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Discussions

Analysis of the characteristics of global virtual water trade network using degree and eigenvector centrality, with a focus on food and feed crops

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Abstract.

This study aims to analyse the characteristics of global virtual water trade (GVWT) such as connectivity of each trader, vulnerable importers, and influential countries using degree and eigenvector centrality during the period 2006-2010. The degree centrality was used to measure the connectivity and eigenvector centrality was used to measure the influence on entire GVWT network. Mexico, Egypt, China, Korea Rep., and Japan were classified to vulnerable importers because they imported a lot of virtual water with the low connectivity. Especially, Egypt had 15.3 Gm³/year blue water savings effects through GVWT, thus the vulnerable structure could cause the water shortage problem in importer. The entire GVWT network could be changed by a few nodes which call influential traders, and we figured out the influential traders using eigenvector centrality. In GVWT for food crops, the USA, Russian Federation, Thailand, and Canada had high eigenvector with a large volume of green water trade. In case of blue water trade, western Asia, Pakistan, and India had high eigenvector centrality. For feed crops, the green water trade in the USA, Brazil, and Argentina was the most influential. However, Argentina and Pakistan used the high proportion of internal water resource for virtual water export (32.9 % and 25.1 %), thus rest of traders should consider the water resource management in these exporters carefully.

Keyword: Virtual water trade; Water footprint; Degree centrality; Eigenvector centrality

1 Introduction

Water scarcity is a local phenomenon sensitive to global food production, since agriculture has the largest share in the consumption of global freshwater resources (Molden, 2007; Biewald et al., 2014). Most of water demand is derived from agriculture, and crop trade could be considered as the main consumer of water because crop production accompanies water consumption which is embedded water in crops (Aldaya et al., 2010).

“Virtual water” indicates the embedded water in the production and processing (Allan, 1993; Hoekstra, 2003; Yang and Zehnder, 2007), and the virtual water concept has been expanded to include the product chain, and the “water footprint”. Building on the virtual water concept, we can convert the crop trade to embedded water trade, and it called virtual water trade (VWT) (Aldaya et al., 2010). In addition, food security is a significant issue in water-poor regions because fresh water is a vital factor for growing crops (Konar et al., 2012; Hanjra and Qureshi, 2010; Hoekstra, 2003). The virtual water trade through various crops trade is regarded as an important variable for global water savings and the regional water management, particularly in the regions where water resource is insufficient such as Middle East region (Hoekstra, 2003; Hoekstra et al., 2011). Accordingly, the concept of VWT brings a new perspective for considering both food security, water scarcity and water resource management (Novo et al., 2009). In addition, the global virtual water trade (GVWT) could lead to a global redistribution of fresh water and water savings (Konar et al., 2013).

Several studies have been conducted regarding the virtual water trade at different spatial scales in order to evaluate VWT impacts on water savings (Chapagain et al., 2006). Early studies focused on the water footprint and VWT. Hoekstra and Hung (2005) found that 13% of total used water for global crop production from 1995 to 1999 was traded internationally. Hanasaki et al. (2010) estimated the global virtual water trade for major crops and livestock products, and Chapagain and Hoekstra (2011) estimated the blue, green, and grey water footprint of rice.

Based on water footprint research, an analysis of VWT has been performed in several studies. Van Oel et al. (2009) quantified the VWT in the Netherlands and evaluate the impact of VWT on water dependency in terms of external water footprint. Bulsink et al. (2010) explained that the VWT could increase the resilience to water scarcity in Java, Indonesia. Zhang and Anadon (2014) tried to investigate how domestic inter-provincial trade shapes China’s VWT. Mubako et al. (2013) calculated water use intensities across economic sectors in California and Illinois, and quantified the water embodied in trade between several states (California, Illinois, and other U.S. states) and the rest of the world. Fader et al. (2011) estimated the internal and external water footprint by VWT and evaluated the effect of VWT on national and global water savings. In addition, climate change is the main issue in water resource management, thus Konar et al. (2013) quantified the climate change impacts on the virtual water flow, and found that climate change derived the decrease of the total volume of virtual water trade because of decreased crop trade and virtual water content. However, the food trade affected to water savings across most climate change.

Recently, several studies have been conducted to analyse the temporal change of VWT structure using network system. For example, Konar et al. (2012) analysed the temporal dynamics of the virtual water trade networks, and found that global food trade affects to water savings and specific crop network could be more efficient from water resource perspective. Dalin et al. (2012) focused on the evolution of the GVWT network considering the number of partners and the volume of virtual water. These studies more focused on entire network structure and analysed the temporal change of GVWT network.

In this study, we applied the network centrality to analyze the characteristics of GVWT during the period 2006-2010 with a focus on the characteristics of each importer and exporter such as connectivity of each trader, vulnerable importers, and influential countries in the GVWT network. The degree centrality of GVWT network was analyzed to evaluate the connectivity of each country, and then vulnerable importers were classified according to connectivity and volume of GVWT. A vulnerable structure in importers indicated the low connectivity with large amount of virtual water imported, and it could cause the water shortage problem in importers. We also analyzed the influential traders of GVWT using eigenvector centrality which is a measure of the importance and influence of a node on the whole network. The change of VWT in influential countries could affect strongly to the rest of traders.

2 Materials and Methods

2.1 Water footprint (WFP) and global virtual water trade (GVWT)

Water footprint (WFP, m³/ton) is the volume of water required for producing one ton of crops in the region and it proposed to consist of green, and blue water (Hoekstra and Chapagain, 2008). The green water footprint indicates the volume of rainwater consumed and the blue water footprint indicates the volume of irrigation water (surface and groundwater). The WFP of a crop indicates crop water requirement (m³/ha) per yield (kg/ha), thus it was estimated using Eq. (1) as follows:

$$\mathrm{WFP}[c] = \frac{\mathrm{CWR}[c]}{\mathrm{Production}\ [c]} \qquad (1)$$

where WFP (m³/ton) is the water required for the production of one ton of a given crop c, CWR is the crop water requirement, and the production is the yield per year.

As the water footprint concept, VWT represents the amount of water embedded in products that are traded internationally. Therefore, it was calculated by multiplying the international crop trade by their associated water footprint, and we quantified the global scale of VWT through the water footprint and crops trade using Eq. (2) as follows:

$$\mathrm{VWT}[n_e, n_i, c, t] = \mathrm{CT}[[n_e, n_i, c, t] \times \mathrm{WFP}[n_e, c] \qquad (2)$$

where VWT indicates that VWT from the exporting country n_e to the importing country n_i, CT represents the crop trade, and WFP represents the water footprint. In addition, c and t indicate crop and year.

Country-scale import and export data of crops for the recent 5years (2006-2010) were obtained from the Personal Computer Trade Analysis System (PC-TAS) produced by the United Nations Statistics Division (UNSD). These data are based on the Commodity Trade Statistics Data Base (COMTRADE) of the UNSD.

The water footprint is defined as the total volume of water consumed within the territory of the nation. Mekonnen and Hoekstra (2010) quantified the average value of green and blue water footprints of crops and crop products at national and sub-national level from 1996 to 2005. The water footprint data indicated the representative index using average value. Therefore, we applied the average value of water footprint during the period 1996-2005 from Mekonnen and Hoekstra (2010) even though this study focused on crop trade in recent 5 years (2006-2010).

2.2 Degree centrality of GVWT by network analysis Subsection (as Heading 2)

The GVWT consists of numerous links among nations, and the network approach could be the appropriate method to analyze the GVWT structural features. In particular, the main flows and the vulnerable nodes were evaluated using the centrality concept. The degree of centrality is one of the simplest indices for evaluating network structure, and it is a count of the number of edges incident upon a given node (Freeman 1979). Therefore, the high level of degree centrality indicates the node has expended connections with various nodes. The degree centrality has the direction, and thus, is divided to in-degree and out-degree centrality. In-degree centrality means the import in the GVWT network and out-degree means the opposite. For example, the high level of in-degree centrality in GVWT indicates the country import virtual water from various exporters, and the high level of out-degree centrality indicates the country exports virtual water to various importers. In other words, the country who has the high level of degree centrality could be identified to the main country in expanded GVWT network. Therefore, degree centrality could be applied to quantify the connectivity of each country in GVWT. The degree centrality of each country in GVWT is calculated as:

$$\mathrm{C_i} = \sum_{\mathrm{j}}^{\mathrm{N}} \mathrm{VWT_{ij}}/(\mathrm{N}-1), \qquad (3)$$

where $\mathrm{C_i}$ is the degree centrality of node i, and N is the number of total nodes. $\mathrm{VWT_{ij}}$ indicates virtual water trade between the $\mathrm{i^{th}}$ and $\mathrm{j^{th}}$ country.

2.3 Eigenvector centrality of GVWT by network analysis

The GVWT consist of complex network but some countries could affect to the entire network system, and it is important to figure out these countries. Therefore, we applied eigenvector centrality to GVWT network in order to find the most influential countries. An eigenvector centrality is used for measuring the importance and influence of a node on the whole network (Ruhnau, 2000). The eigenvector centrality represents relative centrality to all nodes in the network, based on the principle that high-level centrality nodes could contribute more to connected nodes than low-level centrality nodes. In other words, the centrality of countries not only depends on the number of trade partners adjacent to it, but also on their values of centrality (Ruhnau, 2000). Accordingly, the eigenvector centrality could be used for determining the influential nodes and influence area. Bonacich (1972) defined the centrality $c(v_i)$ of a node v_i as the positive multiple of the sum of adjacent centralities, as follows:

$$\lambda c(v_i) = \sum_{j=1}^{n} \alpha_{ij} c(v_j) \qquad \forall i. \qquad (4)$$

In matrix notation, with $\mathrm{c} = (c(v_i), \ldots, c(v_n))$, the above equation yields

$$\mathrm{Ac} = \lambda \mathrm{c} \qquad (5)$$

This type of equation is solved using the eigenvalues and eigenvectors. An eigenvector of the maximal eigenvalue with only non-negative entries does exist, and we call a non-negative eigenvector $(\mathrm{c} \geq 0)$ of the maximal eigenvalue the principal eigenvector, and we call the entry $c(v_i)$ the eigenvector-centrality of node v_i (Ruhnau, 2000). The eigenvector centrality of a node is proportional to the sum of eigenvector centralities of the nodes connected (Bonacich, 1972). In addition, eigenvector centrality indicates the principal eigenvector that has the largest eigenvalue among every eigenvectors. We used NetMiner 3.0 (http://www.netminer.com) for estimating the degree and the eigenvector centrality.

3 Results and Discussion

3.1 Estimation of the GVWT of food and feed crops

The GVWT is depended on water footprint of each country, and a few countries cultivate and export water intensive crops. Fig. 1 showed relationship between green, blue water export and crop export during the period 2006-2010. In Fig. 1(a), green water export and crop export showed the strong relationship in most of exporters, and the dispersion of scattered points of green water export and crop export was small. However, Fig 1(b) indicated the blue water export and crop export, and the dispersion of scattered points was bigger than green water export. It means that blue water consumption for crop export is more depended on the exporting country rather than green water consumption even if the amount of blue water consumption for crop export was smaller than green water consumption.

In addition, we calculated the total amount of green and blue water trade of each country from 2006 to 2010. For food crops such as wheat, rice, barley etc., total crop trade was 985.6 Mton and the GVWT was 1631.0 Gm^3 (green water: 1453.1 Gm^3, blue water: 177.9 Gm^3) from between 2006 and 2010. The GVWT of wheat had the highest proportion, totalling 1057.8 Gm^3, but the largest amount of blue water was traded by rice. About 136.7 Gm^3 of blue water was traded through the rice trade, 4 times higher than traded through wheat. Barley presented as a less water intensive crop than either wheat or rice. Feed crops, such as maize and beans crops, totalled 1243.8 Mton, with the GVWT at 1811.9 Gm^3 between 2006 and 2010. The beans crops were the representative, water intensive crops, and about 1360.4 Gm^3 of virtual water was traded between 2006 and 2010. In contrast, the amount of maize traded was 531.2 Mton, but the virtual water involved was only 451.5 Gm^3.

3.2 Analysis of the connectivity and intensity of GVWT using degree centrality

3.2.1 Analysis of connectivity in GVWT

The GVWT network includes both of the volume of virtual water and connection among countries. Fig. 2 indicated the GVWT network of food and feed crops in 2010, and it showed that the GVWT for food crops has the dispersed network but the GVWT for feed crops has more centralized on a few main exporters.

The degree centrality was applied to understand the connectivity of GVWT in this study. The degree centrality was divided to in- and out- degree by the direction of GVWT. The in-degree means the imports and out-degree means the exports. We analyzed the in- and out-degree centrality of the GVWT of food and feed crops during the period 2006-2010, and the results were shown on Fig. 3. The exporters in GVWT for food crops had more connectivity with expended structure rather than exporters in GVWT for feed crops. In addition, the importers in the GVWT of food trade had various connections with exporters.

We also looked into the connectivity of each country accompanying with the volume of GVWT, and the higher rank (1) indicated the larger degree centrality. Considering the out-degree centrality of GVWT for food crops, the USA constructed the expanded connectivity with various importers, followed by Asian countries such as Thailand, Pakistan, Vietnam, and India. Ukraine also had high connectivity to various importers accompanying with large amount of virtual water export. These countries paly the main role for virtual water supply in the GVWT. In contrast, Russian Federation, Kazakhstan, and Australia had lower connectivity even if they exported a lot of virtual water by food crops trade. Considering the out-degree centrality of the GVWT for feed crops, the exporters who exported a lot of virtual water had the high connectivity as well. For example, the USA, Brazil, and Argentina had high ranks in both of the volume and connectivity of GVWT. These countries exported the highest amount of virtual water to eastern Asian countries, such as China, Japan, and Korea Rep. but also had various connections with importers.

In-degree centrality indicated the connection of virtual water import according to importer's perspective. Therefore, the importer who has high rank of in-degree centrality imports virtual water from various exporters, and it means this importer has robust trade structure. Therefore, if the importer has the low rank of in-degree centrality with larger volume of virtual water import, this importer might be highly depended on just a few exporters. For example, Egypt and Japan imported a lot of virtual water by food crops trade but the rank of in-degree centrality was 21st and 33rd. Actually, Egypt imported over 50% of wheat from only the USA and Russian Federation. In terms of feed crops trade, most of virtual water was imported to China but the connectivity was very low. In contrast, Netherlands, Spain, and Germany had the high ranks in both of volume and connectivity of virtual water import through feed crops trade, and these results indicated that these countries had robust trade structure. In fact, the European countries had robust internal trade network with various connections among the European countries.

3.2.2 Evaluation of vulnerability of virtual water importers through connectivity and volume of GVWT

The importers in the GVWT were passive by water shortage in exporters, and the GVWT network of importers could be a vulnerable structure by the number of the connections with exporter. For example, the few importers could be dominated by the main exporters when the GVWT is concentrated in a few countries in the trend of the increase of crop trade. It means that these importers might be depended on a few exporters with a low resilient structure. Fig. 4 indicated the average virtual water import from one exporter. In terms of GVWT for food crops, Mexico imported average 8.1 Gm^3 from one exporter, and it means that Mexico is highly depended on a few exporters. In case of feed crops trade, China has the largest average virtual water imported from one exporter followed by Mexico and Uruguay. In these importers, virtual water import could be a main issue for sustainable water management but the VWT which is highly depended on a few exporters could be regarded as the vulnerable trade structure. Therefore, it is important to understand the vulnerability of VWT with consideration of connectivity and volume of virtual water import.

In this study, the importers of VWT were classified with both of connectivity and volume of virtual water import. In Table 1-2, we classified importing countries according to the volume of GVWT (Ⅰ-Ⅲ) and connectivity of GVWT (A-C). When importers are classified into A-Ⅲ sector, we considered that they had an intensive virtual water import with vulnerable structure.

In terms of intensive virtual water import by food crops, Mexico who located in A-Ⅱ sector was the vulnerable importers in GVWT. In addition, the phenomenon of the low in-degree centrality with links of GVWT was shown in Asia countries even if they imported a lot of virtual water. For example, Iran, and Philippines were classified into B-Ⅱ sector and even Japan was classified into B-Ⅲ. However the European countries such as Spain, Turkey, and Netherlands were classified into C-Ⅰ sector. These results represented that the Asian countries imported a lot of virtual water from a few exporters and the European countries have connected to various exporters even if they imported the comparable virtual water.

In terms of intensive virtual water import by feed crops, Mexico, Korea Rep. and Germany were in Ⅲ sector, but Mexico (A-Ⅲ sector) and Korea Rep. (B-Ⅲ sector) had a lower connectivity than that of Germany(C-Ⅲ sector), that is, Mexico and Korea Rep. imported large amounts of virtual water from a few countries and they had the vulnerable structure of GVWT. In addition, China was regarded as the exclusive importer in GVWT network. In contrast, the European countries such as Netherlands, Spain and Germany, have a more distributed structure than eastern Asian countries, who imported the numerous virtual water by feed crops trade.

Virtual water trade could help the importers to save water resources by crops import. For example, if the importing country replaces crop import with domestic production, additional water use will be accompanied. Table 3 indicated the water savings by virtual water import in main importers from 2006 to 2010. China and Japan saved 24.7 Gm^3/yr and 18.7 Gm^3/yr of green water by crops import. In addition, Egypt and Iran saved 15.3 Gm^3/yr and 10.1 Gm^3/yr of blue water by crops import because these countries depended on the irrigation water for domestic crop production. Especially, Egypt and Iran has a little water resources, therefore, the virtual water impacts on water resource savings in these countries might be larger than other importers. Therefore, VWT is very important issue for these importers, thus the vulnerable structure of VWT could cause the water shortage problem to importing countries.

3.3 Analysis of influential countries in GVWT using Eigenvector centrality

The GVWT was complicated to understand and it is difficult to estimate the influence of each trader on GVWT. The country which has relationship with main exporters and importers could influence the GVWT even if the amount of trade volume is small. Apart from degree centrality, this country has the distinctive centrality in terms of the influence on entire GVWT network.

Accordingly, we estimated the eigenvector centrality of green and blue water trade in GVWT, and the influential importers and exporters were analyzed using degree and eigenvector centrality. The degree centrality could show the connectivity and volume of the VWT, and the eigenvector centrality could show the influence of countries on entire GVWT network structure. Therefore, the most influential traders have the high degree and eigenvector centrality at the same time, and the other traders should keep an eye on the change of trade policy and water management of the influential traders.

Tables 4-5 indicated the eigenvector centrality in green and blue water trade, and the degree centrality in connection and volume of GVWT network. The USA showed the high out-degree centrality and high eigenvector centrality and it indicated the USA was the most influential exporter in the green water trade through food crops trade. The green water trade also had the secondary influential exporters such as Canada, Russian Federation, Thailand, and Australia. The influence exporting area of green water was constructed by each exporter such as the USA, Russian Federation, Thailand and Australia. In terms of import, Japan, Mexico and Egypt were represented to the influential importers on green water trade, and the influence importing area of green water trade was distributed to South America, Europe, western Asia, and East Asia.

In contrast, the influential exporters and importers of blue water trade were different from green water trade. The global blue water export by food crops was influenced on the USA, Pakistan, India, and Thailand. Also, the global blue water import was dominated by western Asia such as Iran, Saudi Arabia and UAE. In other words, the influence exporting area of blue water was constructed centering Pakistan including India and Thailand, and the influence importing area was concentrated on western Asia.

For feed crops, the green water in the USA, Brazil, and Argentina was exported to eastern Asian countries such as China, Korea Rep., and Japan. In particular, Brazil and Argentina were dependent on green water. However, the USA used a lot of blue water overwhelmingly for exporting maize and beans crops. The USA, Mexico, China, and Japan constructed influential lines from the Americas to eastern Asia.

Crop production accompanies with water consumption, thus the crop trade could be also affected by water resource status in exporting country. Table 6 indicated the water resources and virtual water use for domestic crop production and export in the influential countries. In Argentina, Canada, and Paraguay, over 50 % of virtual water use for food and feed crops production was used for exporting crops. However, in Argentina and Pakistan, over 25 % of internal water resources were used for exporting crop. In addition, Thailand and Paraguay also used 39.5 % and 54.2 % of domestic virtual water use for virtual water export, respectively but the dependence on internal water resources were over 10 % in both of two countries. Therefore virtual water export of these countries could be affected by internal water resources strongly, and it could have a negative impact on importers.

4. Conclusions

Crop production accompanies with water consumption, thus the crop trade could be also affected by water resource status in exporting country. Virtual water trade could help the importers to save national water resources by crops import. For example, if the importing country replaces importing crops with domestic production, additional water use will be accompanied. National water savings achieved by the virtual water trade are equal to the import volume multiplied by the volume of water required to domestically produce the commodity. However, the virtual water trade could cause water “losses” for the exporting countries (Chapagain et al., 2006). For example, countries whose major industry is agriculture spend their water resources for food trade. In addition, the available global freshwater is decreasing due to climate change, suggesting that water be considered a precious natural resource.

Therefore, the virtual water trade is the main component for water management in both or exporters and importers, thus it is important to understand the characteristics of virtual water trade. In this study, we analyzed the structural characteristics of the global virtual water trade(GVWT) such as connectivity of each trader, vulnerable importers, and influential countries using degree and eigenvector centrality during the period 2006-2010. This study only considered the recent 5 years trade, and it has limitation about prediction. In addition, the global crop trade is related to various factors such as price, climate, and policy etc., thus it is very hard to predict the future trade condition.

However, the virtual water concept could give the extended views for understanding food, water, and trade relationship. Especially, the importers who had the vulnerable GVWT structure were classified according to connectivity and volume of GVWT. Mexico, Egypt, China, Korea Rep., and Japan were classified to vulnerable importers because they imported a lot of virtual water with the low connectivity. The VWT could bring the national water savings but the vulnerable structure of VWT could cause the problem about water security in importers. For example, Egypt had 15.3 Gm^3/year blue water savings effects through GVWT, thus the vulnerable structure could cause the water shortage problem.

The entire GVWT network could be changed by a few nodes which call influential traders. In addition, if the influential countries have the water shortage, it becomes the not only national scale problem but also global threat. Therefore, we classified the influential countries in GVWT using eigenvector centrality which is generally used to measure the influence on entire network. For the food crops trade, the influential traders were distinguished by green and blue water trade, For example, the USA, Russian Federation, Thailand, and Canada were classified to influential traders in green water trade. However, in blue water trade, western Asia, Pakistan, and India were classified to influential traders. The feed crops trade was much dominated by green water rather than blue water, and the USA, Brazil, and Argentina were classified to the most influential traders. Especially, Argentina and Pakistan used the high proportion of internal water resource for virtual water export (32.9 % and 25.1 %), thus rest of traders should consider the water resource management in these exporters carefully. This study could provide the information for the integrated global water strategy and arouse the main importers attention about the risk of the serious dependency on foreign water resource.

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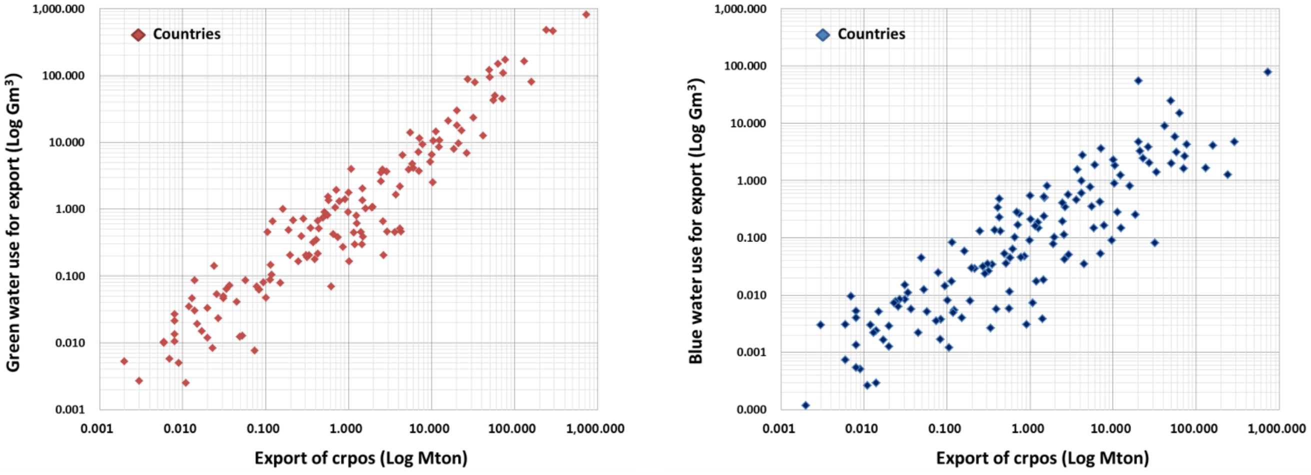
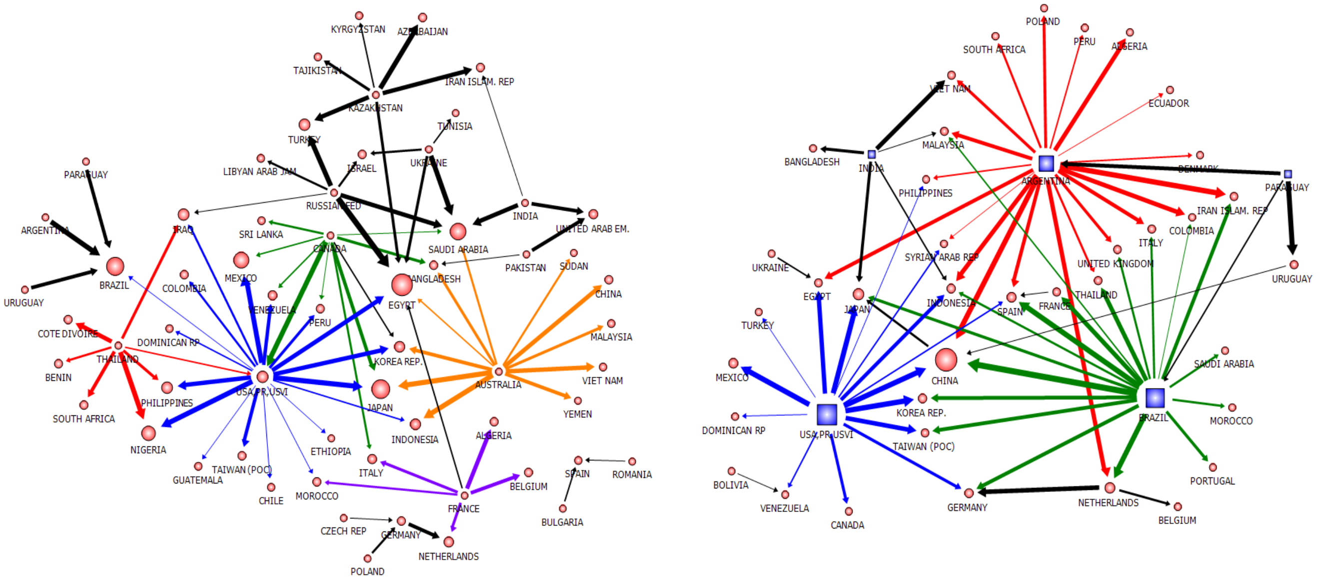


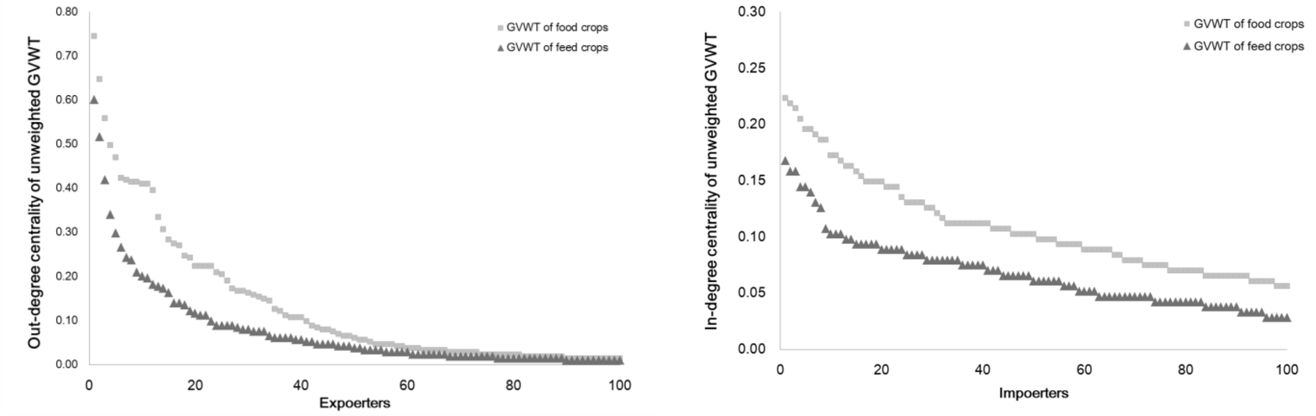
(a) Crop export and green water export **(b) Crop export and blue water export**

Figure 1: A comparison between virtual water export and crop export during the period 2006-2010 (wheat, barley, rice, rye, sorghum, maize, and beans crops).



(a)) Food crops (wheat, barley, rice, and others) **(b) Feed crops (maize and soybean)**

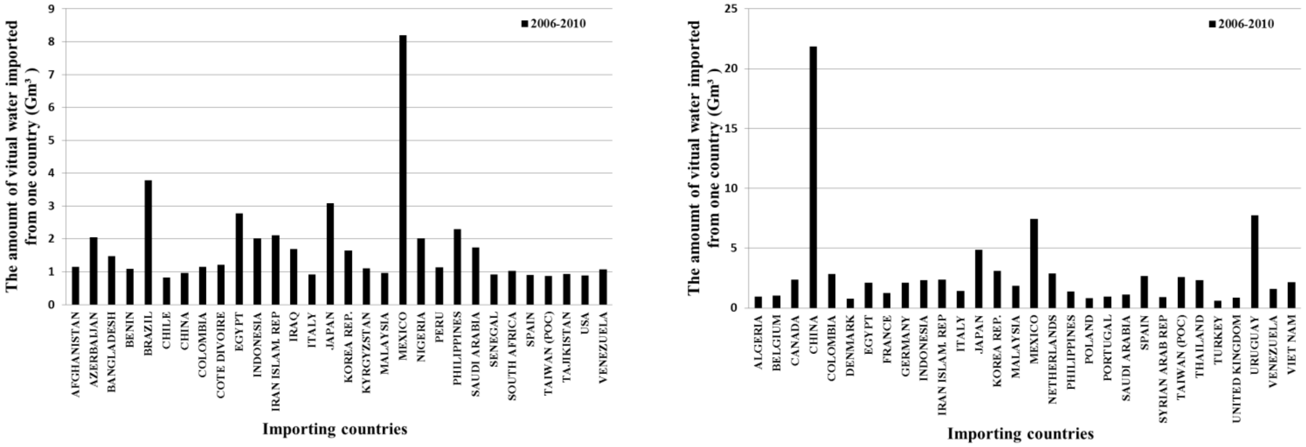
Figure 2: The GVWT network through food and feed crops trade in 2010.



(a) Out-degree centrality

(b) In-degree centrality

Figure 3: Out- and in-degree centrality in connection network of GVWT for food and feed crops during the period 2006-2010.



(a) Food crops (wheat, barley, rice, and others)

(b) Feed crops (maize and soybean)

Figure 4: The intensive inflow of virtual water by food and feed crops import.

Table 1: Classification of importers by connectivity and volume of GVWT for food crops (wheat, barley, rice, and others).

GVWT of food crops		Connectivity of GVWT		
		Low (A)	**Medium (B)**	**High (C)**
Volume of GVWT	**Small (Ⅰ)**		INDONESIA IRAQ BANGLADESH KOREA REP. YEMEN SOUTH AFRICA	SPAIN TURKEY USA NETHERLANDS ALGERIA GERMANY UAE BELGIUM
	Medium (Ⅱ)	MEXICO	NIGERIA IRAN PHILIPPINES	ITALY
	Large (Ⅲ)		EGYPT JAPAN BRAZIL	SAUDI ARABIA

Table 2: Classification of importers by connectivity and volume of GVWT for feed crops (maize and soybean).

GVWT of feed crops		Connectivity of GVWT		
		Low (A)	**Medium (B)**	**High (C)**
Volume of GVWT	**Small (Ⅰ)**	COLOMBIA URUGUAY	TAIWAN IRAN THAILAND VIET NAM EGYPT MALAYSIA	UK
	Medium (Ⅱ)		INDONESIA	ITALY FRANCE
	Large (Ⅲ)	MEXICO	CHINA JAPAN KOREA REP	NETHERLANDS SPAIN GERMANY

Table 3: Water resource and virtual water savings by importing crops.

Importers	Water resource (Gm^3)		VWI* by crop trade (Gm^3/yr)		VWU* for producing imported crops (Gm^3/yr)		Water savings (Gm^3/yr)	
	Internal (1)	External (2)	Green water (3)	Blue water (4)	Green water (5)	Blue water (6)	Green water (3)-(5)	Blue water (4)-(6)
CHINA	221	65	105.3	10.6	80.6	2.1	24.7	8.5
EGYPT	65	5	3.2	16.2	23.4	0.9	-20.2	15.3
IRAN	2	56	9.8	11.6	15.8	1.5	-6	10.1
JAPAN	409	48	53.1	1.3	34.4	2.7	18.7	-1.4
MEXICO	129	9	36.1	5.5	21.1	2.2	15	3.3

* VWI: virtual water import
* VWU: virtual water use

Table 4: Eigenvector centrality of green water trade and degree centrality of GVWT.

Countries	Eigenvector centrality	In-degree centrality		Out-degree centrality	
	Green water trade	Volume of GVWT	Connection of GVWT	Volume of GVWT	Connection of GVWT
GVWT for food crops					
USA	0.62	0.14	0.16	1.64	0.74
Japan	0.34	0.34	0.11	0.00	0.11
Canada	0.29	0.02	0.08	0.68	0.41
Mexico	0.28	0.23	0.03	0.02	0.08
Egypt	0.23	0.40	0.14	0.01	0.24
Nigeria	0.23	0.23	0.12	0.00	0.01
Russian Federation	0.17	0.05	0.13	0.81	0.41
Thailand	0.17	0.05	0.11	0.66	0.65
Philippines	0.15	0.21	0.09	0.00	0.00
Iraq	0.13	0.17	0.10	0.00	0.00
Korea Rep.	0.12	0.15	0.09	0.00	0.01
Indonesia	0.11	0.19	0.09	0.00	0.03
Australia	0.10	0.01	0.09	0.44	0.28
GVWT for feed crops					
China	0.62	1.83	0.08	0.10	0.17
USA	0.47	0.03	0.10	2.49	0.60
Brazil	0.45	0.07	0.02	2.16	0.42
Argentina	0.26	0.06	0.04	1.78	0.52
Japan	0.17	0.52	0.11	0.00	0.01
Netherlands	0.15	0.48	0.17	0.20	0.20
Mexico	0.11	0.31	0.04	0.01	0.06
Spain	0.10	0.39	0.14	0.02	0.07
Korea Rep.	0.10	0.30	0.10	0.00	0.03

Table 5: Eigenvector and degree centrality of blue water trade and degree centrality of GVWT.

Countries	Eigenvector centrality of Blue water trade	In-degree centrality		Out-degree centrality	
		Volume of GVWT	Connection of GVWT	Volume of GVWT	Connection of GVWT
GVWT for food crops					
Pakistan	0.63	0.05	0.10	0.33	0.56
UAE	0.38	0.12	0.17	0.01	0.12
Iran	0.27	0.22	0.10	0.01	0.05
USA	0.22	0.14	0.16	1.64	0.74
Kenya	0.19	0.06	0.15	0.00	0.04
Afghanistan	0.17	0.04	0.03	0.00	0.00
Saudi Arabia	0.17	0.34	0.20	0.00	0.04
Thailand	0.16	0.05	0.11	0.66	0.65
India	0.16	0.07	0.13	0.24	0.47
Mozambique	0.13	0.04	0.09	0.00	0.02
South Africa	0.11	0.11	0.11	0.01	0.07
Mexico	0.11	0.23	0.03	0.02	0.08
Iraq	0.10	0.17	0.10	0.00	0.00
Philippines	0.10	0.21	0.09	0.00	0.00
Oman	0.10	0.03	0.11	0.00	0.03
GVWT for feed crops					
China	0.62	1.83	0.08	0.10	0.17
USA	0.47	0.03	0.10	2.49	0.60
Brazil	0.45	0.07	0.02	2.16	0.42
Argentina	0.26	0.06	0.04	1.78	0.52
Japan	0.17	0.52	0.11	0.00	0.01
Netherlands	0.15	0.48	0.17	0.20	0.20
Mexico	0.11	0.31	0.04	0.01	0.06
Spain	0.10	0.39	0.14	0.02	0.07
Korea Rep.	0.10	0.30	0.10	0.00	0.03

Table 6: Water resource and virtual water use for production and exporting crops.

Exporters	Water resource (Gm³)		VWU* for crop production (Gm³/yr)		VWE* by crop trade (Gm³/yr)		Proportion of VWE* (%)	
	Internal (1)	External (2)	Green water (3)	Blue water (4)	Green water (5)	Blue water (6)	{(5)+(6)} /(1)	{(5)+(6)} /{(3)+(4)}
ARGENTINA	276	538	140.6	1.2	90.5	0.4	32.9	64.1
BRAZIL	5,418	2,815	213.5	0.1	92.8	0.0	1.7	43.5
CANADA	2,850	52	42.5	0.2	28.7	0.1	1.0	67.5
FRANCE	200	11	34.2	1.6	15.4	0.6	8.0	44.9
PAKISTAN	55	192	21.2	53.2	3.2	10.6	25.1	18.6
PARAGUAY	94	242	19.1	0.0	10.4	0.0	11.0	54.2
RUSSIAN FED	4,313	195	168.5	4.2	33.9	0.5	0.8	19.9
THAILAND	226	214	59.4	12.1	23.4	4.8	12.6	39.5
UKRAINE	53	86	48.1	0.7	9.9	0.4	19.4	21.1
USA	2,818	251	423.7	42.8	162.3	15.0	6.3	38.0

* VWU: virtual water use
* VWE: virtual water export