), 2017).

4. Conclusions

The magnitudes, shares and spatial distribution of WF components of Saffron production in Iran were studied using the assessment frameworks proposed by Hoekstra and Chapagain (2008), Ababaei and Ramezani, (2017) and Hoekstra et al. (2009) in the period of 2008–2014.

Saffron is a big part of non-oil exports in Iran. More than 95% of the Saffron-cultivated lands are located in the arid and semi-arid regions. These lands are facing with water shortage and groundwater depletion. Thus, using efficient irrigation systems and planting the higher-yield varieties are very essential practices in Saffron-cultivated lands.

Resuls of this study showed the share of WF_{Green} is very low (about 12% of the total average WF in Saffron production). In contrast the share of blue + white WFs is very high (82% of the total average WF). Introducing the varieties with low water requirement and adapt to the wet periods can be very helpful in order to extend the rain-fed cropping in regions with sufficient precipitation, especially in grow seasons, which can lead to a sustainable strategy in a water-scarce country like Iran. Also selecting the regions with high precipitation such as Lorestan, Eastern Azarbaijan, Esfahan and Kermanshah for Saffron cultivation are very useful.

On the other hand, the overall share of white + grey WFs is about 46%, which this is the results of low efficiency of water use and high rates of fertilizer consumption, especially in the regions with high contributions of national Saffron cultivation (e.g. Razavi Khorasan and South Khorasan). Although a partial of these WFs return to the water cycle, contamination and inaccessibility at least for one year can be considerable issues by the authorities. Increasing water productivity and irrigation system efficiency are the main strategy for reducing these WFs.

Based on the literature, virtual water concept is a source of great concern. But one of the important drawbacks of this concept is that we actually cannot rely on crop imports with high confidence. As we know many countries will deal with water and food-safety problems in future. Therefore, they may have problems with growing crops and enough freshwater for irrigation. They can not actually rely on crop imports from other countries as a sustainable solution, since they may have their own water and food problems and hence couldn't provide our need. Thus, saving the freshwater resources and having a sustainable development will occur based on the water policy in the country.

In the near future, virtual water will play an important role in the international trade of strategic products. Therefore, it is necessary to study and explore the temporal and spatial distribution of WF with the aim of improving productivity and reducing water consumption. Results of this research provide the managers and policy-makers with valuable information on the distribution of the Saffron WF across Iran

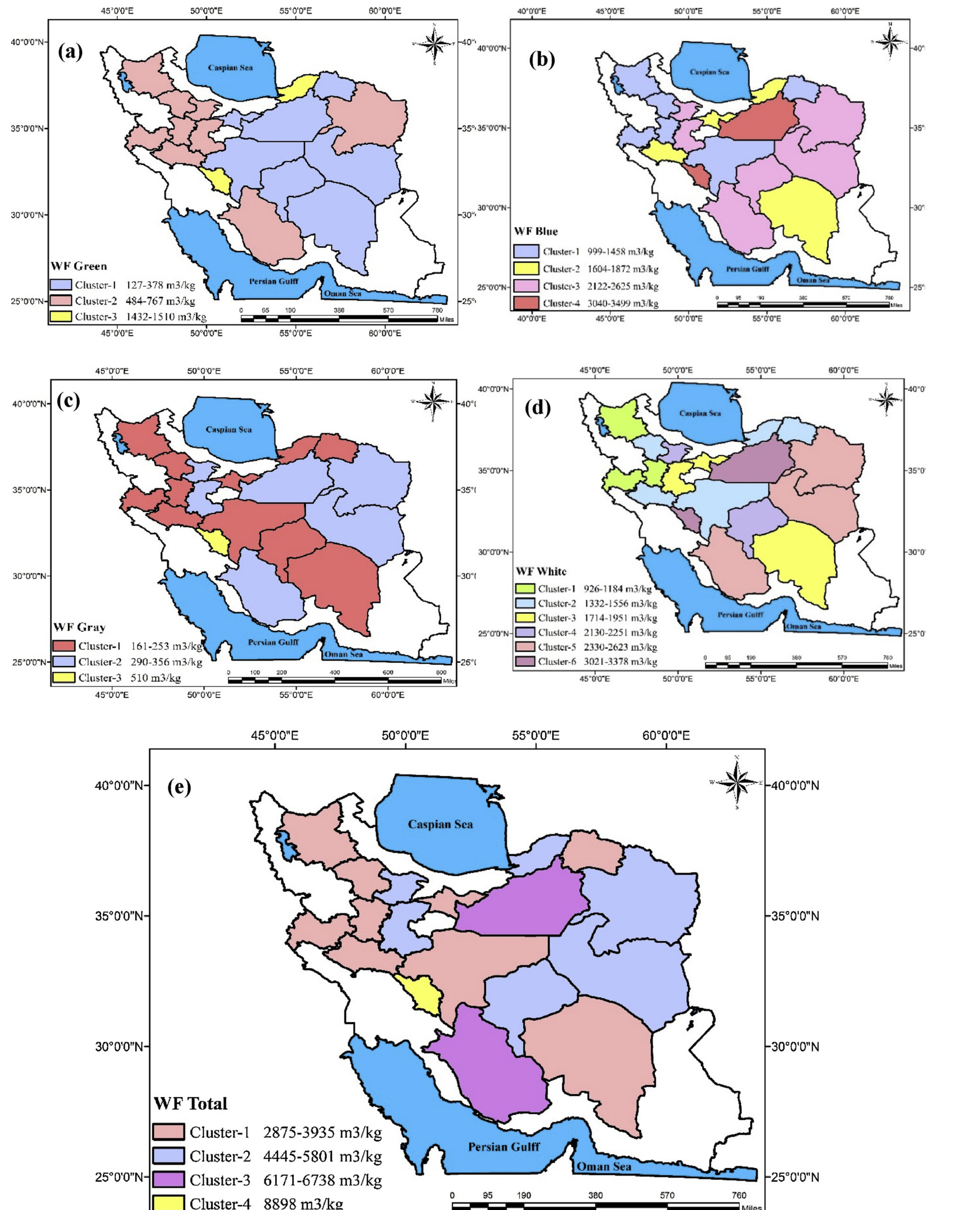

Fig. 2. Clustering of in WF_{Green}(a), WF_{Blue}(b), WF_{Grey} (c), WF_{White} (d) and WF_{Total} (e) in the Saffron producing provinces in Iran.

and helps optimizing the water consumption and cultivation of Saffron at a regional and national scale.

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