IRRIGATION AND DRAINAGE
Irrig. and Drain. **65**: 48–56 (2016)
Published online 20 January 2016 in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/ird.1957

EVALUATION OF THE DEPENDENCY AND INTENSITY OF THE VIRTUAL WATER TRADE IN KOREA†

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ABSTRACT

Trading in crops can be regarded as the primary source of water demand in terms of virtual water trade, and the main importers would have to consider the trading in crops from a water management perspective. The aim of this paper was to evaluate the dependency and intensity of the virtual water trade in Korea. The virtual water trade values of 41 crops were quantified from 2006 to 2010. About 9.5% of global blue water trade was captured by Korea through maize trade. In addition, we evaluated the water dependency and trade intensity of the virtual water trade. Water dependency was evaluated by examining the proportions of external to internal water footprints. Korea exhibited the highest water dependency of 99%, followed by maize and pulse crops. Virtual water trade intensity indicates the importance of trading partners. The results show that the USA and China have been the most important trading partners, and the trade intensity with Romania, Ukraine and Australia has increased from 2006 to 2010. These results, such as water dependency and trade intensity of virtual water trade, should be useful indices for sustainable crop trade and water management in Korea. Copyright © 2016 John Wiley & Sons, Ltd.

KEY WORDS: virtual water trade; water footprint; water dependency; trade intensity

Received 11 April 2015; Revised 26 May 2015; Accepted 30 May 2015

RÈSUMÈ

Le commerce de produits agricoles peut être considéré comme la principale source de l'eau virtuelle, et les principaux importateurs gagneraient à considérer le commerce agricole du point de vue de la gestion de l'eau. Le but de cette étude était d'évaluer la dépendance et l'intensité du commerce de l'eau virtuelle en Corée. Les valeurs commerciales virtuelles de l'eau de 41 cultures ont été quantifiées de 2006 à 2010. Environ 9.5% du commerce mondial de l'eau bleue a été capturé par la Corée à travers le commerce de maïs. La dépendance de l'eau a été évaluée en examinant les proportions d'empreintes de l'eau externes aux empreintes internes. La Corée expose la dépendance de l'eau la plus élevée de 99%, suivi par le maïs et les légumineuses. L'intensité des échanges d'eau virtuelle indique l'importance des partenaires commerciaux. Les résultats montrent que les États-Unis et la Chine ont été les partenaires les plus importants de négociation, et que l'intensité des échanges avec la Roumanie, l'Ukraine et l'Australie a augmenté de 2006 à 2010. Ces résultats sur la dépendance de l'eau et de l'intensité des échanges du commerce de l'eau virtuelle devraient être des indices utiles pour le commerce durable des cultures et de la gestion de l'eau en Corée. Copyright © 2016 John Wiley & Sons, Ltd.

MOTS CLÉS: commerce de l'eau virtuelle; empreinte de l'eau; dépendance de l'eau; intensité du commerce

INTRODUCTION

The demand for food for a growing population is increasing and more irrigation water will be needed (Bouwer, 2002). The term 'virtual water' first referred to the water needed for agricultural products; subsequently, the term developed into the volume of water used in the production of a commodity

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or service (Allan, 1993; Hoekstra, 2003). In addition, Hoekstra proposed the concept of the water footprint (WFP) to indicate the water use relative to human consumption (Hoekstra and Hung, 2002; Wang *et al.*, 2013). The WFP includes green and blue water, which refers to the volume of rainwater and irrigation water consumed, respectively. Building on this concept, virtual water trade (VWT) represents the amount of water embedded in products that are traded (Aldays *et al.*, 2010). Virtual water adds a new dimension to international trade and brings a new perspective regarding water scarcity and water resources management (Novo *et al.*, 2009). The transfer of virtual water embedded in various crops that are traded is becoming an important component of water management at the global as well as the regional level, particularly in regions where water is scarce (Hoekstra, 2003). As water scarcity becomes serious, the VWT is becoming more important for the formulation of water resource management policies. Therefore, VWT could play an important role in decreasing water stress via the appropriate redistribution of water resources.

For these reasons, VWT has been studied at different spatial scales, but mostly for a specific time period, in an effort to determine the quantity of water saved through trade (Chapagain *et al.*, 2006). In the study by Hoekstra and Hung (2005), 13% of the water used for worldwide crop production was traded internationally during 1995–1999. Chapagain and Hoekstra (2008) ascertained that 16% of the global water resource is used in production and export. In addition, several studies have been performed to evaluate VWT. Fader *et al.* (2011) evaluated the effect of VWT on water savings, and Konar *et al.* (2013) quantified the potential impacts of climate change on global VWT and the associated savings. Most studies have focused on quantifying VWT and evaluating it related to water savings. However, it is important to evaluate how dependent VWT is on a few primary countries and to analyse the unequal distribution of VWT. In particular, the crop trading is a large part of crop consumption in Korea, and one of the greatest water problems around the world is scarcity. In addition, approaching the limits of water supplies could lead to widespread social disruption due to the conflict over competing uses in the agricultural, domestic and industrial sectors (Yoo *et al.*, 2012).

This paper aims to quantify the VWT in Korea, and evaluates the water dependency and intensity of the Korean virtual water trade (KVWT). The term ‘water dependency’ refers to the level to which a nation relies on foreign water resources through VWT, and it was evaluated regarding the proportions of the external water footprint (EWFP) to internal water footprint (IWFP). Additionally, the importance of trading partners was evaluated by the trade intensity index of KVWT.

MATERIALS AND METHODS

This study provides an assessment of VWT associated with crop trading, and discusses water dependency and intensity of VWT in Korea. Therefore, this study consists of two parts: estimation and evaluation of VWT, and the flowchart is shown in Figure 1.

Water footprint and virtual water trade

Water footprint (WFP, $m^3\ t^{-1}$) is the quantity of water needed to produce 1 t of crop and animal at the place where the product is actually produced. The WFP of a crop is calculated by dividing crop water requirement ($m^3\ ha^{-1}$) by the yield ($t\ ha^{-1}$). The data of the water footprint of Korea and the world were obtained from Lee (2013) and Hoekstra *et al.* (2011), respectively. In addition, the WFP was divided into green and blue water by water resources. Green WFP indicated the used rainfall, thus it is related to climate change. In contrast, blue WFP indicated the irrigation water, thus it is related to water savings:

$$WFP[c] = CWR[c]/Production \tag{1}$$

in which WFP is the water required for the production of 1 t of a given crop *c*, CWR is the quantity of crop water requirement, and production is the quantity harvested per year.

VWT represents the amount of water embedded in products traded internationally and is calculated by multiplying the international crop trade by their associated water footprint. Country-scale import and export data of agricultural crops for the years 2006–2010 were obtained from the Personal Computer Trade Analysis System (PC-TAS) produced by the United Nations Statistics Division (UNSD).

If one country exports crops to another country, then it also exports water in virtual form. Therefore, the VWT is calculated by multiplying the international crop trade by their associated green and blue WFP. VWT is thus calculated as

$$VWT[n_e,\ n_i,\ c,t] =\ CT[n_e,\ n_i,\ c,t]\times WFP[n_e,\ c] \tag{2}$$

in which VWT denotes the VWT from exporting country n_e to importing country n_i in year *t* as a result of trade in crop *c*. CT represents the crop trade from exporting country n_e to importing country n_i in year *t* as a result of trade in crop *c*. WFP represents the water footprint of crop *c* in the exporting country.

DOI: 10.1002/ird

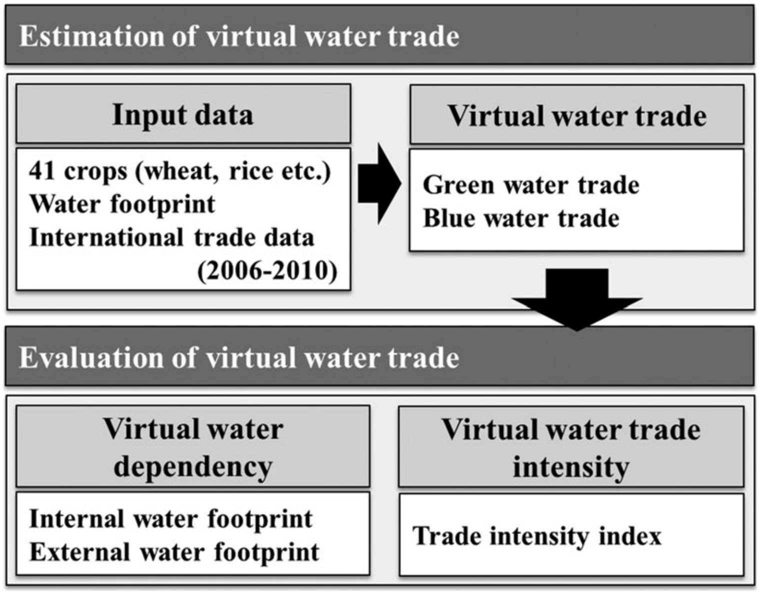

Figure 1. A flowchart for evaluating virtual water dependency and trade intensity

Water dependency by internal and external water footprint

The water dependency is evaluated using IWFP and EWFP, which are the virtual water budget according to the products, trade and consumption of commodities (Chapagain and Hoekstra, 2004). The IWFP is the total domestic virtual water use, and the EWFP is the foreign water use for all imported crops. Accordingly, we sought a proper indicator of water dependency on VWT. This indicator should reflect the level to which a nation relies on foreign water resources through import of water in virtual form. In this study, the water dependency of Korea was calculated as the ratio of the EWFP to the total national water consumption (IWFP + EWFP) and is described as

$$\text{Water Dependency } (WD) = \frac{EWFP}{(IWFP + EWFP)} \times 100\ (\%) \tag{3}$$

Virtual water trade intensity

We quantified the KVWT from 2006 to 2010 and evaluated the VWT intensity. The intensity represents the value of the importance between Korea and its trade partners, and is used to determine whether the value of trade between two countries is greater or smaller. The VWT intensity is defined as the share of one country's imports going to a partner divided by the share of the world imports going to the partner (Bowen, 1983; Son, 2007; Kim and Kim, 2009):

$$Trade\ Intensity\ \left(TI_{ij}\right) = \frac{X_{ij}/X_i}{M_j/(M_w - M_i)} \tag{4}$$

In this equation, X_{ij} is the amount of export from country *i* to country *j*, and X_i is the total export of country *i*. In addition, M_i, M_j, and M_w are the total imports of country *i, j* and the world, respectively.

RESULTS AND DISCUSSION

Estimation of virtual water trade

The amount of green virtual water trade (GVWT) of grain, maize, root crops, tubers, pulse crops, vegetables and fruit was calculated to be 3540 Gm^3 in the period 2006–2010. Table I shows that the amount of green virtual water trade was 3270 Gm^3, and the blue water was 261 Gm^3. The majority of the export of virtual water was from the USA, Argentina and Brazil (Figures 2 and 3). The bulk of virtual water traded was by wheat and maize. In addition, the results showed that rice was the most blue water intensive crop in the world and about 50% of global blue water trade was captured by the rice trade. Korea is one of the biggest crop importers and it is important to quantify the KVWT and compare it to GVWT. Korea imported a volume of 96.2 Gm^3 of virtual water via the crop trade in the period 2006–2010 (Figure 4). The most virtual water was imported by wheat (28.4 Gm^3), maize (32.3 Gm^3), and pulse crops (32.4 Gm^3). In particular, pulse crops were indicated to the most water-intensive crops. Korea imported 15.7 Mt of pulse crops, and it led to 32.4 Gm^3 of virtual water imports.

In addition, the VWT was differentiated into green and blue water trade. The green and blue virtual water imports were estimated to be 90.4 and 5.8 Gm^3 from 2006 to 2010

DOI: 10.1002/ird

Table I. Global virtual water trade (GVWT) by crop trade in the period 2006–2010

Crops		Amount of trade			
		Crop (Mt)	Green water (Gm^3)	Blue water (Gm^3)	Total water (Gm^3)
Grain crops	Wheat	675	1020	34	1060
	Rice	149	247	137	384
	Barley	125	136	5	141
	Others	37	46	2	48
Root and tuber crops		45	5	2	6
Maize		531	423	29	452
Pulse crops		713	1330	31	1360
Vegetables		157	21	7	28
Fruit		105	43	15	58
Total		2540	3270	261	3540

respectively (Table II). Irrigation will have to play an important role in increasing food production, and quantification of the blue water trade could be important data. Also, the green water supply will be affected by climate change and we would have to be prepared for the low efficiency of green water use. Therefore, it is important to estimate green and blue water trade separately, and the Korean government needs to consider in particular how much blue water is imported from countries. According to the study, the amount of imported wheat in Korea reached 2.4% of the global wheat trade and the green water import of wheat was 2.6%. Also, the blue water import in Korea was 4.2% of global virtual water trade. The maize trade showed the most dependency on global water resources. About 9.5% of global blue water trade is captured by Korea. Although the amount of virtual water exported was 811 Mm3 from 2006 to 2010 (Figure 5), the Korean government would have to increase the self-sufficiency of feed crops to decrease this high dependency.

These results focused on the volume of VWT and KVWT but VWT consists of a complex network, thus the characteristics of VWT were analysed in order to apply VWT to water management, food and trade policy. Accordingly, we

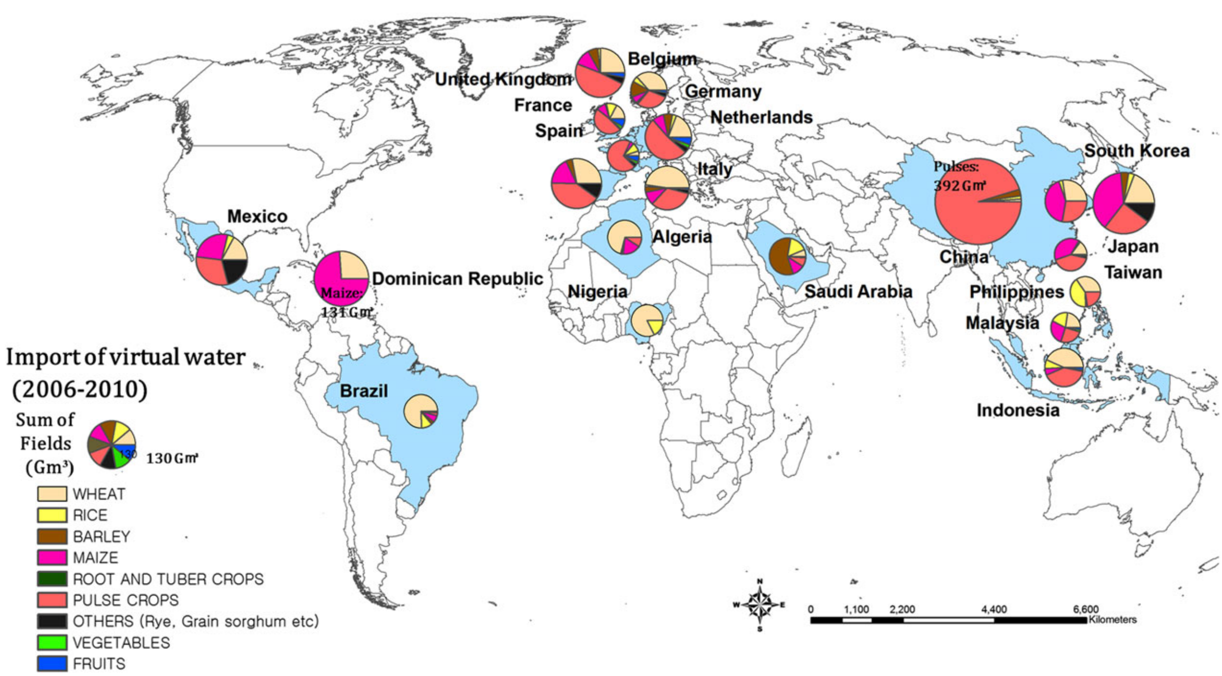

Figure 2. Global virtual water import by crop trade in the period 2006–2010

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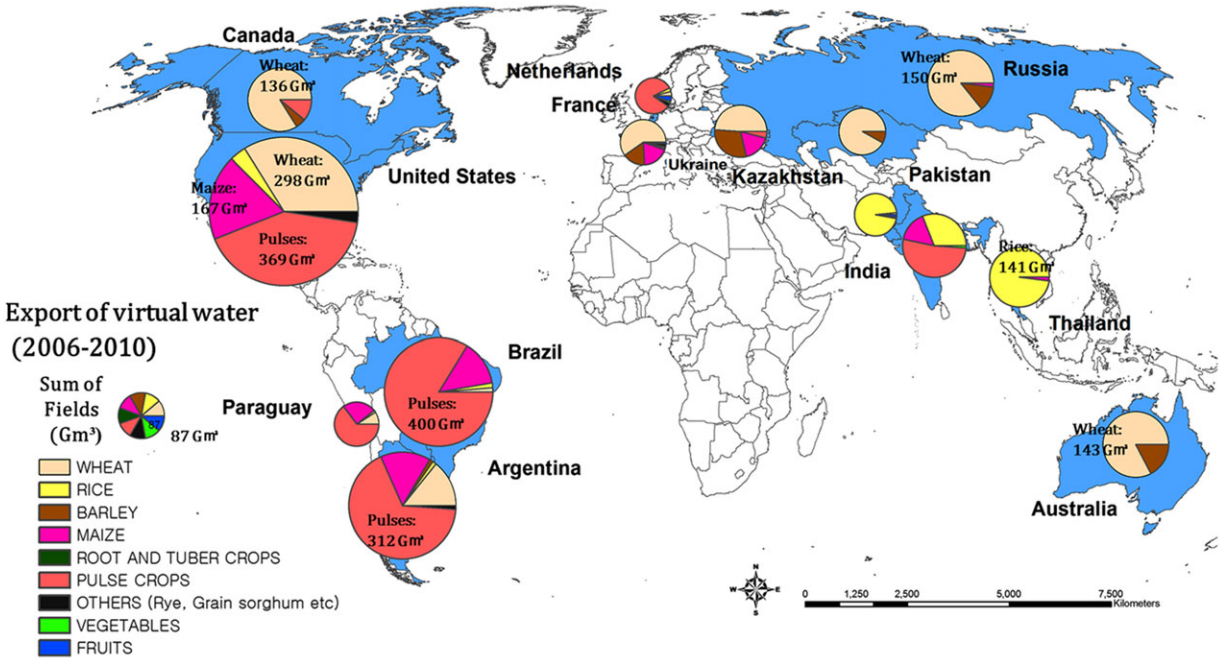

Figure 3. Global virtual water export by crop trade in the period 2006–2010

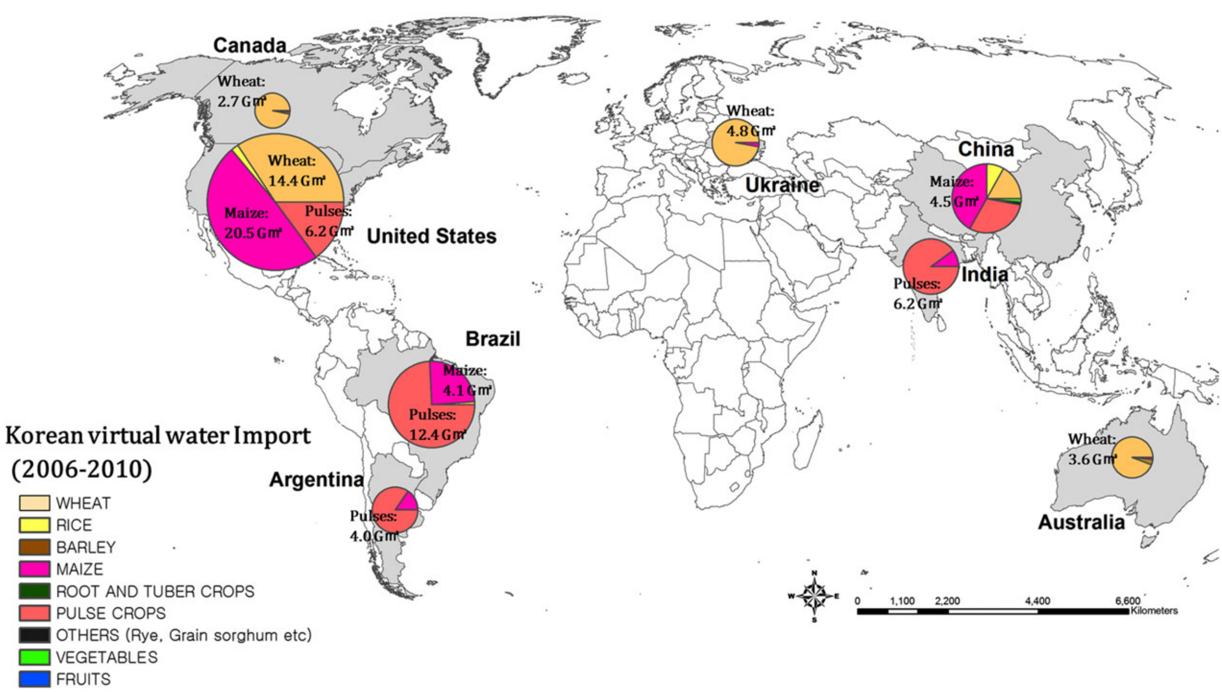

Figure 4. Korean virtual water import by crop trade in the period 2006–2010

Table II. Korean virtual water trade (KVWT) by crop trade in the period 2006–2010

Crops		Import				Export			
		Crop (1000 t)	Green water (Mm^3)	Blue water (Mm^3)	Total water (Mm^3)	Crop (1000 t)	Green water (Mm^3)	Blue water (Mm^3)	Total water (Mm^3)
Grain crops	Wheat	16 000	27 000	1 430	28 400	0	0	0	0
	Rice	1 500	1 440	892	2 340	6	2	4	6
	Barley	166	203	10	213	0	0	0	0
	Others	168	255	8	263	0	0	0	0
Root and tuber crops		89	8	7	16	0	0	0	0
Maize		45 100	29 600	2 710	32 300	0	0	0	0
Pulse crops		15 700	31 700	675	32 400	213	596	0	596
Vegetables		982	187	8	195	162	100	2	102
Fruit		181	37	14	51	178	107	0	107
Total		80 000	90 400	5 760	96 200	559	805	6	811

analysed the dependency and intensity of VWT to evaluate the dependency on foreign water resources and importance of trading partners in terms of water management.

Evaluation of water dependency by internal and external water footprint

The water resource was sensitive to climate change and drought. The high dependency of virtual water imports on a few exporters could make the trade system vulnerable to global droughts. Therefore, we analysed water dependency by applying IWFP and EWFP in Korea (Figure 6). In the case of wheat, the IWFP and EWFP were calculated to be 86 and 28 400 Mm^3, respectively. This result indicated that the water dependency of wheat was over 99% and that the VWT was dependent on the USA and Ukraine (Table III). Therefore, the condition of foreign water resources should be observed carefully to maintain a stable supply of wheat. The maize and pulse crops, which are also representative forage crops in Korea, were dependent on water resources of trading countries. The water dependency of the maize and pulse crops was 98.8 and 94.6%, respectively. In addition, the representative forage crops (maize and pulse crops) were dependent on green water, which was primarily

Figure 5. Korean virtual water export by crop trade in the period 2006–2010

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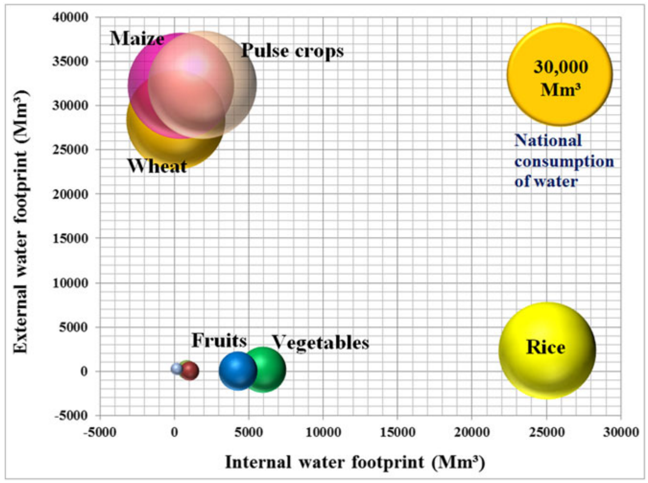

Figure 6. Internal and external water footprint in Korea in the period 2006–2010

imported from Argentina and Brazil. In contrast, the water dependency of rice was much lower than for other crops. The total volume of the IWFP was 27 400 Mm^3, and that of the EWFP 2340 Mm^3. The water dependency was calculated to be 8.5%. It means that the virtual water of rice was dependent on domestic water resources, and the low water dependency of rice could compensate for the risk of the high water dependency of other crops.

The KVWT has a dichotomous structure, which means that the difference between minimum and maximum dependency is significant. In addition, Korea was very dependent on foreign water resources and sensitive to water scarcity of exporters, according to the high water dependency on green and blue VWT. Since the high dependency of blue VWT was more related to water resources such as groundwater, the high dependency on blue VWT could involve the risk of export regulation by water shortage. In addition, climate change could influence the low efficiency of water use in exporting countries. Therefore, the Korean government would have to increase the self-sufficiency of wheat, maize and pulse crops through the increase of domestic production. In addition, the development of new water resources and the multilateral water use for crops, which are dependent on foreign water, could be considered in water management. In terms of international trade, Korea would have to expend the VWT to other exporters and observe the available water resources of exporting countries closely.

Evaluation of the trade intensity of virtual water imports

The trade intensity index is an indicator for evaluating the importance of trading partners. In this context, the trade intensity of virtual water imports represents the importance of

Table III. Water dependency by Korean virtual water trade (KVWT) in the period 2006–2010

Crops		IWFP (Mm^3)			EWFP (Mm^3)			Water dependency (%)		
		Green	Blue	Total	Green	Blue	Total	Green	Blue	Total
Grain crops	Wheat	86	0	86	27 000	1 430	28 400	99.7	100	99.7
	Rice	9 500	15 500	25 000	1 440	892	2 340	13.2	5	8.5
	Barley	807	0	807	203	10	213	20.1	100	20.9
	Others	150	0	150	255	8	263	63.0	100	63.7
Root and tuber crops		1 010	0	1 010	8	7	16	0.8	100	1.6
Maize		408	0	408	29 600	2 710	32 300	98.6	100	98.8
Pulse crops		1 840	0	1 840	31 700	675	32 400	94.5	100	94.6
Vegetables		5 250	666	5 920	187	8	195	3.4	1	3.2
Fruit		4 260	0	4 260	37	14	51	0.9	100	1.2
Total		23 300	16 200	39 500	90 400	5 760	96 200	79.5	26	70.9

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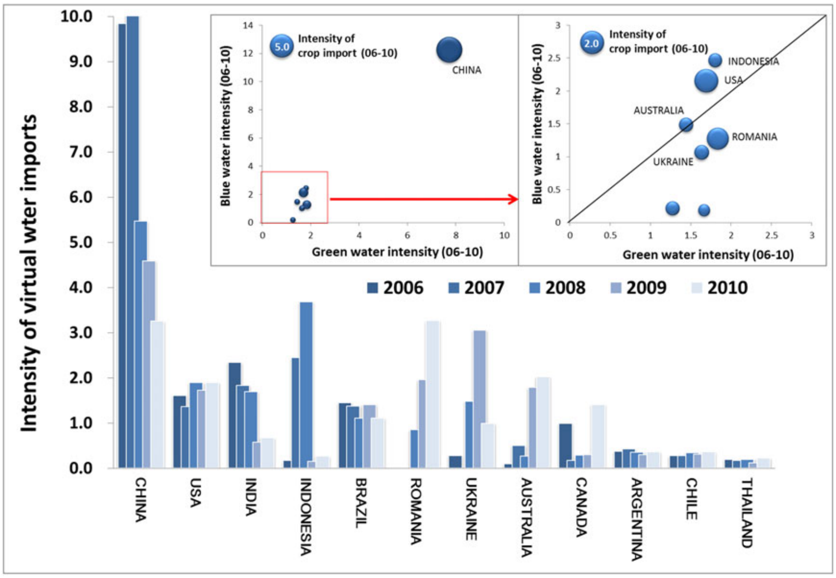

Figure 7. Trade intensity of Korean virtual water import in the period 2006-2010

the main sources for supplying virtual water to Korea. The intensity of VWT is shown in Figure 7 and Table IV. The intensity of VWT with China was the highest. After China, the intensity of VWT of the USA, Indonesia and Romania were the next highest. However, the intensity of VWT with China decreased sharply in 2008, and the decreasing trend continued until 2010. This result indicated that KVWT needs to consider not only China but also other exporters. For example, the intensity of VWT with Romania increased steadily in the years 2006–2010, and the intensity with Australia and Ukraine increased sharply from 2009 to 2010. Accordingly, the Korean government would have to focus more on the water resources of new main exporters such as Romania, Australia, Canada and Ukraine.

From Table IV, note that the ranking of countries in terms of VWT intensity became different when the type of water was considered, such as green and blue water. For example, China and Indonesia were the top countries for green VWT intensity, while Brazil and Argentina decreased in rank in the case of blue VWT. In addition, China, Australia and the USA were the top countries for blue VWT intensity. In particular, the blue water trade intensity of China was still high and the intensity of the USA, Romania and Australia much higher than for other countries in comparison to green water. It means that the blue water trade had a more concentrated structure than green water. Therefore, the crop trade in Korea has a risk of water shortage even if the volume of the blue water trade was smaller than green water.

Table IV. Trade intensity of green and blue virtual water imports in Korea in the period 2006–2010

Trade partner	2006		2007		2008		2009		2010		2006–2010	
	Green	Blue	Green	Blue	Green	Blue	Green	Blue	Green	Blue	Green	Blue
China	9.62	13.02	11.96	12.48	5.32	7.03	4.29	10.25	2.95	8.36	7.96	12.43
USA	1.59	2.00	1.36	1.32	1.86	2.31	1.68	2.68	1.86	2.73	1.73	2.18
India	2.53	0.16	2.08	0.12	1.79	0.40	0.61	0.07	0.71	0.07	1.89	1.29
Indonesia	0.18	0.06	2.19	4.48	3.88	1.27	0.16	0.10	0.28	0.15	6.99	1.19
Brazil	1.42	0.31	1.38	0.31	1.10	0.13	1.38	0.24	1.09	0.25	1.68	1.08
Romania	0.00	0.00	0.00	0.00	0.86	0.51	1.93	1.77	3.23	2.97	2.12	0.64
Ukraine	0.28	0.20	0.00	0.00	1.49	0.86	3.00	2.59	0.99	0.56	1.31	0.23
Australia	0.09	0.23	0.49	0.76	0.22	1.68	1.74	2.20	1.98	2.39	1.82	2.46
Canada	0.98	0.52	0.17	0.07	0.29	0.13	0.30	0.19	1.39	0.66	2.11	0.30
Argentina	0.37	0.13	0.42	0.21	0.35	0.10	0.30	0.22	0.35	0.30	1.71	0.19
Chile	0.36	0.02	0.38	0.02	0.45	0.02	0.40	0.03	0.46	0.03	0.46	0.03
Thailand	0.19	0.25	0.18	0.17	0.19	0.22	0.12	0.20	0.22	0.33	0.22	0.33

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The exporters could be regarded as the major crop supply sources but also major water resources in terms of VWT. Accordingly, drought in countries of exporters causes problems in the crop trade. Korea is one of the biggest virtual water importers and the government needs to understand which importers are more important in terms of VWT. This study showed the importance of trade partners by applying the intensity of VWT. The results of VWT intensity indicated that the USA and China were the most important trading partners and that Romania, Ukraine and Australia became more important during the period. Accordingly, the Korean government needs to consider the change of intensity index of the main exporters for sustainable crop trade.

CONCLUSIONS

Traditional water resources management has primarily been conducted within administrative boundaries or river basins. However, the consideration of virtual water extends the scope of water resources management further, beyond country boundaries. Implementing a virtual water strategy can be an effective way to alleviate water scarcity in a country and the virtual water import is effective for domestic water savings.

However, high dependency on virtual water imports could cause vulnerability of trade, which is very sensitive to the exporter's water scarcity. Since high dependency on VWT was related to water resources such as groundwater and surface water, high dependency on VWT could involve the risk of export regulation by water shortage. Accordingly, water dependency could be used to evaluate the risk of VWT, and suggests the need for the development of new water resources in order to increase the domestic crop supply. In addition, climate change and the contamination of water supplies contribute to water scarcity, which is expected to aggravate the crop trade situation. Therefore, it is important to evaluate the importance of each trading partner in VWT, and trade intensity could be useful for determining the significant traders when the government sets out sustainable trade policy in terms of global water scarcity.

Accordingly, the water dependency and trade intensity of VWT associated with the crop trade could be useful indices for evaluating the risk in crop trading and determining the important trading partners in terms of global water scarcity.

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