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ARTICLE

Estimation of the international virtual water flow of grain crop products in Korea

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Abstract The Korean 2008 self-sufficiency rate for grain was only 26.2%. Because of this, the quantity virtual water (VW) for crop product imports is much greater than that of other countries. International VW trade is especially important to Korea due to its dependency on foreign imports to maintain food security and to establish an agricultural water resource policy. Using international crop products trade statistics during 2003–2007, this study analyzed the virtual water content (VWC) and international virtual water flow (VWF) of major crops. The national water savings and global water savings were also estimated. Major grain products, including 28 products made from 13 crops, were selected for the analysis, based on the net import and export of products totaling more than 10,000 tons. VWCs were computed for the selected major crop products using the VWC of the primary crop of Korea. International VWFs were estimated using the VWC of each crop products. The amount of imported VW was 16,804 and 226 M m^3 was exported, so that the net imported VW was 16,578 M m^3. VW import is concentrated in wheat, rice, maize (corn), and soybean crops. A small number of countries, including the USA, China, Brazil, etc., account for over 96% of the imported VW, indicating Korea's heavy dependence on these countries. The average national water savings for Korea and the average global water savings according to crop were estimated using VW flow from international crop products trade during 2003–2007. The estimate of national water savings was 23,870.3 M m^3. Three major crops, namely wheat, maize and soybean, account for 95.3% of this total VW saving. Global water savings from the VW trade amounted to 7,253.0 M m^3. Korea depends heavily on VW imports concentrated in specific crops and which are primarily imported from a particular set of countries. This indicates that Korea is vulnerable to disruptions in the international grain harvest such as those caused by natural disasters such as floods and drought. Any such disruption could easily become a critical issue for governmental planners who establish food and water supply policies for Korea.

Keywords Virtual water · Virtual water flow · Water footprint · Grain crop · Water saving

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Introduction

The Korean self-sufficiency rate for grain was 26.2% in 2008, and those for wheat, maize and beans were only 0.4, 0.9, and 7.1%, respectively. The self-sufficiency rates for these crops are very low in comparison to those of rice and root and tuber crops, with rates of 94.4 and 98.5%, respectively. Korea has experienced remarkable economic growth during the past three decades, accompanied by an increase in food consumption per capita despite a comparably low ratio of arable land to the population. This explains the need for such large quantities of imported foreign agricultural products such as grain, beef, pork, fruit, and so on.

Statistics from the PC-TAS (The Personal Computer Trade Analysis System) show that Korea imported 22.45 M tons of agricultural and processed products in 2007. Among them, 8.67 M tons of maize, 3.43 M tons of soybean and 3.25 M tons of wheat were predominant. The three crop products accounted for 68.4% of the total crop product imports to Korea.

Water is a required input for the production of any agricultural commodity. For instance, 6,445 kg of rice is yielded per hectare and 1,601 m^3 water is consumed for 1 ton of rice production in Korea (Yoo et al. 2009).

The concept of the virtual water content (VWC) of a commodity, defined as the volume of water required to produce that specific amount of commodity, was initially introduced by Allan (1993). He suggested that the industrial and agricultural commodity trade was also a trade in the water used for production of those commodities.

The import and export of any specific commodity is simultaneously a water trade because water is necessarily used to cultivate the crops. The virtual water in agricultural products can vary with growing conditions such as the weather and the diverse cultivation methods used in each country. Therefore, the trade in agricultural products among countries can be regarded also as international water flow, ideally prompting each country to estimate the VWCs in their agricultural products, thereby tracing their national water footprint (WFP) and policy making of agricultural water resources. The WFP is an indicator of water use, expressed as VWC, and it furthers explanations of water flows related to commodity production and processing.

Hoekstra and Hung (2005) quantified the volume of crop-related international virtual water flowing between nations during 1995–1999. According to their research, 13% of the water used for worldwide crop production is traded internationally. Chapagain and Hoekstra (2008) ascertained that 16% of global water is used in production and export, suggesting that virtual water trade saves water. Chapagain et al. (2006) estimated that cotton-related international virtual water flow is about 84% of the virtual water of cotton consumption in the EU25 region traded from outside Europe in the period 1997–2001. Aldaya and Hoekstra (2010) analyzed the WFP and its impacts of two typical Italian dishes, pizza margherita and pasta. They showed that the WFP of pizza (725 g) was about 1,216 l and that of pasta was about 1,924 l/kg. The impact is concentrated in Puglia, Sicily, and Emilia-Romagna, all of which suffer from water mismanagement. Van Oel et al. (2009) analyzed the virtual water flow in the Netherlands and its relationship to the impact of their external WFP. Chapagain and Hoekstra (2007) analyzed the WFP related to coffee and tea processing in the Netherlands and showed that the farming of Dutch coffee and tea uses water from Brazil, Colombia, Indonesia, China, and Sri Lanka. Hoekstra and Chapagain (2007) assessed the WFP of Morocco and showed that 640 M m^3 global water per year was saved because of agricultural trade with the Netherlands. Bulsink et al. (2010) showed that the external virtual water flow relieved water scarcity in Java, a densely populated area in Indonesia where water scarcity is maximal. Ma et al. (2006) quantified the volumes of virtual water flow between regions in China. They demonstrated that northern China exported 52 G m^3 of water in virtual form to southern China, more than the planned real water transfer from south to north via Water Transfer Projects.

Yoo et al. (2009) estimated the VWC of 44 primary crops in Korea from 1991 to 2007. They showed that an average of 13.7 billion m^3 of virtual water was used for the production of 44 primary crops between 2003 and 2007. Of the total, 11.1 G m^3 virtual water was used for grain crops and 10.1 G m^3 (91%) was dedicated to rice production. This result reflects the facts that rice cultivation is a main source of agricultural water use in Korea.

Korea is vulnerable to shift in the international grain harvest such as those brought about by natural disasters, such as floods and drought, because the demand for agricultural products in Korea is highly dependent on imported grain. If imports of agricultural and livestock products are hindered due to international trade problems, the shortage of water could result in difficulty supplying adequate quantities of agricultural products, despite having sufficient farmland and advanced agricultural techniques. Approaching the limits of water supplies could lead to widespread social disruption due to the conflict over competing uses in the agricultural, living, and industrial sectors. Virtual water trade in both imported and exported crops is quite an important issue that must be taken into consideration when evaluating the Korean government's food supply policy.

In this study, the VWCs were estimated for the major food crops based on trade statistics from PC-TAS and KATI (Korea Agricultural Trade Information) during 2003 and 2007. Virtual water flow and national/global water savings estimates are based on the analysis of trade statistics.

Methods

Concept of the WFP

The WFP concept was introduced in order to estimate net water consumption in a country (Hoekstra and Hung 2002). Virtual water (VW) theory is used to quantify water consumption utilizing the WFP. The WFP of a country is calculated using the budget of the VW for commodity production and service imports and exports (Chapagain and Hoekstra 2004). The WFP is computed using Eq. 1

$$\text{WFP} = \text{IWFP} + \text{EWFP} \quad (1)$$

where IWFP is the internal WFP or the total domestic water resources used for the commodities and services consumed, and EWFP is the external WFP or the water used for all imported commodities and services.

Virtual water estimation for primary crop

Virtual water content (m^3/ton) is the quantity of water needed for the production of one ton of a given crop and can be estimated from the ratio of total crop produced to the amount of water used in its cultivation. The VWC is estimated using Eq. 2. Using the VWC of primary crops, it is possible to calculate the VWC of secondary agricultural and industry products (Chapagain and Hoekstra 2004). The VWC is used as the reference value for the tracking of water movement across international boundaries in the agricultural and industry product trades.

$$\text{VWC} = \frac{\text{CWR}[c]}{\text{Production }[c]} \quad (2)$$

where VWC is the water required for production of one ton of a given crop, the CWR is the quantity of water requirement to farm the amount of the crop actually produced, and the *production* is the quantity harvested per year.

In this study, the VWCs suggested by Yoo et al. (2009) were used for the crops cultivated in Korea, and the VWCs of primary crops calculated by Chapagain and Hoekstra (2004) were used for the crops of other countries. Table 1 shows the VWCs of major crops used in this study.

Virtual water estimation for crop products

The VWC of a processed product depends on the VWC of the primary crop from which it is derived. Likewise, the VWCs for secondary and tertiary products can be calculated. The first step is always to obtain the VWC of the input (root) product and the water requirement to process it. The total of these two elements is then distributed over the various output products, based on their product and value fractions. The VWC of a crop product can be calculated using Eq. 3 (Chapagain and Hoekstra 2004). In this study, the product fraction and value fraction suggested by Chapagain and Hoekstra (2004) were used for crop products.

$$\text{VWC }[p] = \text{VWC }[c \text{ or } r] \times \frac{vf\ [p]}{pf\ [p]} \quad (3)$$

where VWC $[p]$ is the VWC (m^3/ton) of the product p, VWC $[c$ or $r]$ is the VWC (m^3/ton) of root crop c or root product r, pf is the product fraction, and vf is the value fraction of product p.

Virtual water flows estimation for international trade

International virtual water flows (VWFs) can be calculated by multiplying the product trade flows by their associated VWC:

$$\text{VWF }[n_e, n_i, p] = T\ [n_e, n_i, p] \times \text{VWC }[n_e, p] \quad (4)$$

where VWF denotes the virtual water flow (m^3/year) from the exporting country n_e to the importing country n_i as a result of trade in product p; T is the product trade (ton/year) from the exporting to the importing country; and VWC is the virtual water content (m^3/ton) of the product, defined as the volume of water used to produce the product in the exporting country. If the exporting country does not produce product p itself, but only imports it for further export, one should use the VWC of the product as that of the country of origin (Hoekstra and Chapagain 2008).

For the calculation of the international VWF that determines the external WFPs, this study has taken into account the trade between countries and territories for

Table 1 The virtual water contents (VWC) of primary crops in Korea and the global averages

Crop code	Crop name	VWC		Crop code	Crop name	VWC	
		Korea[a]	Global[b] average			Korea	Global average
15	Wheat	1,071.6	1,333.5	83	Sorghum	2,546.7	2,852.8
27	Rice, paddy	1,600.1	2,290.6	116	Potato	134.8	255.0
44	Barley	823.0	1,387.7	125	Cassava	–	605.1
56	Maize	1,021.8	909.2	176	Dry bean	3,069.0	4,252.9
71	Rye	2,869.4	901.4	211	Mung bean	3,889.5	3,929.3
75	Oat	–	1,596.8	236	Soybean	3,308.5	1,788.8
79	Millet	3,023.3	4,596.3				

[a] Yoo et al. (2009)

[b] Chapagain and Hoekstra (2008)

which international trade data is available in the Personal Computer Trade Analysis System (PC-TAS 2007) of the International Trade Centre, UNCTAD/WTO and KATI.

Water savings related to trade

The national water saving S_n (m^3/year) of a country n as a result of trade in product p has been defined as:

$$S_n\,[n,p] = (T_i\,[n,p] - T_e\,[n,p]) \times \text{VWC}\,[n,p] \quad (5)$$

where VWC is the virtual water content (m^3/ton) of product p in country n, T_i is the amount of product p imported (ton/year), and T_e is the amount of product p exported (ton/year). Obviously, S_n could have a negative sign if the export of product p exceeds the import, indicating a net water loss instead of a savings (Hoekstra and Chapagain 2008).

The global water savings S_g (m^3/year) through the trade in product p from an exporting country n_e to an importing country n_i is:

$$S_g\,[n_e,n_i,p] = T\,[n_e,n_i,p] \times (\text{VWC}\,[n_i,p] - \text{VWC}\,[n_e,p]) \quad (6)$$

where T denotes the trade volume (ton/year) between the two countries. The global saving is thus obtained as the difference between the water productivities of the trading partners. Particularly, when the importing country is not able to produce the product domestically, the global savings is calculated as the difference between the global average VWC of the product and the VWC in the exporting country. The total global water savings can be obtained by summing the global savings of all international trade flows. By definition, the total global water savings is equal to the sum of the national savings of all countries (Hoekstra and Chapagain 2008).

Results and discussion

Statistical data collection

In this study, trade statistics for 21 grain crops during 2003–2007 were collected from PC-TAS and KATI. The food crops are categorized as follows:

- Grains: Wheat, Rice (paddy), Barley, Maize, Rye, Millet, Sorghum, Buckwheat, Oat, Canary Seed, Cereals n.e.s.
- Roots and Tubers: Potato, Sweet Potato, Cassava
- Pulse: Dry bean, Mung bean, Soybean, Dry pea, Chickpea, Lentil, Pulses n.e.s.

According to the PC-TAS and KATI statistics, Korea imports 51 crop products from 21 crops and exports 36 products from 14 crops. Among those, the net imports and exports of 28 products from 13 crops total more than 10,000 tons.

Table 2 shows the average imports, exports, and net imports from 2003 to 2007. Korea imported 16,230.1 M tons and exported 132.8 M tons in major grains and crop products for a net import of 16,097.3 M tons. In other words, imports were 122 times greater than exports. Maize is the most abundant imported grain, with 8,657.0 M tons of import, accounting for 53.3% of total grain imports. Four grains, including 3,515.4 M tons of wheat, 200.9 M tons of rice, 8,598.1 M tons of maize, and 3,126.7 M tons of soybean, comprise 95.9% of total net imports.

The VWCs of crop products needed to be calculated to estimate Korea's international VWF. In this study, the VWCs of primary crops provided by Yoo et al. (2009) were used for the crops cultivated in Korea and the VWCs of primary crops calculated by Chapagain and Hoekstra (2004) were adapted for foreign crops.

Table 3 provides the VWCs for 28 crop products from 13 crops. The VWCs of oat and cassava were estimated using global average VWC as given by Chapagain and Hoekstra (2004), because those crops are not cultivated in Korea. The VWCs of several derivative products were much larger than the VWCs of the root product; for example, the VWC of "beer made from malt" is 2,049.8 m^3/ton, 249% of the VWC of the primary crop (823.0 m^3/ton). Similarly, the VWC of 'potato starch' is 709.5 m^3/ton, 526% of the VWC of the primary crop (134.8 m^3/ton). The VWC of "soya-bean oil crude—whether or not degummed" is 6,249.4 m^3/ton, 189% of the VWC of the primary crop (3,308.5 m^3/ton), and the VWC of "soya-bean oil crude" is the greatest among all of the analyzed crop products.

Estimation of international virtual water flows

The average international VWF was estimated using import and export data and the VWCs during 2003–2007. Table 4 shows the results of virtual water flow through the crop products trade. Korea imported 16,804.0 M m^3 VW and exported 225.7 M m^3 VW, with a net import VW of 16,578.3 M m^3, for an import 74.4 times that of exports. The largest net import VW in a crop product is the "maize (corn) n.e.s (100590)" with a 6,147.7 M m^3 net import VW for the import of 6,148.0 M m^3 and the export of 0.32 M m^3. Among root crops, maize (56) is has the greatest net VW import of 6,140.95 M m^3, importing 6,224.1 M m^3, and exporting 83.1 M m^3, which is 37.0% of the total net VW imported. Four major crops including wheat (15), rice (27), maize (44), and soybean (236) account for 96.4% of the total trade, with net VW imports of 4,020.56 M m^3 for wheat, 449.17 M m^3 for rice, 6,140.95 M m^3 for maize and 5,369.17 M m^3 for soybean.

Table 2 Average crop product trades in Korea during 2003–2007 (PC-TAS 2007; KATI 2010)

PC-TAS code	Crop product name	Root crop	Import (tons)	Export (tons)	Net import (tons)
100190	Wheat n.e.s. and meslin	Wheat	3,495,918	–	3,495,918
110100	Wheat or muslin flour		30,572	11,071	19,501
100620	Rice, husked (brown)	Rice, paddy	189,615	3	189,612
100630	Rice, semi-milled or wholly milled, whether or not polished or glazed		11,458	170	11,288
100300	Barley	Barley	56,025	165	55,860
110710	Malt, not roasted		131,069	–	131,069
220300	Beer made from malt		25,520	61,707	−36,187
100590	Maize (corn) n.e.s.	Maize	8,586,853	317	8,586,536
110220	Maize (corn) flour		7,574	102	7,472
110423	Maize (corn), hulled, pearled, sliced or kibbled		9,893	–	9,893
110812	Maize (corn) starch		44,415	58,502	−14,087
151521	Maize (corn) oil crude		8,293	40	8,253
100200	Rye	Rye	29,147	–	29,147
100400	Oats	Oat	6,457	–	6,457
100820	Millet	Millet	19,482	3	19,479
100700	Grain sorghum	Sorghum	10,972	–	10,972
070190	Potatoes, fresh or chilled n.e.s.	Potato	19,825	9	19,816
110813	Potato starch		32,915	23	32,892
071410	Manioc (cassava), fresh or dried, whether or not sliced or pelleted	Cassava	308,507	–	308,507
110814	Manioc (cassava) starch		16,440	104	16,337
071332	Beans, small red (Adzuki) dried, shelled, whether or not skinned or split	Dry bean	30,858	128	30,730
071333	Kidney beans and white pea beans dried shelled, whether or not skinned or split		16,732	9	16,724
071339	Beans dried, shelled, whether or not skinned or split, n.e.s		7,707	10	7,697
071331	Urd, mung, black/green gram beans dried shelled, whether/not skinned/split	Mung bean	6,779	10	6,769
120100	Soya beans	Soybean	1,286,814	304	1,286,510
120810	Soya-bean flour and meals		20,998	–	20,998
150710	Soya-bean oil crude, whether or not degummed		234,865	33	234,832
230400	Soya-bean oil-cake & oth solid residues, whether or not ground or pellet		1,584,398	88	1,584,309
Total			16,230,101	132,798	16,097,303

n.e.s. not elsewhere specified

These four major crops total a net 96.4% of VW import, with 24.3% for wheat, 2.7% for rice, 37.0% for maize and 32.4% for soybean. Although soybean accounts for 19.4% of the total, it represents 32.4% of the net VW import because soybean has a larger VWC than those of the other crops.

Figure 1 depicts the seven major countries which export more than 0.50 G m^3 net VW to Korea through the trade of grain: USA, China, Brazil, India, Australia, Argentina, and Canada. Korea imports 96.8% of its VW from these seven countries, with the most VW, 4.50 G m^3, coming from the USA, accounting for 27.2% of its imported VW. The next highest VW exporter to Korea is China (4.40 G m^3, 26.5%), and the third is Brazil (2.06 G m^3, 12.4%). It means that the import portion is quite high on the specific countries.

The details of VW imports for wheat, rice, maize and soybean by country are shown in Figs. 2, 3, 4, and 5. In the case of wheat, a total of 4.02 G m^3 of VW is imported, with more than 0.1 G m^3 of VW imported from each of six different countries. Korea imports 39.5%, 1.59 G m^3, of its wheat VW from Australia, the largest wheat import into the country. The second largest VW exporter to Korea is the USA (26.5%), followed by Canada (17.7%), China (8.7%),

Table 3 The product fractions (*pf*), value fractions (*vf*), and virtual water contents of crop products in Korea

Product code	Root product code	Root crop	pf[a]	vf[a]	VWC	Product code	Root product code	Root crop	pf[a]	vf[a]	VWC
100190	–	15	1.00	1.00	1,071.6	100820	–	79	1.00	1.00	3,023.3
110100	100110		0.79	0.89	1,207.2	100700	–	83	1.00	1.00	2,546.7
100620	–	27	0.77	1.00	2,078.1	070190	–	116	1.00	1.00	134.8
100630	100620		0.90	1.00	2,308.9	110813	070190		0.19	1.00	709.5
100300	–	44	1.00	1.00	823.0	071410	–	125	1.00	1.00	605.1
110710	100300		0.73	1.00	1,127.4	110814	071410		0.25	1.00	2,420.4
220300	110710		0.55	1.00	2,049.8	071332	–	176	1.00	1.00	3069.0
100590	–	56	1.00	1.00	1,021.8	071333	–		1.00	1.00	3069.0
110220	100590		0.82	0.85	1,059.2	071339	–		1.00	1.00	3069.0
110423	100590		0.93	1.00	1,098.7	071331	–	211	1.00	1.00	3,889.5
110812	110220		0.75	1.00	1,412.2	120100	–	236	1.00	1.00	3,308.5
151521	100590		0.03	0.06	2043.6	120810	120100		0.85	1.00	3,892.4
100200	–	71	1.00	1.00	2,869.4	150710	120100		0.18	0.34	6,249.4
100400	–	75	1.00	1.00	1,596.8	230400	12100		0.79	0.66	2,764.1

[a] Chapagain and Hoekstra (2008)

Table 4 Average international virtual water flows of crop products in Korea during 2003–2007

Crop code	Product code	Virtual water flow (M m^3)			Crop code	Product code	Virtual water flow (M m^3)		
		Import	Export	Net Import			Import	Export	Net Import
15	100190	3,992.84	–	3,992.84	79	100820	36.39	0.01	36.38
	110100	41.09	13.36	27.73	83	100700	23.01	–	23.01
	Sub total	4,033.93	13.36	4,020.56	116	070190	2.66	0.001	2.66
27	100620	424.88	0.01	424.88		110813	17.07	0.02	17.06
	100630	24.68	0.39	24.29		Sub total	19.73	0.02	19.71
	Sub total	449.56	0.40	449.17	125	071410	155.50	–	155.50
44	100300	74.97	0.14	74.84		110814	29.25	0.25	29.00
	110710	230.08	–	203.08		Sub total	184.75	0.25	184.50
	220300	5.20	126.49	−121.28	176	071332	57.48	0.39	57.08
	Sub total	310.25	126.62	183.63		071333	31.74	0.03	31.72
56	100590	6,148.01	0.32	6,147.69		071339	20.72	0.03	20.69
	110220	4.19	0.11	4.08		Sub total	109.94	0.45	109.49
	110423	12.20	–	12.20	211	071331	11.46	0.04	11.42
	110812	48.78	82.62	−33.84	236	120100	2,142.49	1.01	2,141.49
	151521	10.90	0.082	10.82		120810	63.62	–	63.62
	Sub total	6,224.08	83.13	6,140.95		150710	543.45	0.20	543.24
71	100200	20.35	–	20.35		230400	2,621.06	0.24	2,620.82
75	100400	9.91	–	9.91		Sub total	5,370.62	1.45	5,369.17
					Total		16,803.98	225.74	16,578.25

the Ukraine (2.9%), and India (2.7%). These six countries account for 97.9% of the wheat VW imported into Korea, demonstrating that Korea depends heavily on these six countries in terms of wheat VW imports.

Korea imports 449.2 M m^3 of rice VW, with more than 50 M m^3 rice VW being imported from each of China, Thailand and the USA, comprising 99.5% of the rice VW imports of Korea. Korea imports 199.0 M m^3 rice of VW from China, accounting for 44.3% of the total rice VW imports; 36.4% of the rice VW is imported from Thailand and 18.8% comes from the USA. Rice is the staple grain for which Korea has the highest degree of self-sufficiency. Korea consumes the largest amount of grain VW in the cultivation of rice. However, the VWF in rice imported to

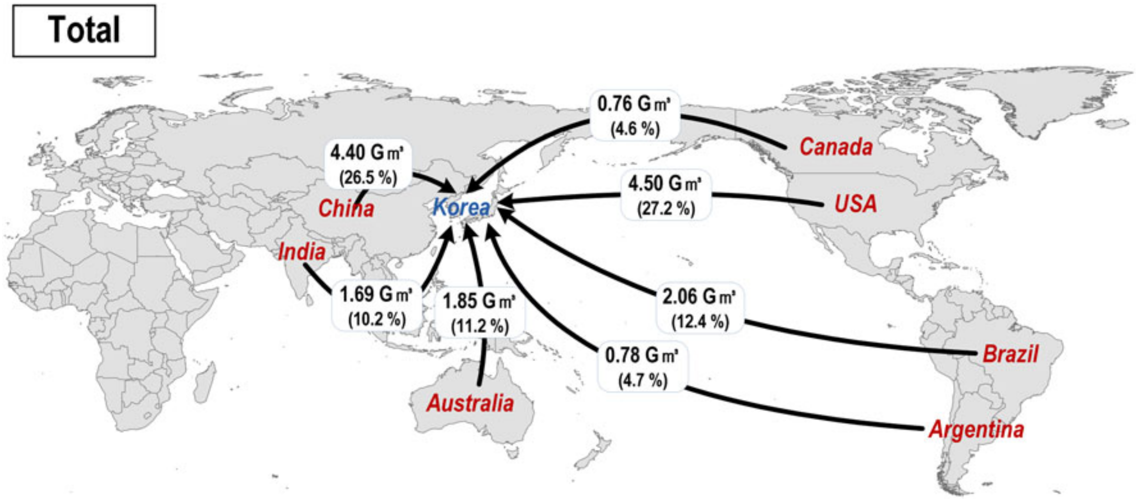

Fig. 1 The largest average net imported virtual water flows (>0.50 G m^3) of grain crop products for Korea during 2003–2007

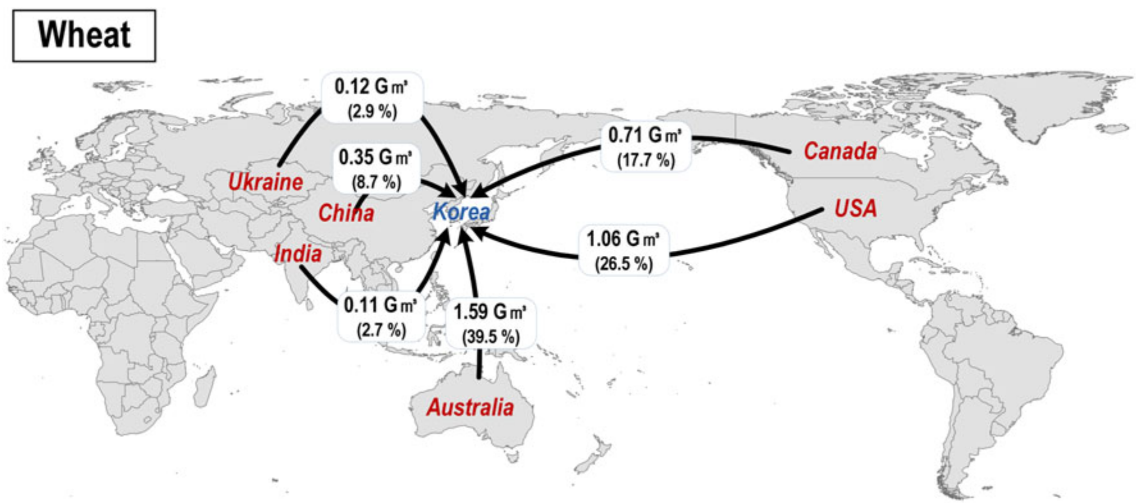

Fig. 2 The largest average net imported virtual water flows (>0.10 G m^3) for wheat products in Korea during 2003–2007

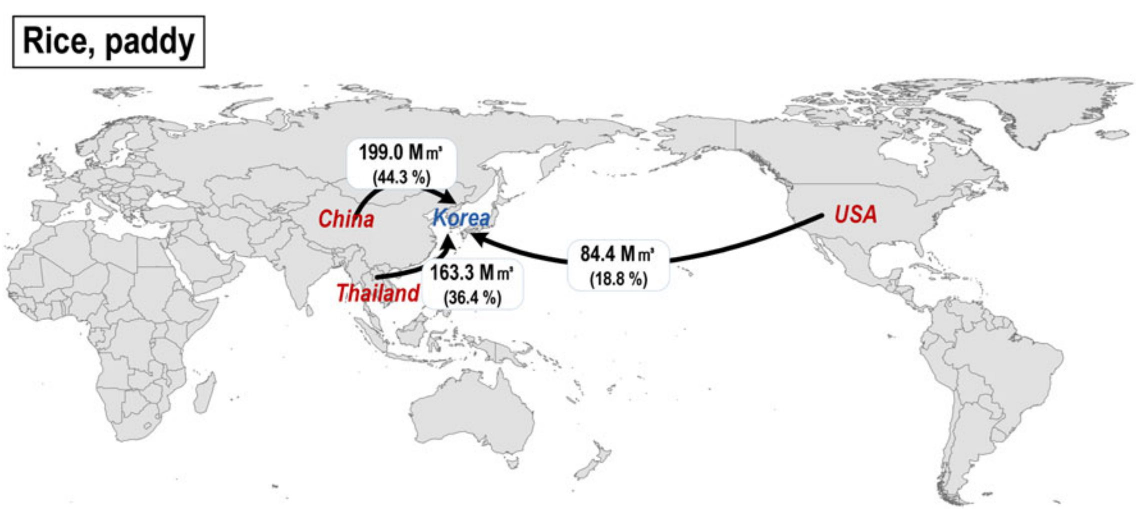

Fig. 3 The largest average net imported virtual water flows (>50 M m^3) for rice (paddy) products in Korea during 2003–2007

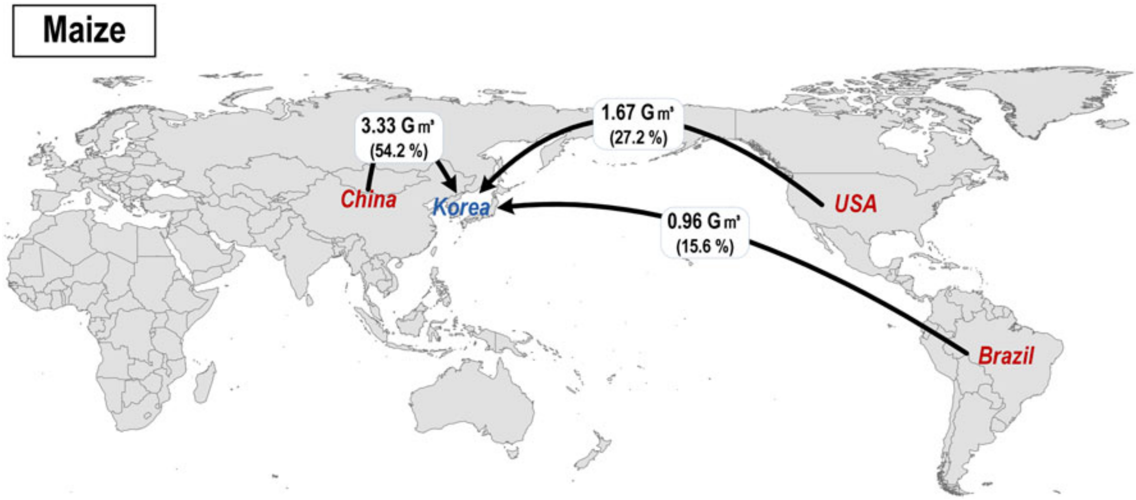

Fig. 4 The largest average net imported virtual water flows (>0.50 G m^3) for maize products in Korea during 2003–2007

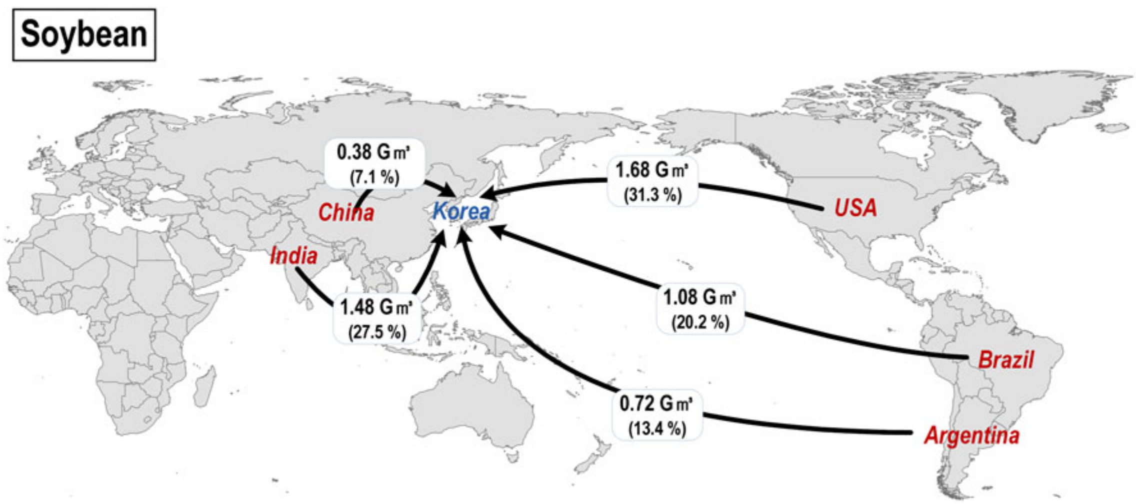

Fig. 5 The largest average net imported virtual water flows (>0.30 G m^3) for soybean products in Korea during 2003–2007

Korea is increasing due to an increase in the amount of rice being imported, following the WTO trade agreement stipulating the opening of Korea's for rice market.

Korea imports 6.14 G m^3 VW in maize of the imports coming mainly from three countries. Korea imports 3.33 G m^3 maize VW from China, a total of 54.2% of total imported maize VW. The USA (27.2%) and Brazil (15.6%) are the three largest exporters by volume to Korea, accounting for 97.1% of all imported maize VW in Korea and underscoring Korea's dependence on these primary trading partners.

Korea imports 5.37 G m^3 VW for soybean. The top five exporting countries account for 99.5% of Korea's total soybean VW imports. Korea imports 1.68 G m^3, 31.3%, of its total soybean VW from the USA. The other top exporters are India (27.5%), Brazil (20.2%), Argentina (13.4%), and China (7.1%).

The total amount of exported VW from Korea to other countries is 225.7 M m^3 as shown in Table 4. The barley and maize accounts for 56.1 and 36.8%, respectively, of total VW exports. The major export crop product was "Beer made from malt (220300)" and "Maize (corn) starch (110812)". Figure 6 depicts major VW export countries for barley and corn, which account for about 92.9% of total VW export. Seven countries including Hongkong, the Philippines, and Mongol import more than 10 M m^3, and they are located near East Asia. These six countries account for 85.6% of the VW exported for barley and maize from Korea, and Hongkong is the largest VW exported country with 74.1 M m^3, 35.3% of the total.

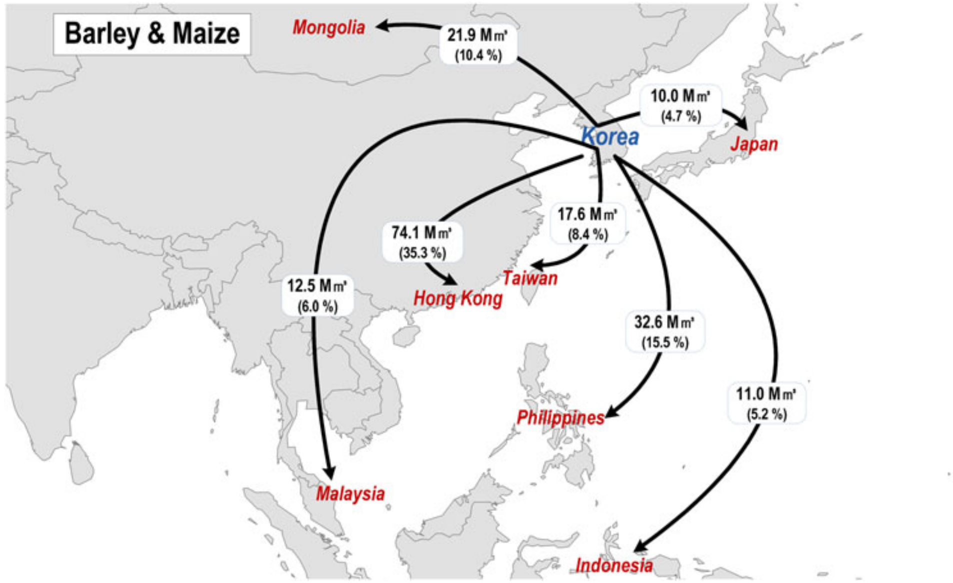

Fig. 6 The largest average exported virtual water flows (>10.0 M m^3) for barley and maize products in Korea during 2003–2007

Although the VW export of Korea takes very low ratio in comparison to the VW import, some export of processed crop product of barley and maize are taking place.

Estimation of water savings related to trade

The average national water savings for Korea and the average global water savings according to crop were estimated using VWF from international crop products trade during 2003–2007. The results are shown in Table 5. The national water savings is the VW savings amount from importing rather than cultivating crop. As shown in the Table 5, the total national water savings during this time period was 23,870.3 M m^3 and the major crops were wheat, maize, and soybean, for which the amounts VW saving were 3,769.8; 8,789.5; and 10,184.9 M m^3, respectively. These three major crops accounted for 95.3% of the total VW savings.

The global water savings was the relatively less than national water savings. This can be attributed to the imbalance in VW trade: the VWCs of import countries were less than those of the exporting countries. Table 5 shows that the total global water savings from VW trade amounted to 7,253.0 M m^3, and that maize and soybean accounted for a major portion of the total, with 2,688.5 and 4,815.4 M m^3, respectively. These two crops accounted for 103.5% of the total global water savings from VW trade.

The VWCs of soybean and wheat, which represented the major portion of VW imports in these years, were 3,308.5 and 1,071.6 m^3/ton, respectively, in Korea. The average

Table 5 The average national water savings for Korea and the average global water savings during 2003–2007

Crop code	National water savings		Global water savings	
	Virtual water (M m^3)	% Total	Virtual water (M m^3)	% Total
15	3,769.8	15.8	−251.3	−3.47
27	420.1	1.8	−29.0	−0.40
44	119.6	0.5	−173.3	−2.39
56	8,789.5	36.8	2,688.5	37.1
71	83.6	0.35	63.3	0.87
75	9.9	0.04	0.1	0.002
79	58.9	0.25	22.5	0.31
83	27.9	0.12	4.9	0.07
116	26.0	0.11	6.3	0.09
125	184.5	0.77	31.2	0.43
176	169.3	0.71	59.6	0.82
211	26.3	0.11	14.9	0.21
236	10,184.9	42.7	4,815.4	66.4
Total	23,870.3	100.0	7,253.0	100.0

VWCs of the top five soybean and wheat importers were 1574.2 and 778.6 m^3/ton, respectively (Chapagain and Hoekstra 2004). The virtual water trade imbalance is so great that the global water savings or these two crops alone is estimated to be greater than those of all of the other crops added together.

Summary and conclusions

The self-sufficiency rate in Korea for grain was 26.2% in 2008, which led to a higher VW gain from agricultural imports relative to those of other countries. The global VWF is important to Korea, and Korean dependency on foreign countries for food security could emerge as an even more critical factor after the implementation of the agricultural water resource policy. In this study, VWCs and international VWFs of major grain crops and products were analyzed using trade statistics. National water savings and global water savings were also estimated.

The major grain crops and products were considered, using the statistics of PC-TAS and KATI, and 28 products of 13 crops were selected for the analysis. Products were included in the study based on the net import and export volumes, only those totaling more than 10,000 tons during 2003–2007 were eligible for inclusion.

"Maize (corn) n.e.s. (100590)" has been imported at an annual average of 8,586.5 M tons, accounting for 53.3% of the total net grain import and establishing it as the largest imported grain in Korea. The VWCs of the selected major crop products were computed using VWCs of Korea's primary crops, and "soya-bean oil crude, whether or not degummed (150710)" ranked first, with 6,249.4 m^3/ton of VWC.

International VWFs were estimated using the VWC of each crop product. The total imported VW was 16,804.0 M m^3, and the total export was 225.7 M m^3, for a net VW import of 16,578.3 M m^3. The VW import was concentrated in wheat, rice, maize, and soybean. Wheat was imported from six countries, including Australia and the USA, rice came from three countries, including China and Thailand, maize came from five countries, including China and the USA, and soybean was imported mainly from the USA and India. These countries accounted for over 96% of the crop imports into Korea, indicating a heavy dependence on the import from these countries.

The average national water savings for Korea and the average global water savings according to crop were estimated using VW flow data from international crop products trade during 2003–2007. The national water savings was 23,870.3 M m^3, and three major crops, wheat, maize, and soybean, accounted for 95.3% of the total national VW savings. Global water savings from the VW trade amounted to 7,253.0 M m^3. Two major crops, maize and soybean, accounted for 103.5% of the total global water savings from the VW trade.

Domestic VW usage for the cultivation of major crops was 13.7 G m^3, while the VW import through four grain crops and processed products was 15.5 G m^3. This indicates the strong Korean dependence on VW imports, concentrated in specific countries and crops. It follows that Korea could face a serious food security crisis if such agricultural disasters as droughts or floods occur in one of the major grain trading partners. In other words, VW imports are not only affected by the issue of water scarcity, but have wider implications for food security and agricultural policy. As domestic dependency on VW imports increases, Korea will be progressively more vulnerable to the international agricultural market. Water resource development and efficient water use will be vital to the grain self-sufficiency of the country. That is, the analyses of trend in VW amount, being consumed or reduced in Korea, the agricultural WFP or VWF depending on the water import or export by the change or prediction of agricultural market can be made possible based on the results of this research. This can be used as fundamental data for the quantitative estimation and analysis of the water resource required for the Korean government's goal of achieving food self-sufficiency as well as the trend analyses of water scarcity, water self-sufficiency, and water import dependency. Therefore, the results of this study are expected to be used as basic data for national water resource policy.

The trade in VW can be interpreted in term of water savings or costs both on a national and on a global scale. A country which has a comparative advantage in terms of water can export water-intensive commodities, while countries facing a water shortage can import those commodities rather than producing them, achieving greater water use efficiency on a global scale. For example Korea is saving 23.9 G m^3 of water nationally and 7.3 G m^3 of water in global water resources by importing of maize and soybean.

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