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The potential role of virtual water in solving water scarcity and food security problems in China

Jingzhu Zhao, Wenhua Liu and Hongbing Deng

Key Laboratory of Systems Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing, China

Key words: Policy relevance, agriculture, food production, water resources, food imports

SUMMARY

Water, as a source of food security, plays an essential role in ensuring sustainable food resources for a growing population. However, water scarcity has increasingly become a constraint to economic development, particularly food production. The water-food challenge is impending because of China's increasing population and water demand. The concept of virtual water is useful to analyze this problem. In this paper, the implications and policy relevance of virtual water are expounded. Based on imported food volumes, it is calculated that an annual average of $10.52 \times 10^9 \text{ m}^3$ of virtual water embodied in imported wheat and maize in the period between 1990 and 2000 is equivalent to 23% of the annual average transfer water volume of the South-North Water Transfer (SNWT) project. Consequently, this $29.3 \times 10^6 \text{ ha}$ of virtual land is equivalent to 19% of China's arable land in 2000. Using the grain import prediction and the agricultural production conditions of China, the virtual water equivalents of China in 2010 and 2020 are evaluated, and are about $88 \times 10^9 \text{ m}^3$ in 2010 and $95 \times 10^9 \text{ m}^3$ in 2020, respectively. Importing virtual water embedded in traded food can alleviate water stress and even achieve food security. Virtual water trade may compensate for water demands for not only the past but also the future. Meanwhile, water trade can store water in its virtual water form, enabling food storage to play a potential role in solving food problems, as well as promoting sustainability of water resources in China.

INTRODUCTION

Water, as a source of food security, plays an essential role in ensuring sustainable food resources for a growing population. However, water scarcity is a common problem in many countries and regions. Because of the uneven distribution of water resources and population densities worldwide, water demand already exceeds water supply in nearly 80 countries that support more than 40% of

the world's population (Bennett 2000). Water scarcity has become an increasing constraint to their economic development, particularly food production – the biggest water user (Hong *et al.* 2002). Nonrenewable fossil water has been exploited to relieve the immediate pressure of water stress; this use has caused the depletion of resources and obstruction of future economic development and

Correspondence: Wenhua Liu, Key Laboratory of Systems Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, 18 Shuangqing Road, Haidian District, Beijing 100085, China. Email: Lwillow0531@yahoo.com.cn

food security. To combat water scarcity and increasing food production, many countries have made efforts to expand irrigation (Barker *et al.* 2001; Bouwer 2000; Postel 1999; Rosegrant *et al.* 1997; Wichelns 2001). Despite a tremendous effort, the coverage ratio of irrigation in most of these countries remains low, simply because of their scarce water resources. The growth of food production overall has lagged and has been unstable (FAO 2001). In contrast to food production, the growth of population and food demand has been rapid in China. Meeting the water-food challenge is difficult in China because of the increasing population and water demand. In order to relieve water stress, many investment projects in China are planned and have been carried out, in order to focus on changing the uneven distribution of water resources, and to fill the gap between water supply and demand. The role of virtual water through food trade as a solution to water scarcity is not recognised in China. Indeed, most researchers do not associate the international food trade with food security. However, they now advocate regional food trading as a solution to water stress in Northern China. These opinions are consistent with Chinese government policies of food security. The considerations of the Chinese government for food trade include domestic food security and social stability, the impact on rural employment when grain production remains the major provider of employment in rural areas, and the pressure of rural-urban migration and the social economic impacts on cities (Hong 2002).

WATER DEFICIT AND DEMAND

Water scarcity in agricultural production

The increasing demand for food needs two basic natural resources for its production, arable land and fresh water. Future food production depends on the availability of adequate and sustainable water resources. Agriculture is responsible for about 70% of all freshwater withdrawn, and it is expected that more water will be used for irrigation as world food production increases. An FAO study of 93 developing countries indicates that some water-scarce nations are already withdrawing water supplies faster than they can be renewed (FAO 2004). Over the years, China has maintained a population increase of 1.4% and an increase in economic development of 9% per year through

using a great deal of water with low efficiency. However, agricultural irrigation is constrained by water scarcity and pollution, with 70% of food output produced on irrigated land, and 73% of the total available water used for irrigation. Furthermore, agriculture is in fierce competition with industry, municipal, living and environment water uses. Actually, in China, agriculture competition for water is below industrial and domestic demands (Hong 1999) because the direct economic output of agricultural production is rather low.

In China, every 10^4 m^3 of water feeds 4.46 persons. North China, Inner Mongolia, Hebei, Beijing, Tianjin, Shanxi, Henan and Shandong, seven provinces, use about $168.5 \times 10^9 \text{ m}^3$, which only can feed 75×10^6 persons, i.e. 23% of the total population. The demand for food by the population is met by food produced in Southern China, where farmland is scarce although water resources are relatively sufficient. Present resources meet the demand for food by the large population. Indeed, the requirement for freshwater resources is four times higher than what is normally available. The required capacity for freshwater resources is the lowest of all the resources estimated (Qu 1992).

At the national level, it is estimated that there may be enough water available, but some regions will face serious water shortages, with inefficient use and serious pollution. In northern areas, water scarcity and water pollution are serious while floods and water pollution are the main problems in southern areas. 95% of available water resources in the north have been exploited, while 6% of water resources have been used in the south. Table 1 shows that water consumption in agriculture increased in North China where land is not a limiting factor for food production. Because water use efficiency is on average 0.4–0.5, irrigation water in the north is 7.5×10^3 – $12 \times 10^3 \text{ m}^3/\text{ha}$, or 2–5 times higher than actual crop water demand (Liu 2000). The management of water use is expected to improve for avoiding water waste and enhancing irrigation capacity.

Water scarcity in the north has resulted in higher opportunity cost than that in the south. The huge investment in the South-North Water Transfer Project also supports this viewpoint. For water-scarce China, water use efficiency is much lower than that of developed countries. With the rapid population growth, water stress is becoming a formidable challenge. Meanwhile, when water resource load

capacity reaches the limit, direct cost of enlargement of food production will quickly increase and result in native food price rises. The most plausible result is that the cost of water for agriculture becomes much higher because of competition between sectors.

Future water demand of agriculture

Agricultural water consumption is the principal source of total water consumption, and is increasing with growing food demand. Irrigated area has increased, but total irrigation water quantity and withdrawal do not balance. This is due to irrigation efficiency enhancement and new irrigation technology improvements. Total water consumption has increased with unchanged available agricultural water quantity. The increasing water demands of economic development and domestic needs make additional water for agriculture more difficult to find, especially in North China. The large acreage of crop production in this area indicates a large irrigation requirement. The planted acreages

of various crops in seven different provinces with a deficit in water demand for irrigation are shown in Table 2.

Because different crops have different irrigation water demands and different arable land acreages in North China (Qian *et al.* 2001), total irrigation water demand is $48.55 \times 10^9 \text{ m}^3$; $5.00 \times 10^9 \text{ m}^3$ for rice, $26.53 \times 10^9 \text{ m}^3$ for wheat and $17.02 \times 10^9 \text{ m}^3$ for maize. Actual irrigation efficiency in agriculture is quite low (0.4–0.5), thus, actual water demand required to support production in North China is about 97.1×10^9 tonnes. The ratio for agriculture water use accounts for about 57.63% of total water resources in North China, which irrigated only 53.12% of its total ploughed acreage. The remainder of the ploughed acreage irrigation demand, as well as other sectors' demands, intensifies water stress, influencing economic development and agricultural production. A water transfer project was selected to alleviate water pressure in North China, but in the view of the economic cost, virtual water trade through food trade may be a better solution for water deficits.

Table 1 Irrigated acreages and irrigation water volumes in typical years in China

Year	Irrigated acreage (10 ⁶ ha)	Irrigation water (10 ⁹ m ³)	Irrigation water in total water use volume (%)	population (10 ⁶)	farmland acreage (10 ⁶ ha)	Total foodstuff output (10 ⁹ kg)
1949	16.00	95.6	92.0	540	97.87	113.2
1957	25.00	185.3	90.0	646	111.80	195.0
1965	32.07	235.0	85.0	725	103.60	194.5
1980	48.87	357.4	80.5	987	99.33	320.6
1988	47.93	387.4	– ¹	1096	95.73	394.1
1993	49.73	344.0	66.5	1185	95.07	456.5
1997	51.27	359.8	70.4	1236	95.00	494.2
2000	53.80	378.4	68.8	1294	108.47	4622

1: number is not available.

Table 2 Crop production acreage of North China in 2000/10⁶ ha

Province	Total crop acreage	Cereal acreage	Cereals	Rice	Wheat	Maize
Beijing	0.46	0.31	0.28	0.02	0.12	0.14
Tianjin	0.53	0.35	0.30	0.02	0.12	0.13
Hebei	9.02	6.92	5.88	0.14	2.68	2.48
Shanxi	4.04	3.19	2.33	0.01	0.89	0.79
Inner Mongolia	5.91	4.44	2.65	0.12	0.62	1.30
Shandong	11.15	7.36	6.44	0.18	3.75	2.41
Henan	13.14	9.03	7.74	0.46	4.92	2.20
Total	44.26	31.59	25.61	0.95	13.10	9.45

Data source: 2001 statistics yearbook

FOOD DEMAND

Population growth

The population in China is about 1.3 billion and has been increasing. Expansion of population influences every aspect of social development. Insufficient natural (fresh water, land, forest, etc.) and productive resources (e.g. food) originate from population growth. Finite resources cannot support the huge demand of the growing population. Resources allocation ratios are very small. These problems interlace and restrict economic development and social advancement. At the same time, potential risks are concealed in the problems. The population control policy, which confines the number of children in a family, cannot restrict overall growth in the short term because the growth is based on an existing huge population (Figure 1). It is predicted that population growth will be negative in 2050 (Kang 1998). The most important problem is that China must have enough food for the population, whether from food production or imports. Freshwater resource scarcity and uneven

distribution strain food production, resulting in an increasing portion of domestic food supply coming from imports. Such imports, in essence, have substituted for the water that would otherwise be needed for producing the food locally. Studies of virtual water and food security in Mediterranean and Africa countries have shown that water scarcity in these countries resulted in food insecurity. China has the same food issues, and uneven distribution of water and land resources has resulted in food supply scarcity. Furthermore, there is rising competition between water needed for agriculture and water for domestic use in burgeoning cities and ever-expanding industrial developments. Consequently, today the world must act wisely to conserve, preserve and improve its water supplies (FAO 2004).

Food demand

Food demand is a function of the size of population and consumption per capita. Rapid population growth will inevitably drive up future food demand, while per capita food consumption is likely to increase as income rises, adding an extra demand for food (Hong *et al.* 2002). The growth in population and foodstuff demand per capita have jointly promoted the growth of total foodstuff demand in China (Kang 1998). Foodstuff demand requires that food supply increases concomitantly. However, expansion of food production is limited by farmland and water resources; thus, the pathways of food supply enlargement are expected to change (Table 3; Kang 1998; Yan and Chen 2001). Increasing output and food import is required to solve food scarcity, together with water resources, to meet the food demand of the population. Water resources and food trade are complex issues for society.

Figure 1 Population growth in China, 1978 to 2001

Table 3 China's food output, demand and import predictions, 2000–2030/10⁶ t

Year	Total cereal demand	Total foodstuff demand	Total cereal output	Total foodstuff output	Cereal import demand	Foodstuff import demand	Dependence %
2000	446	489	432	455	32	34	7.0
2010	509	536	429	452	80	84	15.7
2020	536	564	449	473	87	91	16.1
2030	557	586	583	614	−26 ¹	−28	−4.8

¹Exports exceed imports, so the numbers are negative.

CROP PRODUCTION AND FOOD IMPORTS

Crop production and food consumption

Cereal production in China provides the basic energy requirement directly as food and indirectly as feed for animals that are used for human consumption. The increase of grain production, including rice, wheat and maize, has been rapid since 1980 (Figure 2). The trend in grain production up to the end of the 1990s was smooth, with only small increases from 1991 to 2000 because land productivity is approaching the limit, and no new productive technology has been created to promote increasing food production. The production of cereals, cotton, oil and sugar was either unchanged or declined, while the production of fisheries and livestock products has rapidly increased (Table 4).

Before 1997 most cereal production was consumed domestically, typically rice, since then, the diet has changed and more non-cereal products are being consumed. With increasing income, meat,

egg and milk demand has increased while cereal consumption has decreased. In contrast to decreasing direct cereal consumption, meat consumption has resulted in indirect cereal consumption by livestock. At present, according to the current GDP per capita, China is positioned by the World Bank in the low-middle income category. However, because of rapid economic development, per capita dietary structure (Table 5) indicates that life quality change is one of the most important variables that influences consumption.

Food trade in the past two decades

Food imports in China have fluctuated, especially wheat imports. This import demand is decided by domestic production capacity, and is a way to ensure food supply. Production technologies, especially water saving technology and multiple crop index improvement, have promoted the productivity of wheat in China. However, the increase in food production is still limited by water and land resources. Although irrigation efficiency has generally improved, insufficient water resources are allocated to agriculture. Food products imported into China from 1980 to 2000 were mainly in the form of wheat and maize. Net import volume has decreased

Figure 2 Changes in production of main agricultural products, 1980–2000

Table 5 Per capita food quotient structures, 1980 to 2001 per kg

Year	1980	1985	1990	1995	2000	2001
Cereals	326.7	360.7	393.1	378.4	366.1	355.9
Animal products	– ¹	–	–	–	38.3	39.5
Fishery products	4.6	6.7	10.9	19.3	33.9	34.4
Milk	1.2	2.4	3.7	4.6	6.6	8.1

¹Data are missing

Table 4 Agricultural production situations, 1991 to 2000 per kg

Year	Cereals	Cotton	Oil products	Sugar products	Livestock products	Fishery products
1991	378.3	4.9	14.2	73.2		11.7
1992	380	3.9	14.1	75.6		13.4
1993	387.4	3.2	15.3	64.7		15.5
1994	373.5	3.6	16.7	61.3		17.9
1995	378.4	3.8	17.6	63.4		19.3
1996	414.1	3.5	18.2	68.7	30.3	23.1
1997	401.7	3.7	17.5	76.3	33.2	29.3
1998	412.4	3.6	18.6	78.8	37.0	31.4
1999	405.5	3.1	20.7	66.5	38.0	32.9
2000	366.1	3.5	23.4	60.5	38.3	33.9

gradually (Figure 3) for wheat from 11.59×10^6 tonnes in 1995 to 0.88×10^6 tonnes in 2000, and for maize from 5.18×10^6 tonnes in 1995 to zero in 2000, because domestic supply has increased. However, in contrast to declining imports, the volume of export products has increased from 1980 to 2000 due to increasing production because of improved agricultural technologies. Growing export products include rice, cotton, pork and fishery products (Figure 4, 5), in which rice export rose from 0.05×10^6 tonnes in 1995 to 3.75×10^6 tonnes in 1998 (Figure 4). Pork exports declined from 3.24×10^6 tonnes in 1982 to 1.96×10^6 tonnes in 1999 because of increased domestic demand.

With the limited potential for additional water supply, the pursuit of water sources for the improvement of water use efficiency has shifted to high-value crops. Vegetables and fruits are typically encouraged in China as economic agricultural products and as a way of raising rural incomes. The exports of vegetables and fruit increased from 1980–2000 (Figure 6). This shift has produced high economic returns and made possible more selections of imports for the alleviation of the intensification of water stress.

ANALYSIS OF THE ROLE OF VIRTUAL WATER

Virtual water implications

Allan defined 'virtual water' as the water embodied in food crops that are traded internationally (Allan 1996a,b, 1998). Allan (1997) termed such food imports as 'virtual imports' due to the fact that they are equivalent to a transfer of water to the importing countries. The concept is used to describe a water-scarce nation's opportunities for achieving food security by purchasing a portion of its food requirements in the international market. It compares the amount of water embodied in a crop that can be purchased internationally with the amount of water which would be required to produce that crop domestically (Wichelns 2001). Virtual water is a term that links water, food and trade (Allan 2003). As the metaphor of virtual water gained currency in the mid-1990s, economists at the World Bank started to use another term the 'water, food and trade nexus' (McCalla 1997). This combines agronomic, economic and political outlooks, with emphasis on water as the key factor of production.

Figure 3 Imports of wheat and maize, 1980–2000

Figure 4 Exports of rice and cotton, 1980–2000

Figure 5 Exports of pork and fishery products, 1980–2000

Figure 6 Exports of vegetable and fruit, 1980–2000

The agronomic component involves the opportunity cost of water, which may include production of alternative crops or use in municipal, industrial or recreational activities (Bouwer 2000; Wichelns 2001). The opportunity cost of water use, which is a key component of the ‘virtual water’ perspective, must be considered when seeking an efficient allocation of scarce water resources. The same concept applies to the water embodied in other productive activities, such as manufacturing and power generation. Some manufactured goods require a greater amount of water in the production process than other goods. Nations in which water is particularly scarce may gain by importing water-intensive manufactured goods, while exporting goods that require less water in production. Similarly, nations with limited freshwater resources may gain by generating electricity in coastal areas, using ocean water for cooling, or by importing electricity from countries with abundant hydroelectric resources (Bouwer 2000, 2003).

Policy relevance of virtual water

Food trade plays an important role in redistributing the water resources of the world. The role of food imports in compensating water scarcity is elaborated with a quantitative accounting of the volume of virtual water embedded in their food imports. It is suggested that water be considered an economic good (Hoekstra *et al.* 2003a,b), and virtual water trade be seen as an instrument to achieve food security and efficient water use (Hofwegen *et al.*, 2003). However, when water policy issues are discussed, further implications of virtual water can be considered. Food imports are used when policy makers care about food security, while the feasibility of food imports is judged by opportunity cost. Wichelns (2003), however, thought that the optimal trading strategy could be determined by examining the comparative advantage, not the opportunity cost. This comparative advantage includes consideration of the water resource endowment and the production technologies in two or more countries that can engage in trade.

On the other side, virtual water has geopolitical implications. Trade induces dependence between countries, and it is influenced by and has

implications on tariffs. Indeed, the issue of virtual water is related to globalization, which raises concerns among many politicians and the general public. Increasing global trade implies increased interdependence of nations (Hofwegen *et al.* 2003). Geopolitical conditions in food trade are not ignored because food security, like water security, is a highly contentious issue that needs carefully examining in terms of the degree and method of food self-sufficiency. Domestic political power has decided traded objectives, volumes and formations (Kang 2000). Bouwer (2000) suggested that an OFEC (Organization of Food Exporting Countries) be established with international controls, and in which the importing countries are ensured that global distribution of food will not be used as a political weapon. This study emphasizes the potential role of virtual water trade on the solution to water resource scarcity and food security.

Virtual water equivalents in traded food

Food production is constrained by water scarcity; thus, importing food compensates for scarce water resources. Table 2 presents estimates of the volumes of virtual water embedded in traded wheat and maize in different years. Virtual land is also evaluated using imports divided by yields per hectare in the same year from the FAO statistics, where virtual water is the amount of imports multiplied by the global average of virtual water in every crop (Hoekstra and Hung 2003). On average, 8.9×10^6 tonnes of wheat and 0.9×10^6 tonnes of maize were imported annually between 1980 and 2000 (Table 6). An average of $10.20 \times 10^9 \text{ m}^3$ water and 27.7×10^6 ha of land would be required to produce this imported wheat, while an average of $0.32 \times 10^9 \text{ m}^3$ water and 1.6×10^6 ha land would be required to produce the imported maize. The sum of $10.52 \times 10^9 \text{ m}^3$ of virtual water is equivalent to 23% of the annual average transfer of water volume for the South-North Water Transfer (SNWT) project. From 1995 to 1999, net virtual water import volume of crops in China was calculated at $101.9 \times 10^9 \text{ m}^3$, and China became the fifth in the top-30 table of net virtual water countries (Hoekstra and Hung 2003). The sum of $29.3 \times 10^6 \text{ m}^3$ of virtual land is equivalent to 19% of crop arable land in 2000.

Table 6 Virtual water equivalent embedded in traded food

<i>Year</i>	<i>Domestic production/ 10⁶ t</i>	<i>Imports/ 10⁶ t</i>	<i>Virtual water/ 10⁹ m³</i>	<i>Virtual land/ 10⁶ hm</i>
Wheat				
1982	68.5	13.8	15.87	56.3
1983	81.4	11.1	12.78	39.7
1989	90.8	14.9	17.11	48.9
1995	102.2	11.6	13.33	32.7
1999	113.9	0.5	0.52	1.1
2000	99.6	0.9	1.01	2.4
Mean	96.8	8.9	10.20	27.7
Maize				
1982	60.7	1.6	0.71	4.8
1983	68.4	2.1	0.95	5.8
1989	78.9	0.1	0.32	0.2
1995	112.0	5.2	2.33	10.5
1999	128.1	0.1	0.03	0.1
2000	106.0	0.0	–	–
Mean	93.5	0.9	0.32	1.6

Sources: Statistics yearbook 2000, 2001

Water compensation through virtual water

Water resource scarcity constrains food production, and food supply cannot completely depend on the enlargement of food production. The basic food supply comes from food production and imports. Food import is appropriate when food price is lower than domestic production cost in the international market (Allan 1999). For virtual water embedded in the cereal imports, an aggregate ratio of 1 kg grain to 1 m³ of water is used. As such, the figures for cereal imports (Table 7) can be transformed into the same numeric volumes of virtual water in m³/per capita. Research shows that virtual water volume embodied in cereal is higher than the global average (Oki *et al.* 2003). This means that imports of virtual water in China should be greater than estimates in this study.

The factors that influence opportunity cost of production caused by the growth of irrigation water volume to enlarge the food supply have two aspects. One is the food supply capacity including food demand, food alternatives, food productive capacity and native import capacity. The native import capacity includes international food prices, native foreign trade conditions and international aid. The

Table 7 China's net food imports and virtual water equivalents for 2000–2030

<i>Year</i>	<i>Cereal imports (10⁶ t)</i>	<i>Foodstuff imports (10⁶ t)</i>	<i>Virtual water embedded in cereal (10⁹ m³)</i>	<i>Virtual water embedded in foodstuff (10⁹ m³)</i>
2000	32	34	32.0	36.0
2010	80	84	80.0	88.0
2020	86	91	86.0	96.0
2030	–26 ¹	–28	/ ²	/

¹Exports exceed imports, so the numbers are negative
²There is no virtual water import because of negative net food import

other aspect is concerned with water resources, embodied in water use efficiency in agriculture, agriculture management, water resource volume, water pollution, wastewater treatment and reuse. Those limiting factors are complex and, when combined, the opportunity cost in different nations and regions are obviously different. The amount of agricultural produce derived from a certain amount of water is subject to a large number of variables. These include the geographic location of the region where crops are grown, the irrigation system used, the management of the irrigation system, soil types and climatic conditions (Turton *et al.* 2002).

Moving virtual water will be much cheaper than moving water itself (Bouwer 2003). Global movement of food from water-rich to water-poor countries should be just as feasible as moving petroleum products from oil-rich to oil-poor countries. Virtual water opportunities for saving local water resources include imports of electric power from areas with more abundant water for cooling of thermal power plants, or with dams for hydroelectric power production (Bouwer 2000). Currently, most researchers in China think food demand and supply in China are on firm ground (Wang 1999; Wang and Lang 2002; Cheng 2003; Kang 1998; Chen *et al.* 2001). Some agreed that the food import dependence ratio might be augmented to 20% (Wang *et al.* 2002), while others argued that food supply should be self-dependent to ensure food security and food trade between regions within China (Cheng 2003). Virtual water is useful to alleviate water scarcity pressure, but many governments are worried that over-dependence on other nations will result in a food crisis and social instability.

CONCLUSIONS

Importing virtual water embedded in traded food in China can be seen to alleviate water stress, and even achieve food security. Virtual water trade may compensate for water demands of not only the past but also the future. Meanwhile, the trade can store water in its virtual water form, especially by food storage, to play a potential role in solving food problems. However, policy considerations of domestic water and food security are needed to promote better understanding of the

measures that need to be taken to ensure their future supply.

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