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Virtual water evaluation for grains products in Iran Case study: pea and bean

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Abstract

Shortage of water is considered as one of the most important straits of agricultural development in Iran. The main purpose of this study is to determine virtual water used to pea and bean production and water use efficiency, select the best area for cultivating these two grains and find the virtual water budget for the aforementioned grains. The results showed that among the three provinces main producers of pea in Iran, the highest virtual water of pea belongs to Lorestan with 3534 $dm^3 \cdot kg^{-1}$ and the lowest belongs to West Azerbaijan with 2660 $dm^3 \cdot kg^{-1}$ in irrigated cultivation. Water use efficiency in irrigated cultivation in Kermanshah and West Azerbaijan are at the same level; however, Kermanshah has enjoyed much more level of virtual water. For beans, the highest amount of virtual water in irrigated cultivation belongs to Lorestan (3651 $dm^3 \cdot kg^{-1}$) and the lowest amount refers to Markazi (2725 $dm^3 \cdot kg^{-1}$) and also the highest level of water use efficiency for this product refers to Markazi. Also it was found that 160.15 mln m^3 of water has been exported from the country water resources by these products so virtual water budget for studied crops were negative.

Key words: *grains, virtual water trade, water crisis, water use efficiency*

INTRODUCTION

Sustainable assurance of food supply is one of the important challenges of the world. Based on the report of "the unorganized situation of the world food supply" published by the United States, 793 millions of people are suffering from malnutrition due to the lack of water [FAO 2015]. Water is considered as the fundamental resources for the sustainable and continuous agricultural production. Climate changes and growth of the world population will be the fundamental factors leading to the change in suitable water access in future [MISRA 2014]. During the past decades, water consumption has been raised due to the population growth, increasing urbanization, economical world development, and climate change [WWC 2015]. It is expected that in the future the demand for water would be raised in all sections [UNESCO 2012]. Water tension increase and the social-economical costs will be increased, if water consumption would not be managed.

Agricultural section is the biggest water consumer in Iran and throughout the world. Although the world average shows that 70% of the whole water resources has been allocated to this section [MOLDEN *et al.* 2007], the related proportion in Iran, being placed in a rainfed area, is 93%. Having proposed a good management for water resources in the world, the concept of virtual water was created. The theory of virtual water is an efficient analytic tool for evaluating the water flow from one part to the other. Strategic management of water first was raised by ALLAN [1998]. The concept of virtual water refers to hidden water (embedded) in the product meaning, how much water is needed to produce a good. Nowadays, the related literature of virtual water proposes variety of views which can be studied on various scales [JIANG *et al.* 2015].

Virtual water which connects business, water and food with each other, has its own environmental, social-economical consequences [TAMEA *et al.* 2016]. Meaning, in the realm of a country, through calculating the virtual water of the target in most parts, it can be found that if the cultivation of a product in one area comparing the other covers less virtual water, that product can be cultivated in this area and exported to the other parts. The aforementioned utilization of virtual water in water resources management is known as the virtual water business [ALDAYA *et al.* 2010J; IANG *et al.* 2015; YANG, ZEHNDER 2007]. With these explanations, it can be stated that low-water areas or countries can depend on their area both through saving water and final product imports [CHAPAGAIN *et al.* 2006] or they can have low-water productions [LIU *et al.* 2017]. If we just consider the industrial and agricultural productions, the world total virtual water flow in the period of 1996–2005 would be 2320 billion m^3 [MEKONNEN, HOEKSTRA 2011]. Using the world data for calculating virtual water business, it was determined that the European Union and America and Japan have ranked the highest level of the virtual water business during 1995–2008 [ARTO *et al.* 2016].

Many studies have been done to determine water consumption level of various products such as agricultural products on different scales [CLARK *et al.* 2016; HASSAN *et al.* 2016; LUO, TAO 2016; ZEITOUN *et al.* 2010]. These studies made the writers of the current research to conduct the first studies on virtual water regarding the most grains of the country in the most important areas of cultivating the product. Putting aside the cereals as the first rank, grains are considered as the second important food resource. Grain seeds having 18–32% level of protein plays an important role in providing the protein materials needed for the human, and its other part is used as the animal feed, fertilizer, etc. Among grains, bean having 20–25% level of protein and more than 19 million ton annual productions occupies the first place in the world and pea among the grains occupies the third place in the world and is the most important product in Iran in a way that it has the first rank among the other grains in terms of cultivation and production [Ministry of Agriculture 2013].

Due to worsening water crisis in different countries, the issue of virtual water is of utmost importance in planning and water macro policy making. Now, with exports and imports of goods and products between different countries, some measure of the imported or the exported water as the virtual water is being conducted. Given the background of the research mentioned above, this need was felt that it is necessary to study the amount of virtual water and water use efficiency regarding the two major products in the basket of the country's grains production meaning the pea and bean in provinces which produce these grains at the level of the country in both irrigated and rainfed cultivation condition.

MATERIAL AND METHODS

In this research, using published statistics by the Ministry of Agricultural, the average, maximum and minimum level of area under cultivation and production and crop yield amount of irrigated and rainfed crops were gathered from the agricultural year of 2001–2002 to 2012–2013. Then, using the following relations, the amount of virtual water and agricultural water use efficiency and other indices in the fields of water sources were studied and calculated to produce crops at the level of the main producing provinces.

For the two studied crops, crop water requirement obtained by using NetWat software which is from CropWat application series.

The virtual water in each group of products (Eq. 1) is obtained through the division of crop water requirement by the average crop yield ($m^3 \cdot t^{-1}$) [ROUHANI *et al.* 2008]:

$$VWC_{c,j} = \frac{CWR_{c,j}}{Y_{c,j}} \tag{1}$$

where: $VWC_{c,j}$ = crop virtual water for crop c in year j, $m^3 \cdot t^{-1}$; $CWR_{c,j}$ = the average water requirement for crop c at the country level in year j, $m^3 \cdot ha^{-1}$; $Y_{c,j}$ = the average crop yield for crop c in year j, $t \cdot ha^{-1}$.

PHYSICAL WATER USE EFFICIENCY

Efficiency in its simplest form can be defined as the division of output to the input. This definition is simply understandable for all and there is no need to be professional. Every person knows that she/he should gain the largest amount of crops and interests of what she/he has. In one group, the main purpose is to evaluate the physical and quantitative aspect of the crops. In other words, in this group, assessment and evaluation of the physical required resources efficiency are focused. Of these indices which are used for the stored water in agriculture is the crop per drop for which its formula is shown [YOUSEFI, MOHAMMADI 2017]:

$$WUE = \frac{Y}{W} \tag{2}$$

where: WUE = the water use efficiency, $kg \cdot m^{-3}$, Y = the crop yield, $kg \cdot ha^{-1}$; W = the required pure water amount, $m^3 \cdot ha^{-1}$.

Therefore, this index shows that how much kg crop is obtained per using one m^3 of water. The highest level of this index represents the better physical water use efficiency. This index can be used for comparing the efficiency of a specific type of crop in different areas, and a specific farmland over time. In other words, this index can be used both for the internal and between areas (between farms) comparison and an internal comparison (time trend) [EHSAN, KHALEDI 2003].

WATER SCARCITY

Water use intensity is defined as the total domestic harvested water for agricultural consumption divided by the total water resources of the country [HOEKSTRA 2003]:

$$WS = \frac{WU}{WA}100 \quad (3)$$

where: WS = water scarcity; WU = the total domestic harvested water for producing foodstuffs, $m^3 \cdot y^{-1}$; WA = the total resource of the country.

Defined in this way, water scarcity will generally range between zero and hundred per cent, but can in exceptional cases (e.g. groundwater mining) be above hundred per cent. As a measure of the national water availability WA we take the annual internal renewable water resources that are the average fresh water resources renewably available over a year from precipitation falling within a country's border [HOEKSTRA 2003].

WATER DEPENDENCY

Water dependency is an indicator which reflects country's affiliation to external water resources by importing virtual water. The value of the water dependency index will per definition vary between zero and hundred per cent. A value of zero means that gross virtual water import and export are in balance or that there is net virtual water export. If on the other extreme the water dependency of a nation approaches hundred percent, the nation nearly completely relies on virtual water import [HOEKSTRA 2003]. It means that water dependency calculates in following equation:

$$WD = \frac{TNVWI}{WY + TNVWI}100 \quad (4)$$

where: WD = water dependency; $TNVWI$ = total net virtual water import, $m^3 \cdot y^{-1}$; WU = domestic water use in the agricultural sector, $m^3 \cdot y^{-1}$.

WATER SELF-SUFFICIENCY

In contrast, water self-sufficiency represents national power to provide the required water for domestic production. If water self-sufficiency gets close to 0, that country would strongly rely on importing virtual water. Thus, water self-sufficiency of a country can be calculated using Equation 5:

$$WSS = 100 - WD \quad (5)$$

Virtual water trade for specific crop includes two parts, export and import amount. By multiplying the quantity of export or import crops by their virtual water, this trade can be calculated [ROUHANI *et al.* 2008]:

$$VWI_{c,j} = VWC_{c,j} \cdot I_{c,j} \quad (6)$$

$$VWE_{c,j} = VWC_{c,j} \cdot E_{c,j} \quad (7)$$

where: $VWI_{c,j}$ = virtual water import for crop (c) in year j, $m^3 \cdot y^{-1}$; $VWE_{c,j}$ = virtual water export for crop (c) in year j, $m^3 \cdot y^{-1}$; $I_{c,j}$ = the annual import amount of crop (c) in year j, $m^3 \cdot y^{-1}$; $E_{c,j}$ = the annual export amount of crop (c) in year j, $m^3 \cdot y^{-1}$. So net virtual water trade is written as follows:

$$NWVTc,j = VWI_{c,j} - VWE_{c,j} \quad (8)$$

where: $NWVTc,j$ = net virtual water trade for crop c in year j, $m^3 \cdot y^{-1}$.

Total virtual water import and total virtual water export for a country calculate as follows [ROUHANI *et al.* 2008]:

$$TVWI_j = \sum_{c=1}^{M} VW_{c,j} \quad (9)$$

$$TVWE_j = \sum_{c=1}^{N} VWE_{c,j} \quad (10)$$

where: $TVWI_j$ = the total virtual water import in year j, $m^3 \cdot y^{-1}$; $TVWE_j$ = the total virtual water export in year j, $m^3 \cdot y^{-1}$; M = the quantity of the imported goods under study; N = the quantity of exported goods under study.

Total net virtual water trade refers to the subtraction of the total import and total export of virtual water [ROUHANI *et al.* 2008]:

$$TNVWT_j = TVWI_j - TVWE_j \quad (11)$$

where: $TNVWT_j$ = total transfer of net virtual water of country in year j, $m^3 \cdot y^{-1}$.

RESULTS AND DISSCUSION

Based on the information obtained from the statistics of the Ministry of Agriculture [2013], in Table 1 the harvest level, the production amount and the pea crop yield by the type of cultivation are represented.

Obviously, up to 2007–2008 cultivation area for pea, has decreased but after that this slope has ascended. The highest amount is for 2001–2002 which is over 700 000 ha. It is remarkable that when the cultivation area is at the highest level, it does not necessarily require the production level be at the same level. As it is clear, in 2006–2007 the production level has the maximum level; however, the cultivation area has normal condition.

Based on the statistics of the Ministry of Agriculture [2013], three provinces, including Kermanshah, West Azerbaijan, and Lorestan have the largest portion of pea in the country, which is shown in Table 2.

As Table 2 depicts, Kermanshah has the highest average of production while it has the high rate of water requirement. According to this table, it can be

Table 1. Cultivation area, crop yield and production of pea and bean during 2001–2013

Crop year	Cultivation area, ha			Production, t			Crop yield, kg·ha^{-1}	
	irrigated	rainfed	sum	irrigated	rainfed	sum	irrigated	rainfed
Pea								
2001–2002	26 721	685 377	712 098	23 583.4	27 8292.9	301 876.3	882.5	406.0
2002–2003	18 469	622 916	641 385	19 843.8	270 292.4	290 136.2	1 074.4	433.9
2003–2004	15 113	557 827	572 940	17 773.1	269 146.6	286 919.7	1 176.0	482.4
2004–2005	15 460	522 064	537 523	16 788.8	248 440.3	265 229.1	1 085.9	475.8
2005–2006	13 743	588 814	602 557	16 159.3	308 626.8	324 786.1	1 175.8	524.1
2006–2007	15 713	580 022	595 735	19 755.3	309 097.4	328 852.7	1 257.2	532.9
2007–2008	12 919	413 329	426 248	9 300.0	98 700.0	108 000.0	719.8	238.7
2008–2009	11 999	519 998	531 998	11 000.0	162 000.0	173 000.0	916.7	311.5
2009–2010	9 316	380 001	289 317	11 000.0	146 000.0	157 000.0	1 180.7	384.2
2010–2011	10 201	383 999	394 200	11 200.0	150 799.0	161 999.0	1 097.9	392.7
2011–2012	11 501	438 999	450 499	12 500.0	163 500.0	176 000.0	1 086.8	372.4
2012–2013	12 000	459 999	471 999	12 600.0	182 400.0	195 000.0	1 050.0	396.5
Bean								
2001–2002	106 210	5 076	111 286	204 395.9	5 224.8	209 620.6	1 924.4	1 029.3
2002–2003	112 471	3 363	115 834	215 143.8	3 713.8	218 857.6	1 912.8	1 104.3
2003–2004	104 568	5 681	110 249	217 499.9	8 220.1	225 720.1	2 079.9	1 446.9
2004–2005	106 059	5 251	111 310	209 682.9	6 448.2	216 131.2	1 977.0	1 228.0
2005–2006	92 981	4 329	97 310	202 377.3	5 908.4	208 285.7	2 176.5	1 364.8
2006–2007	105 574	3 781	109 355	217 988.2	5 314.8	223 303.0	2 064.7	1 405.6
2007–2008	105 001	6 647	111 648	171 122.0	1 878.0	175 000.0	1 629.7	583.4
2008–2009	89 999	2 894	93 893	145 292.0	4 708.0	150 000.0	1 614.3	1 209.0
2009–2010	85 998	3 500	89 498	144 401.0	4 600.0	149 001.0	1 679.1	1 314.2
2010–2011	110 640	1 887	112 527	176 699.0	2 300.0	178 999.0	1 597.0	1 218.8
2011–2012	110 000	2 889	112 889	178 400.0	3 600.0	182 000.0	1 621.8	1 246.1
2012–2013	111 001	3 400	114 400	185 400.0	4 599.0	189 999.0	1 670.2	1 352.6

Source: own study.

Table 2. Main provinces in pea and bean production

Province	Average of production, 10^3 t	Water requirement average, m^3·ha^{-1}
Pea		
Kermanshah	116	3 434
West Azerbaijan	46	2 816
Lorestan	39	3 848
Bean		
Lorestan	40.8	6 678
Fars	40.0	5 702
Markazi	34.6	4 984

Source: own study.

distinguished that due to the water requirement level in West Azerbaijan (which is lower than other provinces) it is better to increase production in this province in comparison with Kermanshah.

As it is mentioned in Table 3, regarding pea, the highest level of water use efficiency in both rainfed and irrigated cultivations belongs to West Azerbaijan and among the three provinces, the lowest virtual water of this crop refers to this province (Fig. 1a). According to Table 4, the index number of water self-sufficiency is high for pea showing that Iran does not depend on virtual water imports through this crop and provide its good required water from domestic water resources which is not good at all.

According to Table 1, during the study period, cultivation area and production of bean have the same fluctuations and follow each other.

According to the statistics of the Ministry of Agriculture [2013], three provinces including Lorestan, Fars, and Markazi had the highest portion of bean production which is shown in Table 2.

Table 3. Calculation of virtual water and water use efficiency of pea and bean in main provinces

Province	Virtual water dm^3·kg^{-1}		Water use efficiency kg·m^{-3}		Total of virtual water mln m^3
	irrigated	rainfed	irrigated	rainfed	
Pea					
Kermanshah	3 234	8 322	0.37	0.12	661
West Azerbaijan	2 660	6 825	0.37	0.14	545
Lorestan	3 634	9 326	0.27	0.10	742
Total	–	–	–	–	1 948
Bean					
Lorestan	3 651	5 525	0.27	0.18	186
Fars	3 118	4 718	0.32	0.21	156
Markazi	2 725	4 124	0.36	0.24	118
Total	–	–	–	–	460

Source: own study.

As it is specified in Table 3, among the three studied provinces, Markazi had the lowest amount of virtual water in bean production in both irrigated and the rainfed cultivations which were 2725, and 4124 dm^3·kg^{-1} respectively. Regarding water use efficiency, Lorestan had the highest amount. In Table 4, the two indices of water dependency and self-efficiency were zero.

As it is seen in Table 3, the highest amount of water use efficiency in producing bean at the level of the country belongs to Markazi. Also, the lowest amount of virtual water use in producing this crop belongs to this province (Tab. 3). In the study period, just in2008–2010–2012, pea was imported from Turkey, Bahrain and Russia. It should be mentioned that in these periods, bean production was zero [IRICA 2013], the imports amount is shown in Figure 1.

Table 4. Numerical amount of water use intensity, water dependence and water self-sufficiency of pea and bean

Index	Water use intensity, %		Water dependence, %		Water self-sufficiency	
	pea	bean	pea	bean	pea	bean
Amount	1.5	0.3	1.6	0	98.4	0

Source: own study.

As it shown in Figure 1, the highest import of pea in the study period refers to Turkey. Based on the results of the current research, if each ton of pea would contain 3100 $m^3 \cdot t^{-1}$ virtual water and the imports amount would be 10 579 t, it can be found that in this period, 32.79 mln m^3 water virtually would be imported to this country through this crop. In contrast, in this period, 62 243 t of pea had been exported to other parts of the world namely, India (having the portion of 99%). Regarding the content of virtual water of this crop 192.9 mln m^3 of water has been gone from the country. With these descriptions, water budget of this crop would be –160.1 mln m^3.

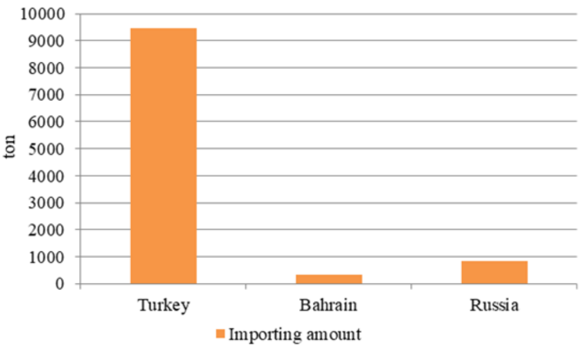

Fig. 1. Amount of the pea import from foreign countries; source: IRICA [2013]

CONCLUSIONS

Considering the fact that grain is the most important foodstuff in the household shopping, pea and bean are of utmost importance in this regard. In the related studies of sustainable development, these crops should be focused as the important and involving factor in production. Of the most important savings in agricultural production it can be referred to water. Now in this study, using the new concept of virtual water, hidden water in bean and pea crops is calculated through the type of cultivation in most provinces which produce these crops. The importance of this issue can be understood in 3 aspects: 1 – to understand which type of cultivation is good for virtual water and water use efficiency to produce pea and bean?; 2 – among the producing provinces, which type is prioritized to produce these crops?; 3 – how much is the amount of water budget for producing pea in Iran? Based on calculations for pea, it was determined that among the three provinces, the highest level of virtual water for production in the rainfed cultivation, belongs to Lorestan with 3534 $dm^3 \cdot kg^{-1}$ and the lowest amount belongs to West Azerbaijan with 2660 $dm^3 \cdot kg^{-1}$. The best status in water use efficiency has been in rainfed cultivation, and is in the same level in Kermanshah and West Azerbaijan. However, the amount of virtual water has been more in Kermanshah. Considering these description, Kermanshah is the best region in pea cultivation in terms of water use management. For bean, the highest level of virtual water for the irrigated cultivation belongs to Lorestam (3651 $dm^3 \cdot kg^{-1}$) and its lowest amount belongs to Markazi (2725 $dm^3 \cdot kg^{-1}$), also the highest level of water use efficiency refers to this province. Comparing these two crops, it is determined that pea production uses much more amount of water in comparison with bean. And at the level of country, we can have multi views toward the imports of this country. And at the level of the province, for instance, pea can be cultivated in West Azerbaijan and be imported to other provinces. In this study, it was determined that both crops enjoy irrigated cultivation, lower level of virtual water and the more water use efficiency. It is suggested that this type of cultivation be considered. During the study period of Lorestan comparing to other provinces, more amount of water has been gone virtually through this cultivation. According to formula which presented for virtual water calculation, crop water requirement and crop yield are basis for this concept. These two factors have direct relation with climate condition. As results shows, provinces that are warmer than another one, have more evapotranspiration in plant growth period then virtual water content increase. So we need to do something to diminish water evaporation from soil surface, such as mulching or do something to increase crop yield rate. In a way that this amount for pea and bean equals 742 mln m^3 and 186 mln m^3 which are considerable amounts. The virtual water budget for pea, which has imports and exports, was calculated as 160.1 mln m^3, which generally means, this amount of water has been gone from the country's borders virtually, and has been added to the other country. It is expected that this research would be a starting point for dividing the cultivation areas of agricultural crops regarding virtual water concept in water resources management and the more attention to the type of its imports and exports.

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Ocena wirtualnej wody w produkcji ziarna w Iranie – przykład grochu i fasoli

STRESZCZENIE

Deficyt wody uznawany jest za jeden z najważniejszych problemów rozwoju rolnictwa w Iranie. Głównym celem badań przedstawionych w pracy jest oznaczenie ilości wody wirtualnej zużywanej do produkcji grochu i fasoli oraz wydajności zużycia wody, wybór najlepszych terenów do uprawy obu roślin i sporządzenie dla nich bilansu wirtualnej wody. Uzyskane wyniki wykazały, że spośród trzech prowincji – głównych producentów grochu w Iranie – największą objętość wirtualnej wody (3534 $dm^3 \cdot kg^{-1}$) zużywa się do nawadnianych upraw w Lorestanie, a najmniejszą (2660 $dm^3 \cdot kg^{-1}$) – do nawadnianych upraw w prowincji Zachodni Azerbejdżan. Wydajność zużycia wody w nawadnianych uprawach w Kermanshah i Zachodnim Azerbejdżanie była podobna, a uprawy w Kermanshah cechowało większe zużycie wody wirtualnej. Do produkcji fasoli największą objętość wirtualnej wody stwierdzono w Lorestanie (3651 $dm^3 \cdot kg^{-1}$), a najmniejszą w Markazi (2725 $dm^3 \cdot kg^{-1}$), gdzie stwierdzono także największą wydajność zużycia wody. Obliczono także, że – eksportując te produkty roślinne – wysłano za granicę 160,15 milionów m^3 wody wirtualnej, skutkiem czego bilans wodny badanych upraw był ujemny.

Słowa kluczowe: *handel wirtualną wodą, kryzys wodny, wydajność zużycia wody, ziarno*