

Full Length Research Paper

Application of virtual water trade theory in inter-regional grain allocation and transportation in China

Cao Xinchun^{1,2}, Wu Pute^{1,2,3,4*}, Wang Yubao^{1,2}, Zhao Xining^{1,2,3,4} and Li Sha¹

¹College of Water Resources and Architectural Engineering, Northwest Agriculture and Forestry University, Yangling, China.

²Institute of Water Saving Agriculture in Arid regions of China, Northwest Agriculture and Forestry University, Yangling, China.

³National Engineering Research Center for Water Saving Irrigation at Yangling, China.

⁴Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, Yangling, 712100, China.

Accepted 30 September, 2011

China was partitioned into eight regions, and the virtual water flow due to regional grain allocation and transportation among these regions was calculated in 2008 based on virtual water and virtual water trade theories. Then, we analyzed the relations between virtual water trade structure and water resources utilization. Results show that the grain output regions in China were Northeast, Huang-Huai-Hai and the Middle-Lower Yangtze regions, where the grain outputs were 5.3×10^7 t, 2.8×10^7 t, and 5.6×10^6 t respectively and the corresponding virtual water exports were 5.55×10^{10} m³, 2.78×10^{10} m³, and 0.53×10^{10} m³, respectively. There were large amounts of virtual water import in the Southern, Southeast and Northern China, and the sum of the three region was up to 7.0×10^{10} m³. The whole country saved about 3.05×10^{10} m³ water resource as a result of the well correspondence between structure of grain allocation and transportation and the comparative advantage of regional water utilization efficiency; but the virtual water export and import conditions in each region mismatched the Endowment of Resources Principle when considering water resource condition. The distribution of national grain production and water resource was not suited with each other. The Chinese government should proposed corresponding measures.

Key words: Endowment of resources, food security, grain allocation and transportation, regional water transfer, virtual water.

INTRODUCTION

China is an agricultural country whose population accounts for 1/5 of the world while per capita possessive amount of water resources is only equal to 1/4 of the world average level (Jia et al., 2004; Zhang et al., 2009). Water and soil resources of China are extremely uneven in regional distribution and the Northeast area, the Middle-Lower Yangtze plain and the Huang-Huai-Hai area produce most grain. The large population, relatively scarce water resources and the imbalanced space and time distribution of water and soil resources, are the bottleneck factors that restrict the country food security

(Liu and Wu, 2002).

The water embodied in grains and traded in company with grain trade is called virtual water (Allan, 1993, 1994). Chen (2003) introduced the virtual water trade theory which was presented by Allan in early 1990s to Chinese scientific community in 2003 and then a number of Chinese researchers linked it to food security and water resource strategy. The concept is thought to provide new ways to mitigate water scarcity and ensure food security. Ma and Chen (2006), Gong et al. (2007), Yang et al. (2008) and Lu et al. (2010) calculated the volume of virtual water import associated with international food trades in China in recent years respectively, and arrived at the conclusion that agricultural trades in virtual water play a role in offsetting the insufficient of domestic grain

*Corresponding author. E-mail: gjzwpt@vip.sina.com.

supply and alleviating the shortage of water resources in agriculture. They also suggested preliminary suggestions and limiting factors in guiding Chinese agricultural structure adjustment and optimizing international food trade using virtual water trade strategy. Liu et al. (2005) and Ke et al. (2004) analyzed international and domestic population growth, the supply and demand of food, agricultural water utilization and food trade issues in the future. They believed that China cannot completely satisfy population with food demand with traditional methods, while food import and virtual water trade strategy can be choices which can realize Chinese food security and sustainable use of water resources. Chinese virtual water trade in grain alleviates the pressure and guarantees the water resource and grain security, at the same time it saves a lot of water and improved water use efficiency in the global scope.

In China, regional virtual water flow circumstance is also a focus of attention. Xu et al. (2003) connected virtual water trade with provincial water resource safe by taking Gansu Province for example. Dong, (2005) studied the situation of agricultural product import and export in various provinces and suggested that regional virtual water trade exists in China, but did not do quantitative analysis for virtual water trade or its influence. Wu et al. (2010) divided mainland of China into southern and northern regions and found that there was an 'agricultural North-to-South water diversion virtual engineering' in China since 1990, and more than 230 billion m³ virtual water is transferred by the 'engineering' every year averagely. By assumption, Ma et al. (2004, 2006) calculated and analyzed regional agricultural product trade and virtual water flow condition in China in 1999, and explained the relationship between virtual water and inter-basin diversion. Wang et al. (2008) studied the relationship between regional agricultural production and consumption and found that the virtual water trade can play an important role in changing the uneven spatial distribution pattern of water resource in China. From the perspective of economy and law, Xiao and Jia, (2007) considered that regional virtual water trade in China is feasible and necessary. Zhou and Shi (2009) research showed that regional virtual water trade in China can solve the district water resource shortage, and proposed that China should implement regional virtual water trade strategy in order to ease the water resource shortage of the Northwest, North of China and other regions, as well as problems of water pollution. Some other researchers even put forward corresponding countermeasure for regional virtual water trade in China (Wang, 2008; Xiao and Jia, 2007; Shi et al., 2009). There are only qualitative or rough analysis about virtual water trade situation in previous researches, and quantitative analysis of virtual water trade is not so much concrete and detailed analysis of the effect on the national food safety and water resources utilization is still less.

Based on grain production and consumption, the aim of

this paper was to analyze the volume quantitatively and direction of virtual water flow due to regional grain trade in China. It also associates current situation of grain production and virtual water flow to national water resources utilization ratio and efficiency. The deeper meaning of this paper is to evaluate regional possession and consumption situation of the water resources and seek some effective ways for solving the agricultural water issues of China.

MATERIALS AND METHODS

There are 31 provinces (municipalities, autonomous regions) in the mainland of China, 16 in South of China and 15 in North. In this study, the mainland of China was divided to eight regions according to the geographical, agriculture and climatic conditions of every province (municipality, autonomous region). We grouped Shanghai, Zhejiang and Fujian into Southeast region (SE), Jiangsu, Hunan, Hubei and Jiangxi into Middle-Lower Yangtze Region (MLY), Guangdong, Guangxi and Hainan into South China (SC), Sichuan, Chongqing, Yunnan, Guizhou and Tibet (Xizang) into Southwest Region (SW), Beijing, Tianjin and Shanxi into North China (NC), Inner Mongolian (Neimenggu), Heilongjiang, Liaoning and Jilin into Northeast Region (NE), Henan, Hebei, Shandong and Anhui into Huang-Huai-Hai Region (HHH), and Shaanxi, Gansu, Ningxia, Xinjiang into Northwest Region (NW). The intuitive zone chart is expressed in Figure 1; Hong Kong, Macao and Taiwan were not considered in this study.

The data of population and grain production in 31 provinces (municipalities, autonomous regions) were from the "China Statistical Yearbook". The date of crop virtual water content of the three general grains (cereals, legumes and tubers) in every province were from Zhang (2009). Crop virtual water content of all the provinces were based on the results calculated through the model; the regional virtual water content of grain from wheat and virtual water content of rice and maize were weighed by production (Table 1).

The "China Agricultural Statistics Yearbook" shows that the grain export trade in 2008 was: import, 43000 tons of wheat, 50000 tons of maize and 37.44 million tons of soybeans; export, 0.97 million tons of rice and 3.05 million tons of potato crops. Rice, wheat and maize have regional differences in consumption, so we considered the three types of crop as cereal. Because the amount of grain import was very small, we classified the wheat and maize to the NC region that required consumption but with the lowest production. The export of rice and potato crops directly comes from the MLY and SW region, in which the production account for 40.10 and 35.89% respectively. The main destinations for the soybeans are soybean oil and various soy products, so we did not think there are regional consumption differences. We distributed the soybean imports according to the proportion of population.

Because the specific data is difficult to obtain, there is an assumption that per capita grain consumption in China is same in this study. This assumption is reasonable according to the "China Statistical Yearbook". Through the analysis of the statistics, we got the per capita "direct" consumption of grain (as staple food) by rural residents and per capita cost for staple food by urban residents in every regions of China during 2008. Considering the average price of grain and the urban population proportion, we calculated the per capita "direct" consumption of grain in the eight regions in 2008. The "direct" consumption of grain by residents in every regions of China in 2008 was around 180 kg (Table 2).

Based on the assumption that per capita grain consumption is same, at the same time, considering the figure of grain production

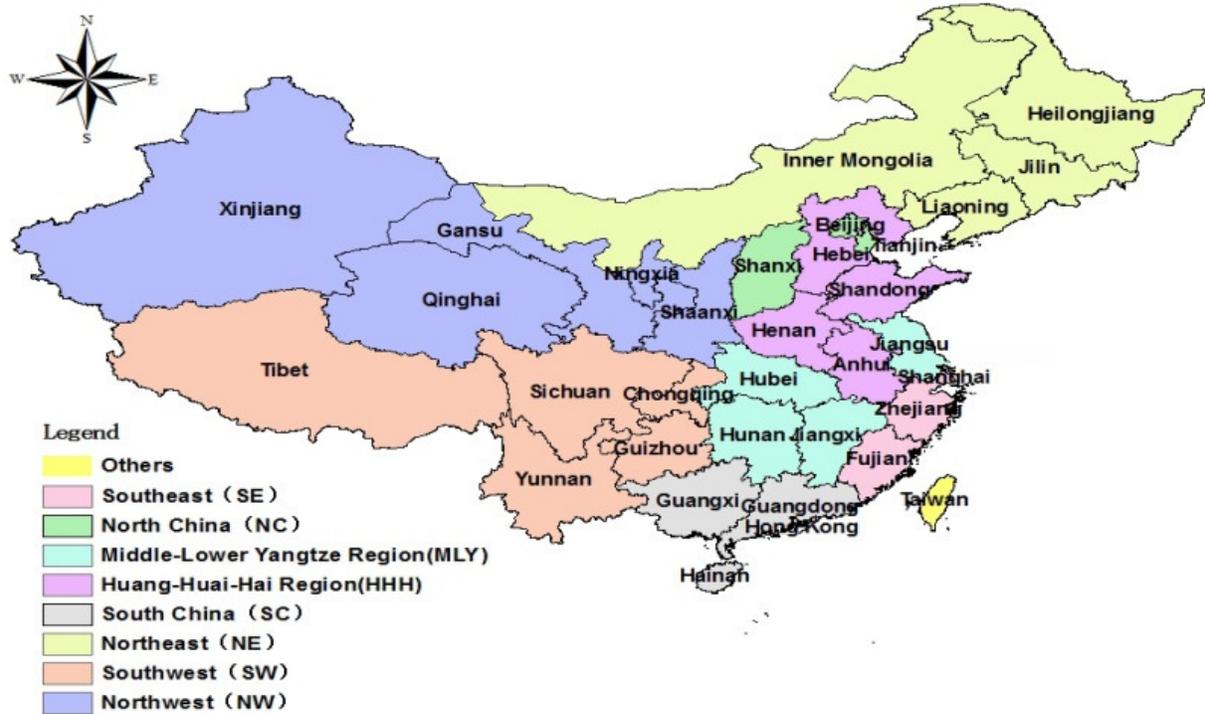


Figure 1. Regional delimitation.

Table 1. Average virtual water content of grains (m³/kg). Period: 1997-2006.

Region	Cereal (wheat, rice, maize)	Legume	Tuber
South of China			
Southeast Region (SE)	1.32	1.99	0.96
Middle-Lower Yangtze Region (MLY)	1.25	2.01	1.04
South China (SC)	1.6	2.72	1.27
Southwest Region (SW)	1.25	2.6	1.43
North of China			
North China (NC)	1.03	3.9	2.41
Northeast Region (NE)	0.89	2.71	1.52
Huang-Huai-Hai Region (HHH)	1.09	3.14	0.9
Northwest Region (NW)	1.13	2.98	1.57

after import and export, we could conclude the regional food self-sufficiency situation. After that, we calculated the amount of export in grain rich region and import in grain deficient region. Combined with virtual water trade theory, we calculated the virtual water discrepancy condition due to the regional grain transfer. We calculated as follows:

$$R_{ij} = G_{ij} - P_j \times \frac{G_i}{P} \tag{1}$$

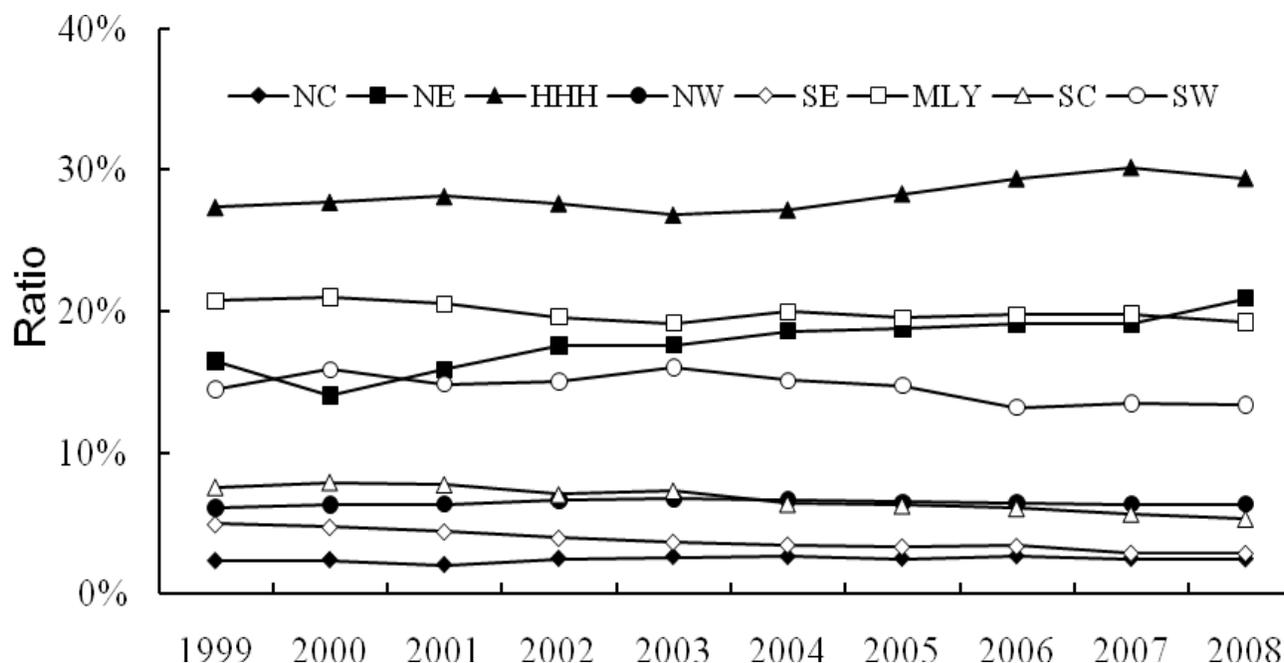
$$VW_{ij} = V_i \times R_{ij} \tag{2}$$

$$W_s = \sum (V_i' \times R_{ij} - VW_{ij}) \tag{3}$$

Where, R_{ij} is the grain transfer amount of the grain i in region j , $R_{ij} > 0$ means export in opposite, $R_{ij} < 0$ means import. G_i , G_{ij} are the national grain production of grain i and the production of i in region j , respectively ($i = 1, 2, 3$, stands for cereals, soybean and potato crops respectively). In order to describe the production differences and transfer characteristics of various grains, we treated three types of grain crops separately; P , P_j are the population of nation and the region j ; V_i , V_i' are virtual water content per unit mass of the grain i in export and import regions respectively; VW_{ij} is the virtual water trade amount of region j because of the transfer of grain i , with the same sign and direction of R_{ij} ; W_s is the domestic

Table 2. Status of “direct” consumption of grain (as staple food) in 2008.

Region	Coat for staple food by urban residents (¥, Yuan/capita)	Staple food consumption by Rural residents (Kg/capita)	Per capita staple food consumption (Kg)
Southeast(SE)	343.6	179.2	174.7
Middle-Lower Yangtze Region(MLY)	328.3	214.4	191.0
South China(SC)	340.1	192.8	180.4
Southwest(SW)	322.2	186.8	177.4
North China(NC)	351.0	173.6	174.8
Northeast(NE)	329.4	183.6	173.1
Huang-Huai-Hai Region (HHH)	300.6	208.0	184.0
Northwest(NW)	323.6	216.8	195.3

**Figure 2.** Accounted national grain yield ratio by every regions during 1999 to 2008.

inter-regional saving or waste water amount due to the virtual water trade.

RESULTS

The regional grain production status

The grain production shows an upward trend over the years. The total productions were over 50 million tons in 2007 and 2008, standing at 50.16 and 52.87 million respectively. The NE, HHH and MLY regions were the major grain production and output areas, and the total output of the three regions accounted for 60% of the total

production in China. Figure 2 shows the proportion of grain production in the eight regions of the total production in China in the ten recent years. The grain production in HHH was the largest, more than 1/4 of the total production, and the proportion were above 26%, peaking at 30% in three recent years; the production in the NE and MLY was just below that in HHH, they all constituted approximately 20% of the total production. The percentage in NE showed obvious upward trend, reaching 16% in 1999 and 21% in 2008; limited by the cultivated area and industry structure, the production in NC, SE, SC and NW were slightly small, the percentages were below 8% and the production in NC was the smallest; 2.47% only. Besides, the production in NC, SE,

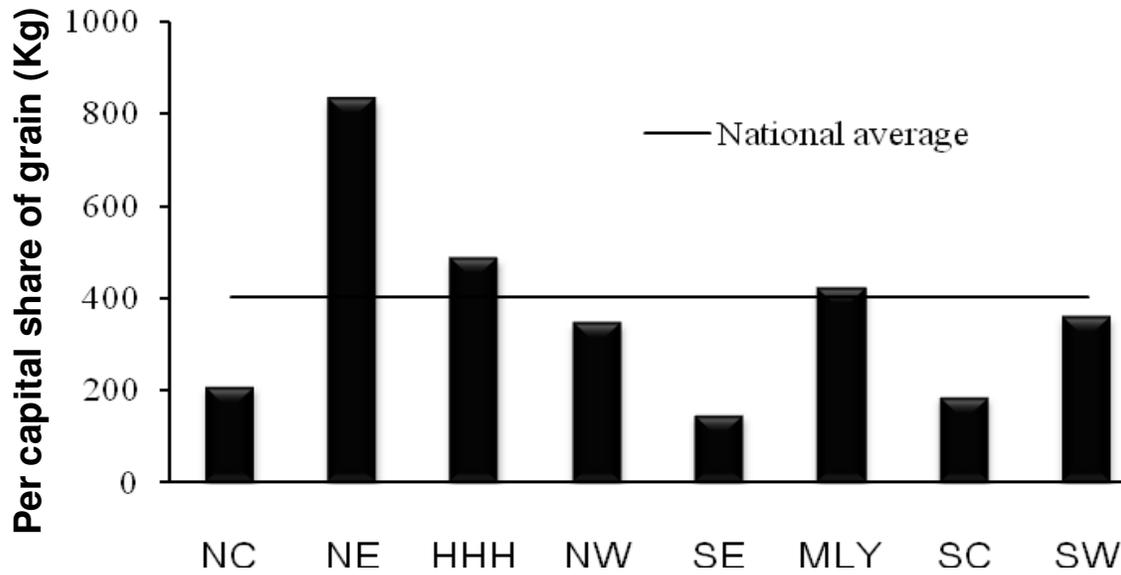


Figure 3. Per capita share of grain of the eight regions and the nation in 2008.

and SC showed a downward trend; SW was the richest area of water resources in China, but is limited by the cultivated area and the spatial and temporal distribution of rainfall, so the grain production was not especially high and the production was only 14.62%.

The pattern of national grain production and demand is not only related to the regional grain production. Per capita share of grain is an index which can reflect the food abundant extent directly. The relationship of grain production proportion in the different regions was the same as before, and the percentages in different regions changed slightly in the different years. Taking year 2008 for example, we researched per capita share of grain in different regions to describe the regional differences of grain production (Figure 3).

Per capita share of grain in China was 404.13 kg in 2008. From Figure 3, we can see that per capita share of grain in the different regions changed a lot: per capita share of grain in NE was the largest and was much larger than that in other regions, reaching 832.08 kg. The number was 2.06 times of the national values; per capita share of grain in HHH and MLY were also higher than the national value; 486.55 and 420.63 kg respectively. Per capita share of grain in NW and SW were 346.75 and 360.46 respectively, and they needed a small amount of grain imports so as to reach the national average. Per capita share of grain in NC and SC were about 200 kg; compared with the demand, there was a big gap. The per capita share of grain in SE was the smallest, which had relatively developed economy, big population density, abundant rainfall, but minimum of cultivated land resources. It was only 1/3 of the national value and 1/6 of the value in NE.

The grain and virtual water allocation and transportation

In the premise that the amount of the national per capita grain consumption is equal, the differences in per capita share of grain will lead to allocation and transportation between regions. We got the situation of the grain (Table 3) in various regions using formula (1) on the basis of considering the import and output of the grain. NE was the largest grain output region in China, including 48 million tons of cereals, 4 million tons of legumes and 5 million tons of potato crops, besides, NE was the only one legumes self-efficiency region in China; HHH and MLY were the major grain producing regions, they were rich in cereals, but they need to import lots of legumes and potato crops; it had advantages in producing potato crops in SW and NW, while there were gaps in producing cereals and legumes, and the gap was close to 15 million and 7 million tons; because of the relationship between crop production area and economic structure, the three types of grain in NC, SE and SC needed comprehensive import, and the amount stand at 11.84 million, 26.44 million and 31.56 million tons. They were 0.91, 1.71 and 1.12 times of the grain production (13.02, 15.43 and 28.22 million respectively).

The overall pattern of grain allocation and transportation is "transfer the grain from north to south". It is difficult for import regions to determine the import source due to the limitation of import and output in different regions. We draw up the principles of grain allocation and transportation on the basis of the principles of transport agricultural products between different regions researched by Ma et al. (2004). First of all, distribute the grain in the

Table 3. Grain surplus and short-comons for every region in 2008 (10⁴ton).

Region	Cereal	Legume	Tuber
Southeast (SE)	-2536	-40	-68
Middle-Lower Yangtze Region (MLY)	+847	-83	-208
South China (SC)	-3025	-60	-71
Southwest (SW)	-1478	-54	+364
North China (NC)	-1080	-23	-81
Northeast (NE)	+4887	+394	+56
Huang-Huai-Hai Region (HHH)	+3079	-105	-184
Northwest (NW)	-693	-30	+193

“+”represent the quantity of excess and “-” represent the quantity of shortage in the corresponding region.

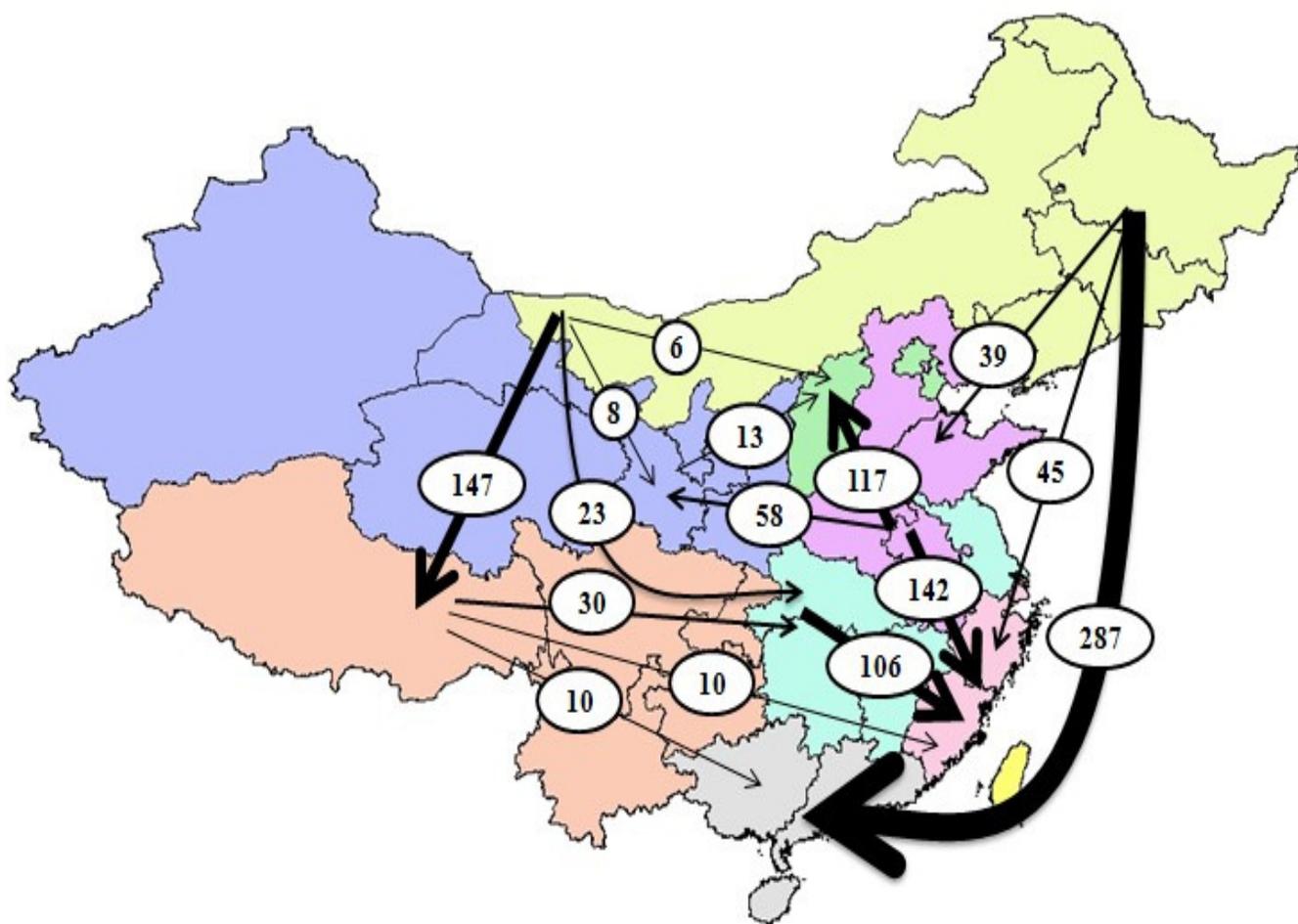


Figure 4. Virtual water flow among regions of China in 2008 (10⁸m³).

same region. The region that cannot be self-sufficient should import the corresponding type of grain, at the same time, the region that are rich in the grain should output the corresponding type of grain; considering the similarity of dietary habits, the priority of grain output should be given to neighboring regions, and the grain transportation to the regions that is far away should be

according to the gap; legumes and potato crops transport according to the gap directly. According to the principles of grain transportation, we calculated the regional situation of virtual water transfer though formula (2) and virtual water trade theory.

From the Figure 4 it can be seen that NE was the only region that had virtual water trade with other regions, and

it was completely under the status of virtual water output. It cost 55.5 billion m^3 water to produce grain for other regions in 2008, providing 28.7 billion and 14.7 billion m^3 for SC and SW respectively; the largest grain production region (HHH) had 31.7 billion m^3 virtual water output, but it needed 3.9 billion m^3 virtual water input due to the shortage of legumes and potato crops production; SW had 50 billion m^3 of virtual water output because of its richness in potato crops, the overall virtual water was import due to the large gap, and the figure of net import was 9.7 billion m^3 although legumes and potato crops in MLY had deficit, it was rich in cereals. It was the only region that had a net output of virtual water in south China, and the amount of virtual water was 5.3 billion m^3 ; NE is in the arid and semi-arid region, had the smallest virtual water trade, and the overall virtual water shows import with the figure arriving at 5.3 billion m^3 ; with the large scale of grain importation, virtual water trade in NC, SC and SE showed net imports in 2008. The amount of virtual water importation in NC was 13.6 billion m^3 , and the values in SC and SE were 30 billion m^3 .

Virtual water trade and utilization of water resources

The agricultural production in different regions cannot be self-sufficient independently because of the population, resource endowments, industrial structure and many other factors; this occurs when agricultural products are traded in the regions. Virtual water trade plays an important role in reducing the differences in regional resource types and endowment. Carrying out the virtual water trade strategy can reduce the water stress in the water scarcity areas through importation of agricultural production especially grain, and ensuring the grain and water security in this region, which is the target of international virtual water trade.

International virtual water trade has been proven to save water resources (Yang et al., 2006), thus virtual water trade between regions in a nation may have similar effects. There are differences in regional water use efficiency. Grain transportation not only save water resources of import regions directly, but also affect the water use efficiency all over the nation. If the crop water use efficiency in the output region is high, that is to say, requiring less water to produce the same weight of grain, it illustrates that the regional crop water use efficiency suit the comparative advantage, therefore, it will save a considerable amount of water for the country compared with the imported region.

Table 1 shows that the amounts of grain virtual water in import and output regions were different; the crop water use efficiency was high in cereals output regions NE and HHH; the virtual water in cereals was only 0.89 and 1.09 m^3/kg respectively, which was under the value of other regions except NC. The cereals virtual water in MLY was 1.25 m^3/kg which was the smallest in the four southern

regions as same as SW, but the excess cereals (mainly rice) in MLY would be transferred to the other parts of the South where had similar diet structure. The cereals in SW and SC were 1.32 and 1.60 m^3/kg respectively, and the legumes virtual water in NC and HHH was over 3.0 m^3/kg . The situation of potato crop was special, as the amount of virtual water in SW, NW and NE were just below the value in NC (2.41 m^3/kg), but over the other regions. Cereals are the main grain in China, and its transportation represented 90% in the grain regional transfer. So, the sizes of virtual water content in cereals provided the foundation for saving water resources in China. We got the regional grain virtual water trade in 2008 using formula (3), which saved as much as 30.5 billion m^3 water for the country. The figure was 34.4% of the sum of the virtual water values of three regions, which made a contribution to the allocation of the stress of national water resources indirectly.

The virtual water trade can affect the water resource import region, at the same time it also related to the water resources and economic situation in the water output region. Resource endowment theory (Ohlin, 1935) shows that a country output its comparative advantage product in the international trade. In the same way, the water-rich region should output intensive products to suit the local development in the virtual water trade. The difference of water resource distribution is large, and we can measure a region's level use per capita possession of water. When the net national virtual water trade in 2008 was compared with per capita possession of water resources, we found that SW, SC, NW and SE whose per capita water resources were the top four needed virtual water import due to the grain scarcity; SW was the richest region of water resources, and per capita possession of water resources was 5840 m^3 which was 2.7 times of national average value (2200 m^3). But in 2008, the region imported net 9.7 billion m^3 virtual water because of grain import; per capita possession of water resources in SE and SC were 2196 and 3337 m^3 respectively, and the import virtual water were 303 and 297 m^3 . These two regions are economic developed regions in China, due to the economic development and industrial structure changes; the proportion of agriculture is reducing. It lead to the grain cannot be self-sufficient, therefore, there was a large amount of virtual water import; HHH was one of the most serious water shortage regions, and per capita possession of water resources was only 550 m^3 . But this region transferred nearly 28 billion m^3 of net virtual water to the outside world in the form of grain supply in 2008, which greatly exceeded the agricultural water that the south to north transfer project, and brought more stress to the local water resources and environment; per capita possession of water resources in NE was 1570 m^3 , and it was just over the numbers in NC and HHH and below the average level. It was also under the "water stress" threshold of 1700 m^3/capita defined by Falkenmark and Withstand (1992). NE was a water shortage region, while

Table 4. Average virtual water content of wheat, maize, and rice for selected countries, in m³/kg.

Crop	Argentina	Australia	Canada	China*	Egypt	Germany	India	Netherlands	USA	Global average
Wheat	0.738	1.588	1.491	1.190	930	0.757	1.654	0.619	0.849	1.334
Maize	0.469	0.744	0.353	0.860	1.031	0.442	1.937	0.408	0.489	0.909
Rice	1.351	1.022		1.370	1.565		2.850		1.275	2.291

*Period: 1997-2006.

the output of the virtual water was large, so the problems of water resources in NC was not optimistic; per capita possession of water resources in MLY was 1800 m³, slightly higher than the threshold of 1700 m³. The current pattern of grain virtual water transfer not only leads to low water use efficiency in the wet zone, but also brings water stress to the virtual water output region, which can influence the national grain and water security.

DISCUSSION

The grain production differences between regions were large in the past ten years. Regional per capita water resources transfer existed as well as the virtual water transfer, and the patterns of grain and virtual water transfer were to the south from the north. In 2008, the net grain and virtual water transfer region were NE, HHH and MLY, and the amount of output virtual water were 55.5 billion, 27.8 and 5.3 billion m³ respectively. There were net grain inputs in SC, SE, NC, NW and SW regions. Because of large population density and relatively small cultivated land, SC, SE and NC regions imported cereals, legumes and potato crops, and the sum of import virtual water in the three regions was more than 70 billion m³.

The grain output in NE was 48.87 million tons, but the virtual water was the smallest in China; less than 0.9 m³/kg. The HHH region also outputted 30.79 million tons of grain, and the volume of virtual water was 1.09 m³/kg. When compared with import regions, this figure was just over 1.09 m³/kg in NC. The grain import in SE and SC were 25.36 and 30.25 million tons respectively, at the same time, the amount of virtual water in these two regions reached 1.32 and 1.60 m³/kg respectively, which were much higher than those in NE and HHH. Besides, they were also more than 1.25 m³/kg in MLY. The cereals accounted for 90% of the grain production, and the crop water use efficiency between the output and input regions suited the comparative advantage, so the regional virtual water trade saved 30.5 billion m³ for China in 2008. So the regional virtual water trade can make contribution to alleviate the stress of national water resources.

Regional virtual water and grain transfer make up the gap of the grain deficit regions, and have made a great contribution to alleviating the water pressure and ensuring national food security. However, the situation in China is that water and cultivated land are distributed in

south and north respectively, and there are 51% cultivated land in the north, but the water resources is only 20%. A per capita water resource in NE which was lack of water was less than 1700 m³, and the figure in HHH was only 550 m³. These regions belonged to the extremely dry land while per capita water resources in SE, SW and SC (they were the three largest regions that import virtual water) were over 2200 m³, and the figure arrived at 5840 m³ in SW. The fact that exists in China is that virtual water was transferred from water resource scarcity regions to the water resource abundant regions. This shows that the regional import and output of virtual water and water resources do not meet the resource endowments, and the pattern of grain production and the distribution are not suitable, which makes the regional grain production and transportation distribution unreasonable. This makes north region where there is lack of water face more severe water stress. The water use efficiency in the south is not so high where lots of water is wasted; this is not conducive to the grain and water security.

Trading virtual water through grain import is one of the measures to ensure the grain security and ease the water pressure. The average of global virtual water content of soybean is 1.789m³/kg (Hoekstra and Chapagain, 2008). China imported 37.44 million tons of soybean in 2008, that means importing 67 billion m³ water. In other words, the country saved 67 billion m³ water at the same time satisfying the grain demand, so, the effect of import grain on reducing domestic water resources utilization was obvious. However, there are many factors which can influence the foreign trade such as political limitation. Besides, expanded imports of grain may cause international grain market forces (Ma et al., 2006). It is unlikely to rely on importing. This is the reason why the government of China takes the food self-sufficiency policy. So, the effective measures that can satisfy the grain and water supply should be found.

China has large agricultural water consumption, and it accounted for 62.0% of the total water consumption in 2008 (not including the use of green water). Table 4 shows the virtual water content of three types of grain in China and eight other countries (Hoekstra and Chapagain, 2008). The figures in China were less than the global average value and the neighbor India which is also a developing country, and were almost the same with Egypt. Compared with developed countries, the

virtual water content of grain was higher in China. It needed less water to produce wheat, maize and rice in the USA, and per unit of water grain production of Netherlands and German was nearly twice as China. Crop water productivity gap with the developed countries shows that China has great potential for water-saving agriculture. We should do more to develop modern water-saving agriculture, reduce crop water requirements during the growth and ease local water pressure.

In addition, regional water transfer plays a visible role in redistributing water. The water from the region which is rich in water but cannot do large-scale agricultural production due to the limitation of cultivated land and the industrial structure should be transferred to the region that has potential to produce grain but is lack of water. In this way, we can meet the national grain demand and ensure grain security. In the world, many countries have done that: 'transfer water from North to South engineering' in California, whose annual transferred water is 50 billion m³ and 30% of those used for irrigation field, can provide more than 133 million square kilometers of farmland with irrigation water (David, 1998); Pakistan's 'transfer water from West to East engineering' has been implemented since 1960, whose annual transferred water reached 218 billion m³ in 1971 to 1978, and restored and developed irrigation area of more than 200 sqkm (Wei, 2001). The south-to-north water diversion project of China was constructed in 2002, whose transferred water is expected to be 448 million m³ in 2030, including 200 billion m³ for agriculture and ecological water requirement.

In conclusion, the government of China should seek the measures to ensure the grain security and regional water supply from both home and abroad, and developing the water-saving agriculture is the fundamental measure. International and regional virtual water trade and water transfer projects are effective measures to solve this problem.

ACKNOWLEDGEMENTS

This work is jointly supported by the Special Foundation of National Natural Science Foundation of China (50809055), National Science & Technology Supporting Plan (2011BAD29B09), '111' Project of Chinese Education Ministerium (111-2-16) and the Supporting Plan of Young Elites of Northwest A & F University.

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