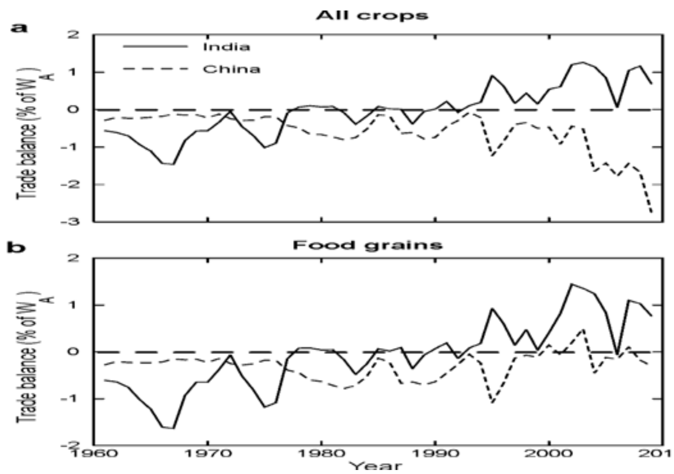
CSIR National Institute of Science, Technology and Development Studies (NISTADS)

Agricultural Trade with Virtual Water Trade Balance

A Policy Framework for Sustainable Agricultural Export

Summary for Policy Makers

Growing export of agricultural products also implies an associated export of water that is embedded in these products. For a sustainable system, it is critical that the trade balance in this virtual water is positive or zero. While this condition of positive trade balance is satisfied for China, India in the recent decades has a persistent negative trade balance in virtual (embedded) water that, if unchecked, can lead to permanent loss of water sustainability. The situation can be checked and reversed with a redesign of our food trade. A policy option, based on available data and the choice of products for export and import, is presented to avoid and reverse the situation. It is, of course, impractical to suggest that trade in agricultural products be reduced. However, such a drastic measure is not necessary. *For example, reduction in export of certain food grains, accompanied by enhanced import of pulses can change the balance*



*Trade balance (Export-Import) in terms of total water embedded in final products as percentage of water available for all crops (**a**) and food grains (**b**) for India (solid line) and China (dash line).*

School of Environment, Ecology and Sustainable Development (EESD)
NISTADS

Prashant Goswami and Shivnarayan Nishad

April, 2016

Prashant Goswami[1*], Shiv Narayan Nishad[2]

[1] CSIR National Institute of Science, Technology and Development Studies (NISTADS), Dr. K.S. Krishnan Marg New Delhi-110012

[2] Department of Mathematics, M. S. Ramaiah University of Applied Sciences, Peenya Campus, Peenya 4th Phase, Bengaluru, Karnataka, India-560058

List of Contents

1. **Executive Summary**
2. **Virtual Water Trade: Concepts and Definitions**
3. **Assessments of Virtual Water Trade: Global and Regional Analyses**
4. **Impact of Negative Trade Balance in Virtual Water: The Indian Story**
5. **Time Scales for Loss of Water Sustainability through Virtual Trade**
6. **A Policy for Water-Sustainable Agricultural Trade for India**
7. **Conclusion and perspective**

Appendix: Methodology and Data

Quoted and related references

1. Executive Summary

India today is a major food exporting country; however, trade of agricultural products also involves exchange of water embedded in the products; a precious primary resource for India. Assessment and policy design for sustainability in primary resources like water need to adopt long-term perspective; even small but persistent effects like net (virtual) export of water may influence sustainability through irreversible losses. With growing agricultural trade, this virtual water trade has become an important element in the water sustainability of a nation. We estimate and contrast the virtual (embedded) water trades of India and China, to present certain quantitative measures and time scales. Estimates show that export of embedded water alone can lead to loss of water sustainability.

The virtual water in our case refers to water embedded (water content) in the food or agricultural product either at the time of production or at the time of export. The focus of our work is on net export of water (embedded water) in agricultural products through trade, as the embedded water in exported/imported food goes outside the usage (production) cycle. The water used in production of crops (~1000 L/Kg), of course, is much larger than the content (~ 1 L/Kg); however, water used during a process is recoverable and recyclable. We have used multiple sources of data like Transport Information Services and Agricultural Research Service, United States Department of Agriculture.

The virtual export of water, especially in terms of water content in end products, implies certain time scales. For example, India's water availability is likely to equal its water demand around the year 2100; for China, the water availability is expected to remain more than 200 percent of the water demand even beyond 2200 and even for a per capita consumption of 650 kg/year.

Items with Major contributions to the Virtual Trade of Water

Sl. No	**Agricultural products**	**Average water content**	**Export of water**			**Import of water**			**Net export of water**		
			A	**M**	**C**	**A**	**M**	**C**	**A**	**M**	**C**
1	Food grains	11.66	4.48	21.2	14.5	4.2	17.83	2.96	0.28	3.37	11.54
2	Vegetables	89.27	0.13	0.57	0.46	0.0028	0.03	0.0033	0.128	0.54	0.456
5.	Pulses	11.52	0.32	2.5	0.65	1.19	6.95	4.79	-0.87	-4.45	-4.14
6.	Oil crops	12.79	1.6	9.6	5.78	0.23	1.41	0.23	1.37	8.2	5.5

This document presents an agricultural trade strategy so that the loss of water through virtual trade is minimized or reversed. The key consideration is the identification of items that are major contributors to the virtual trade (Table above); a selection of products is then possible to balance the trade. It is, of course, not practical to suggest a reduction in agricultural trade; however, such a step is not necessary for a remedial measure. *For example, reduction in export of certain food grains, accompanied by enhanced import of pulses can change the balance.*

2. Virtual Water Trade: Concept and Definitions

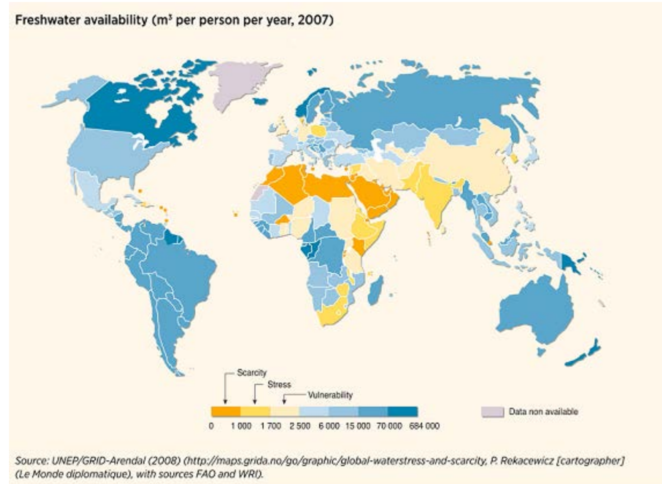


Figure 1: National water losses related to international trade of agricultural products for the period 1997-2001

Water availability, quality, management and distribution have emerged as critical issues at regional scales for populous countries like China and India[1]. Several studies have highlighted the challenges faced by both China and India in meeting their water demands[2-5]. In general, water sustainability has emerged as a major global concern[6-8], with uncertainties and added vulnerability due to climate change[9,10]. An emerging issue of growing importance and debate in the context of water and food sustainability is the virtual water trade[11, 12].

Virtual trade of water has become an important component of global fresh water demand and supply[13] and has resulted in globalization of water resource[14-17]. It has also become a medium of the global fresh water sharing[15-18]. It needs to be further emphasized that the demands of virtual trade of water also need to take into account the trade requirement of food, and hence the potential production[19-21].The role of virtual water in the overall resource management has been recognized early[21-23]. Several studies have emphasized the role of virtual water trade in globalization of water resource and in the overall food requirement. Several studies have emphasized the emerging but critical roles of network of virtual water trade in water management[21-23] and regional water systems[22].

While virtual water can provide a more integrated approach to water management[23], it can also affect regional food sustainability[24] and other processes[25]. Importance and impacts of virtual water trade on food and water sustainability have been discussed at the global[26, 27] as well as regional scale[28-30].

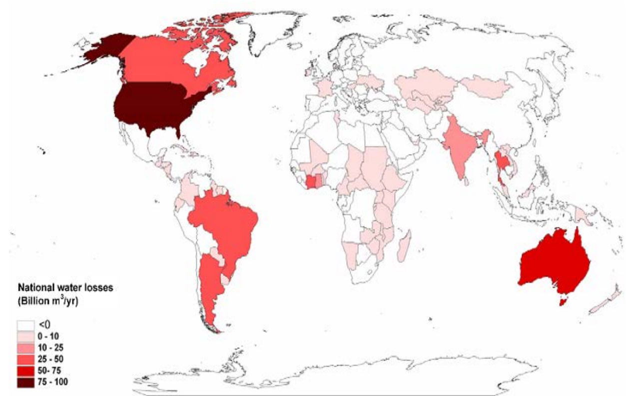


Figure 2 *Country-wise per capita fresh water availability for the year 2007.*

An index for water scarcity based on virtual water has been also proposed[25], highlighting the importance of water use efficiency; however, such an index is focused on usage and influence of virtual water and not on implications for water sustainability due to trade of virtual (embedded) water. Analysis of virtual water profiles at global and regional scales using input-output model for 112 nation-level regions revealed India, USA, and China as the world's leading virtual water consumers[16,17].

In terms of agriculture and food, virtual water can be defined both in terms of water required for the production, and as water content embedded in the end products[24, 27]. In production perspective, the volume of water used to produce an agricultural product is considered; this volume of water depends on the agricultural practices, water use efficiency, place and time of production[31,32]. Water footprint of a crop also strongly depends on local climate conditions; for example, water required for producing 1 kg of a crop in an arid region is two or three times more than that in a humid region[31,32]. Thus assessment of water sustainability in terms of agricultural production needs to adopt a regional perspective. The issue of virtual water is a particularly important concept for water scarce countries[19-28] with large demands. India and China are the two most populous countries with limited arable land[33] and fresh water resources. Similarly, fresh water resources of India and China are, respectively, 3.83 percent and 6 percent of the world's fresh water resources[34]. A large fraction of the total annual rainfall is precipitated in the monsoon season from June to September in India and China; thus decrease in monsoon rainfall can also strongly impact water availability[35].

It is, however, important to elaborate the usage of the term virtual water in our study. The water content available in the crop is defined as the water content embedded in the crop at the time of trade as percentage of weight of the crop, which differs from the virtual water content or water footprint of the crop. For example, the amount of water content in cereals at the time of trade is around 9-15% of its weight while in the vegetables and fruits it is around 70-96 per cent of their weight. Therefore, analysis of water content embedded in the end-products is not negligible. While several approaches and frameworks for assessing virtual water are available, an important but less explored question is the long-term effect of export of embedded water through water content in exported food. A comparative and quantitative analysis of virtual (embedded) water trade and its effects, combining constraints due to limits on primary resource (arable land), can provide significant insights into the dynamics and the implications on water sustainability. The main objective of the present study is an assessment and analysis of the dynamics of virtual (embedded) water trade for India and China. A primary focus is the implications, and time scales, for loss of water sustainability through export of virtual (embedded) water alone. While computing virtual water export, we have considered primary crop products only.

The primary parameter is the net water exported (embedded water) through trade, as the embedded water in exported/imported food goes outside the usage (production) cycle. The water used in production of crops, of course (~1000 L/Kg) is much larger than the content (~ 1 L/Kg); however, water used during a process is recoverable and recyclable. Thus the virtual water in our case refers to water embedded (water content) in the food or agricultural product either at the time of production or at the time of export. However, we shall also consider water used in production and overall water demand to compare the embedded water. The water content in the end products of the agricultural commodities has been taken from Transport Information Services[36] and Agricultural Research Service, United States Department of Agriculture[37].

3. Assessments of Virtual Water Trade: Global and Regional Analyses

A comparison of water resource and water budget for India and China shows that while India receives about 50 percent more annual rainfall than China, the total water available for India is only about 67 percent of that of China. For India, the available water varies between 1600-2100x10^9 m^3 during 1960-

2010 (Fig. 3a); for China, the corresponding range is 2500-3600x10^9 m^3 (Fig. 3b). Both countries are characterized by declining trends in available and surplus; the per capita water availability for India has decreased from 4098 m^3/capita/year in 1961 to 1519 m^3/capita/year in 2010. Similar decline is also seen for China: from 4113 m^3/capita/year in 1961 to 2051 m^3/capita/year in 2010[28, 29], although the trend in water available for India (-0.18 percent) is much smaller than that for China (-0.3 percent) (Fig. 3). At the same time, India requires much larger amount (537x10^9 m^3) of water for production of its food grains than the corresponding requirement (537x10^9 m^3) for China; similar conclusion also holds for water requirement for all crops. As a result, the water required for production of food grains has reached almost the same level (~500x10^9 m^3) for both countries. Thus water sustainability for both India and China can be affected by virtual trade of water.

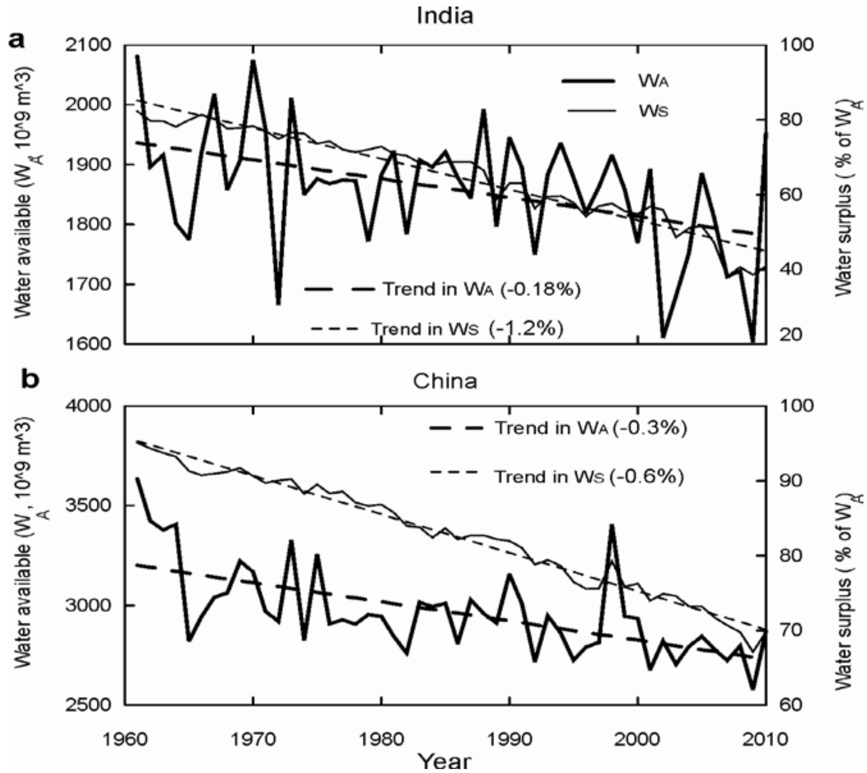


Fig. 3 *Water availability, W_A, (left y axis, thick solid line) and water surplus (W_S) (right y axis, thin line) for India (**a**) and China (**b**). The thick and thin dash line, respectively, represents the linear trend for water available and water surplus for the respective case. The coefficients of linear trend are given in the brackets as percentage of respective mean in the corresponding panel.*

4. Impact of Negative Trade Balance in Virtual Water: The Indian Story

From a negligible value until about 1990, India's virtual export of water for all crops has risen to about 1.5 percent of the available water (Fig. 4a), or about 2.5 percent of annual water involved in production (Fig. 4b). In terms of actual quantity, this export is about 30x10^9 m^3 for India; which is equivalent to the annual water demand of 33 million people (Fig. 4c). On the other hand, India's virtual water import was 7 percent of its total water involved in production during 1960-1970, which then fell to negligible values during 1980-2000 (the current value is 2 %). As percentage of water available, China has virtual import of water higher than its virtual export of water throughout the period 1960-2010 (Fig. 4d). In contrast, China has a virtual import of water (as percentage of water required for food production) nearly double of its virtual export, essentially throughout the period of 1960-2010 (Fig. 4e). Thus the ratio of export to import of virtual water has steadily grown for India, with some decline in the recent years (Fig. 4c, dash line); this ratio has been much less than 1 for China, with marked decline in the recent years (Fig. 4f, dash line).

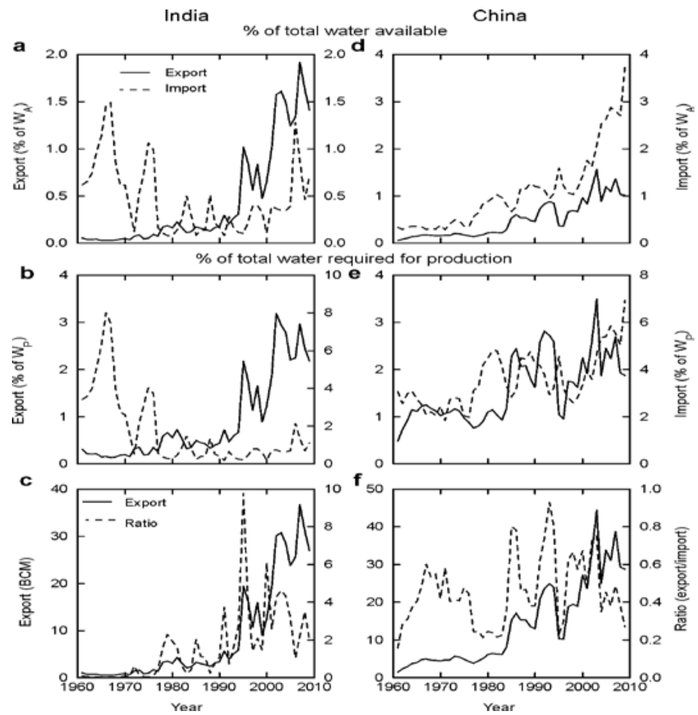


Fig. 4 *Export (left y axis, solid line) and import (right y axis, dash line) in terms of water involved in production for all crops*

a, d: As percentage of total water available for India (a) and China (d), respectively.

b, e: As percentage of total water required for production for all crops for India (b) and China (e), respectively.

c, f: *Export (10^9 m^3, left y axis) and ratio of export to the import (right y axis, dash line) for India (**c**) and China (**f**), respectively.*

In terms of virtual export only in food grains (Fig. 5), the pattern for India (Fig. 5a, 5b, 5c) is very similar to that for all crops (Fig. 4a, 4b, 4c). However, this pattern is very different for China, in particular, the import of water far exceeds export of water in terms of food grains (Fig. 5d, 5e, 5f).

India was strongly dependent on food import until about 1970; this is reflected in India's virtual water trade. From an import-intensive paradigm during 1960-1970, India has moved to an export-intensive regime in virtual water trade (Fig. 4); currently, India's water import for food grains is virtually nill (Fig. 5a, 5b, 5c). In contrast, China has maintained essentially an import-intensive virtual water trade since 1960, although the export-import ratio is close to 1 in the recent years (Fig. 4f). This shift in export of food has considerable impact on water sustainability.

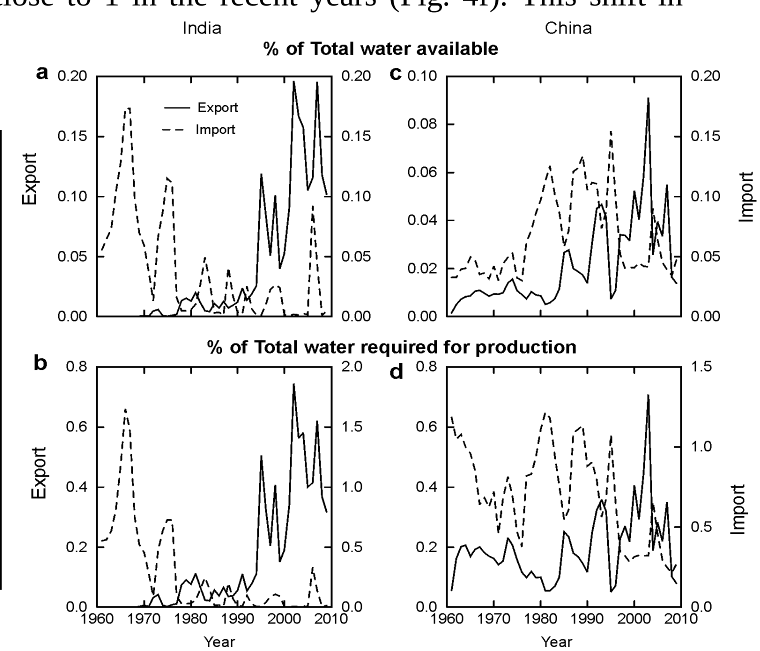


Fig. 5 *Export (left y axis, solid line) and import (right y axis, dash line) of total water export for food grains (W_{ET}) as percentage of total water availability (top panel) and total water requirement for production of crops (middle panel) for India and China. The bottom panel represents export (left y axis; solid line) in terms of actual quantity (10^9 m^3) and ratio of export-import (dash line, right y axis) for India and China.*

Considered in terms of water content available in food grains, India's current water export is much higher than its corresponding imports (Fig. 6a, 6b, dash line) for both scenarios as percentage of available water (Fig. 6a) and percentage of water required for production (Fig. 6b). The situation had been opposite for China until around 2000, since 2000, China's import of water nearly equals export in terms of water content (Fig. 6c, 6d). Thus, while India's trade balance in virtual water has turned positive in the recent years, China's has shown a dramatic negative balance for all crops (Fig. 6a, dash line) as well as food grains (Fig.6b, dash line). For India (solid line, Fig. 6), total trade balance (export-import), as percentage of available water (Fig. 6), has been negative until around 1980; however, it has turned increasingly positive (export > import) since 1990 for all crops (Fig. 6a, solid line) as well as food grains (Fig. 6b, solid line); the current deficit amounts to about 1 percent of total water available (~3×10^9 m^3). In contrast, the virtual water has been more import oriented for China (dash line, Fig. 6), with trade balance negative essentially for the entire period of 1960-2010 (Fig. 6).

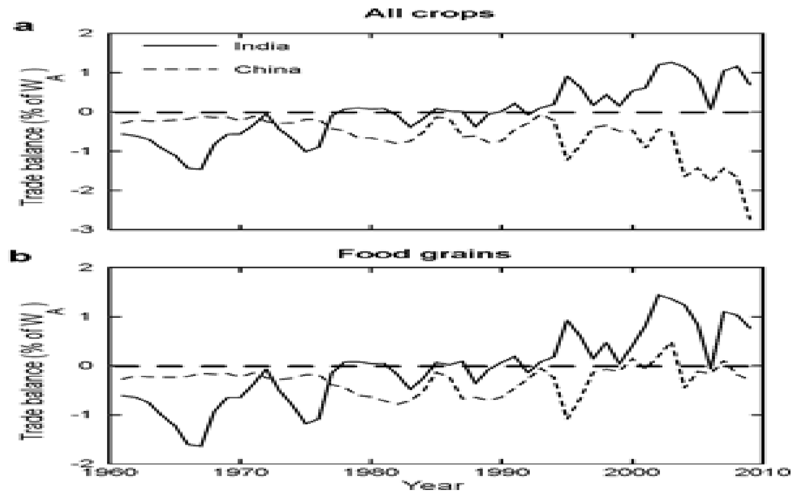


Fig.6 *Trade balance (Export-Import) in terms of total water involved in end products as percentage of water available for all crops (**a**) and food grains (**b**) for India (solid line) and China (dash line).*

A comparison of trade balance (export-import) of India and China shows (Fig. 7) China to have maintained a negative (more import) value essentially for the entire period of 1961-2010.

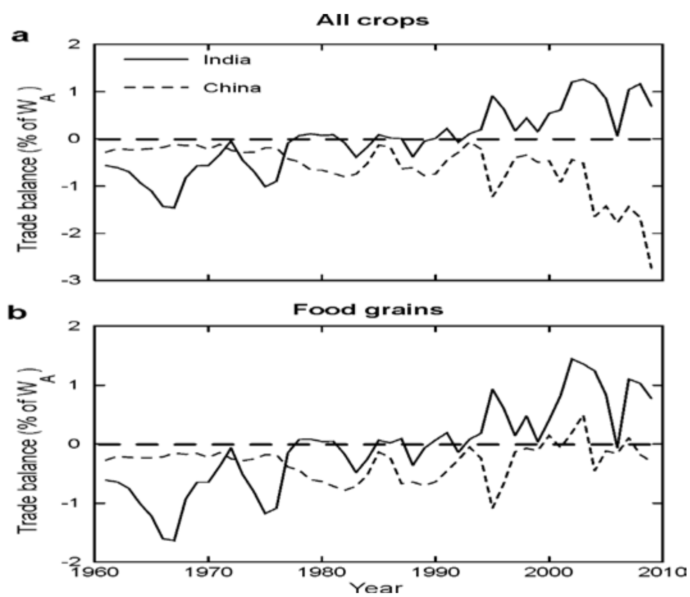


Fig. 7 *Trade balance (Export-Import) in terms of total water involved in production as percentage of water available for all crops (**a**) and food grains (**b**) for India (solid line) and China (dash line).*

5. Time Scales for Loss of Water Sustainability through Virtual Trade

The virtual export of water, especially in terms of water content in end products, implies certain time scales. For example, India's water availability is likely to equal its water demand around the year 2100 (Fig. 8a); for China, the water availability is expected to remain more than 200 percent of the water demand even beyond 2200 and even for a per capita consumption of 650 kg/year (Fig. 8b). Although the projections have their inherent uncertainties, they validate well against observations during 1960-2010 (insets), with correlation coefficients above 99 percent significance level (Fig. 8). Considered only in terms of food grains, the water availability for India can saturate above the critical value for the population scenario considered (Fig. 8c); a similar conclusion holds for China (Fig. 8d). However, these conclusions critically depend on the population growth scenarios considered.

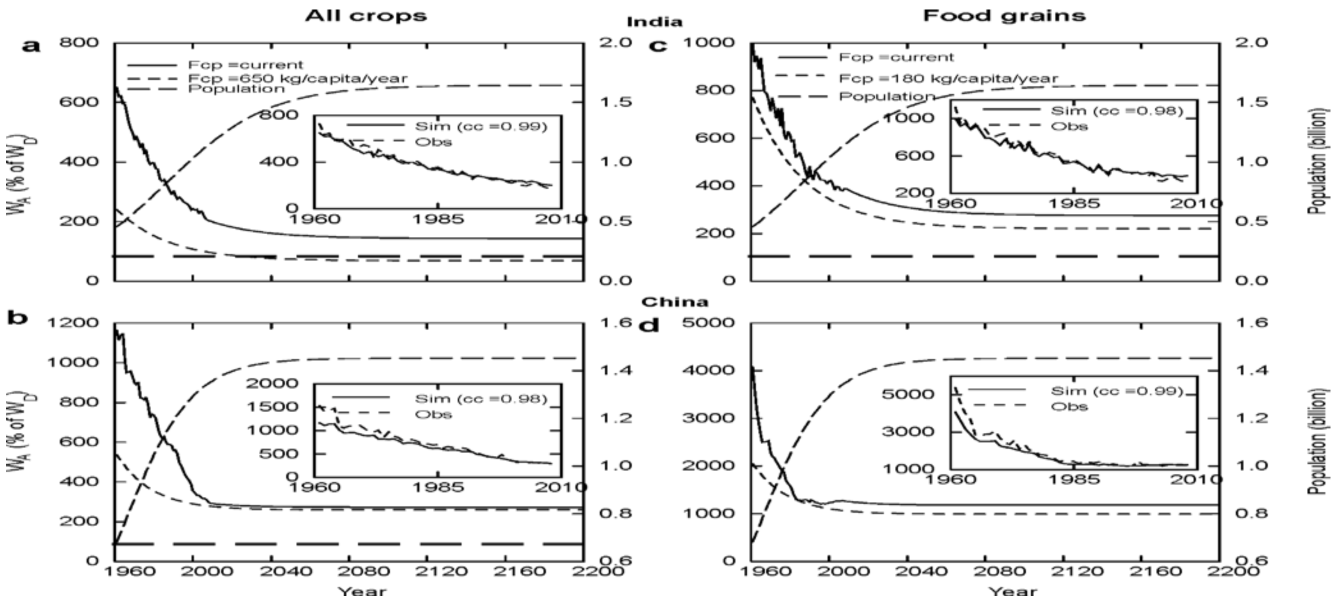


__Fig. 8__ Simulation (1960-2010) and projection of water availability (2010-2200) (as percentage water demand) for all crops (left panels) and food grains (right panels) for two values of per capita food consumption
***a, b:** current and 650 kg/capita/year of all crops for India (**a**) and China (**b**).*

***c, d:** current and 180 kg/capita/year of food grains for India (**c**) and China (**d**).*

The horizontal long dash line represents the level at which the water demand equals the total water available. The inset figure in each panel shows the simulation (solid line) and observation of the water availability as percentage of water demand for the annual per capita food consumption of all crops and food grains for the respective country; the correlation coefficient between simulation and observation is given in the bracket.

For average (1990-2010) net export of virtual water in all crops in terms of water involved in production, the time scale (years) in which the net export equals water surplus can be as short as 120 years for a population of 1700 million (Fig. 9a); for the current or the maximum values of net export, these time scales are even shorter. Expectedly, the time scales are longer in terms of water involved in production of either for all crops (Fig. 9c) or food grains (Fig. 9d). The time scales for loss of water for sustainability for average rate of export of total virtual water are expectedly shorter than those for average net export. However, even if water involved in production is not all lost (unlike in export in food grains), conditions where water requirement in production equals water availability can create appreciable stress. These time scales are higher in water export in terms of water content available in end-product; the time scales (in years), for average, maximum and current export scenarios equal to the water available, water required for production and water surplus (Table 1) vary between 1500 years to a few decades.

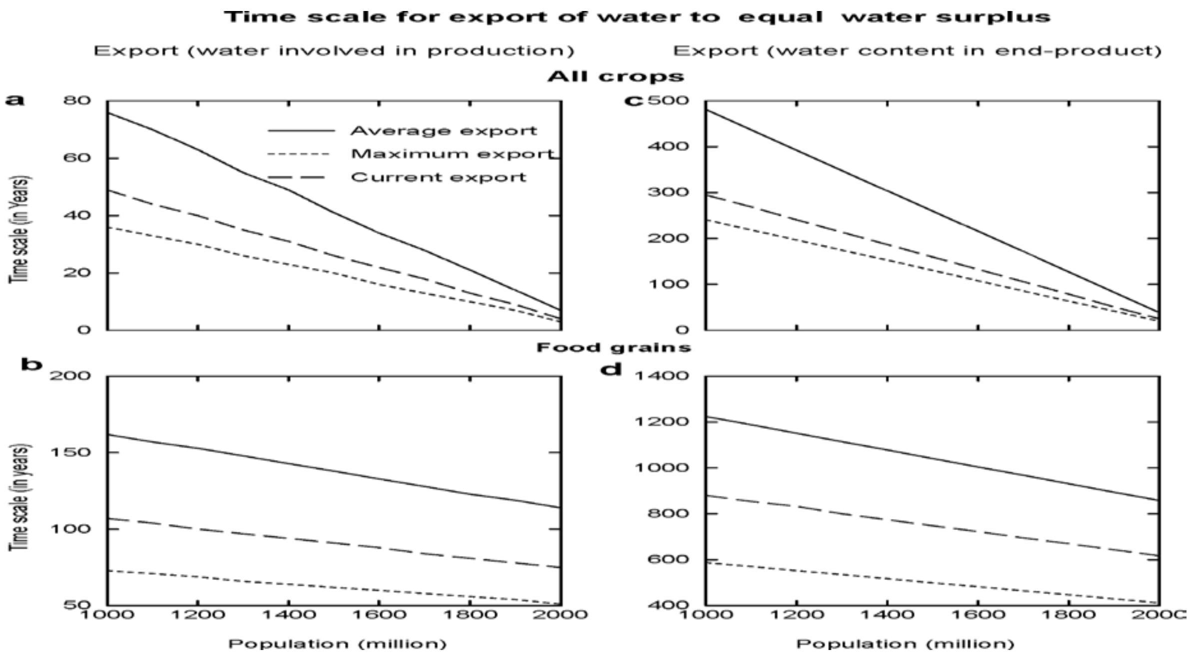


***Fig. 9** Time scales for India for loss of water sustainability through virtual net export in terms of water involved in production for all crops (**a**) and food grains (**b**), and in terms of water content in end-products for all crops (**c**) and food grains (**d**) equals to water surplus for all food crops (top panels) and food grains (bottom panels). The net export is projected by taking three different values of net export: Average (1990-2009, solid line), maximum (1990-2009, dotted line) and current (2005-2009; average, long dash line). We have taken 350 kg/capita and 150 kg/capita/year, respectively, per capita consumption of all crops and food grains. The vertical dash line represents the current population.*

***Table 1** Time scales for water export in terms of water content in end-product (W_{EC}) and total water involved in production of exports (W_{ET}) to equal total water available (W_A) and current water required for production (W_{PF}) and the water surplus (W_S) for India for three different scenarios of export of agricultural products (all crops and food grains): average (1990-2009), maximum (1990-2009) and current (2005-2009, average) of export.*

Time scale	**Water export scenarios**	**Time (in years) for export scenario**					
		Average export		**Maximum export**		**Current export**	
		Food grains	**All crops**	**Food grains**	**All crops**	**Food grains**	**All crops**
N_{CA}	$W_{EC} \sim W_A$	1593	924	765	463	1145	567
N_{CP}	$W_{EC} \sim W_{PF}$	428	562	205	282	307	345
N_{CS}	$W_{EC} \sim W_S$	482	546	231	274	346	336
N_{TA}	$W_{ET} \sim W_A$	211	147	95	69	139	100
N_{TP}	$W_{ET} \sim W_{PF}$	57	89	26	42	37	57
N_{TS}	$W_{ET} \sim W_S$	64	87	29	41	42	55

6. A policy option for water-sustainable agricultural export

The overall sustainability of a nation depends on two major primary resources: arable land and water; while the former is essentially immobile, water can be, and is, transported across countries through water (embedded) in agricultural items. Thus a trade network of food or agricultural products is accompanied by a network of virtual trading of water. Our analysis shows that the magnitude and the impact of such a virtual trade of water can affect overall sustainability of a nation. In particular, a net export of water through export of agricultural products, as in the case of India, can lead to irreversible loss of water sustainability. There is thus need for a review of India's agricultural trade policy.

It is, of course, impractical to suggest that trade in agricultural products be reduced. However, such a drastic measure is neither necessary. A scrutiny of virtual trade of water in a number of categories of agricultural products shows that (table 2) the major sources of net water export are food items and oil seeds, on the other hand, pulses provide significant net water import.

Table 2. Average water content, export, import and net export of crops for India. The export import and the net exports is given in three scenarios: Average (A, 1961-2011), Maximum (M, 1961-2011) and current (C, average over 2005-2011).

Sl. No	**Agricultural products**	**Average water content**	**Export of water**			**Import of water**			**Net export of water**		
			A	**M**	**C**	**A**	**M**	**C**	**A**	**M**	**C**
1	Food grains	11.66	4.48	21.2	14.5	4.2	17.83	2.96	0.28	3.37	11.54
2	Vegetables	89.27	0.13	0.57	0.46	0.0028	0.03	0.0033	0.128	0.54	0.456
3	Fruits	83.5	0.14	0.7	0.59	0.28	0.8	0.71	-0.14	-0.1	-0.12
4	Roots & Tubers	74.4	0.011	0.063	0.04	0.0027	0.019	0.012	0.008	0.044	0.028
5.	Pulses	11.52	0.32	2.5	0.65	1.19	6.95	4.79	-0.87	-4.45	-4.14
6.	Oil crops	12.79	1.6	9.6	5.78	0.23	1.41	0.23	1.37	8.2	5.5
7	**All crops**	**47.2**	**6.76**	**32.8**	**22.53**	**5.9**	**18.4**	**7.99**	**0.86**	**14.4**	**14.54**

The revised export policy can therefore identify and select products in such a way that there is net import of water through virtual trade within the demand-supply constraints. A continuation of current agricultural export policy, on the other hand, can lead to slow but irreversible damage.

7. Conclusion and perspective

An important conclusion of our study is that the net virtual water export alone can lead to loss of water sustainability of a nation in time scales that cannot be considered too long for a nation. For India, the time scales for loss of water sustainability through virtual export is 269 years (for water requirement) and 451 years (for water available). Since we are considering actual water content available in food grains, the loss is irreversible. Increase in food demand, and reduction in surface water due to climate change[33] can further reduce these time scales. Our analysis thus suggests that sustainable food or agricultural policy must be based on zero trade deficit in virtual water; while it is possible to meet these conditions, and are met for China, they are grossly off for India. Even a partial but irreversible loss of water resource of a populous country like India, on the other hand, will have large impacts on the global economy and sustainability. While improved and efficient water management can help, such measures can only delay the inevitable if net virtual export continues. Additional constraints on water sustainability are expected as water demands in other sectors like manufacturing, services and construction increase.

It needs to be emphasized that the time scales estimated here are time scales of onset of criticality; however, projections of water availability themselves are affected by many uncertainties. At the same time, these estimates of time scales or water sustainability are only likely to be optimistic; increase of use of water in other sectors like manufacture, service and others are likely to introduce further constraints and reduce these time scales of onset of criticality. On the other hand, improvements in water use efficiency through improved technology like laser land leveling and better agronomical practices can reduce water demand for production. However, as water content in a given crop is essentially constant, the conclusions and the estimates of embedded water are unlikely to change. Indeed, while improved water use efficiency, and export-import policy can delay the times of onset, increase on food demand due to increase in population as well as consumption can hasten these onsets.

The present analysis has been carried out based on current annual rainfall for the respective country; changes in temporal and spatial distributions of rainfall can introduce additional factors. There are indications that the spatio-temporal extent of India's rainy season (summer monsoon) is reducing[33]. Similarly, while global or oceanic monsoon rainfall may be increasing[40], the continental rainfall over India may decrease in a changed climate[41]. Mitigative measures to reduce virtual water export will have to take into account the role of agricultural export in the overall economy. Similar considerations, although of less serious implications, also apply for regional (domestic) virtual water export. It is clear that the effects of virtual export of water will emerge long before the critically condition is reached.

Appendix

Materials and Methods

The observed data for production, consumption, export and import of food grains and all crops has been adopted from public domain data portal (Table 1) like Food and Agriculture Statistics Division[31]. The observed data for arable land and population, for India and China, is available at Food and Agriculture Statistics Division[31]. The observed data for total water available, surface water, ground water and per capita water available is adopted from AQUASTAT[32]. We have considered virtual water trade for two categories: all crops and food grains. We have included cereals, vegetable, fruits, pulses, roots and tubers and oil crops in the category of all crops; the category of food grains includes only cereals (wheat, rice, barley, maize, millet, rye, oats and sorghum) are included in the category of food grains. Except for water footprint, the data is available at yearly time scale for the period 1961-2009/10 from FAOSTAT[33] or AQUASTAT[34]; for water footprint average data for the period 1996-2005 has been used[31, 32] (Table 2).

The virtual water footprints of primary and processed crop products, livestock products and industrial products of many counties is based on analysis given by Chapagain and Hoekstra31. While computing virtual water export and import, we have considered primary food crops in two groups all crops and food grains. The virtual water footprints of livestock products and industrial products have not considered in the present study. The data for water footprints for all crops has been adopted from Water Stat; Water Footprint Network, Netherlands[31,32]. The water footprints are changing with location, time and due to climatic conditions and agricultural practices. The water required to produce 1 ton of food (m^3/ton) of food is calculated as the average value of the water footprints of all crops for India, China and the world based on data available in literature[31]. The water content in the end products of the agricultural commodities has been taken from Transport Information Services[36] and Agricultural Research Service, United States Department of Agriculture[37] (Table 3a-3f). The rainfall data has been extracted from NCEP daily reanalysis on a global grid[41].

The formalism and analyses are based on, and available in

1. P Goswami and S N Nishad, 2015, Virtual water trade and time scales for loss of water sustainability: A comparative regional analysis, **Nature Scientific Reports**, DOI: 10.1038/srep09306

2. P Goswami and Shiv Narayan Nishad, 2014, Assessment of agricultural sustainability in changing scenarios: A case study for India, **Current Science**, 10, 6 (4), 552-557.

Quoted and related references

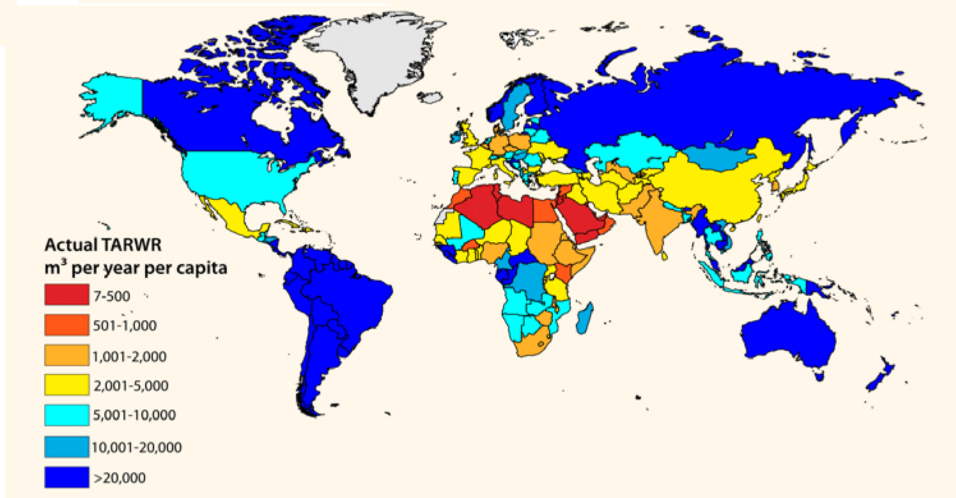
1. Cai, X., Rosegrant, M. Water management and food production in China and India. *Water Policy* **7**, 643–663 (2005).
2. Xiong, et al. Climate change, water availability and future cereal production in China. *Agr Ecosyst Enviorn* **135**, 58-69 (2010).
3. Kumar, R., Singh, R.D., Sharma, K.D. Water resources of India. *Curr Sci India* **89**, 794-811 (2006).
4. Cheng, H., Zhao, H. J. Meeting China's water shortage crisis: current practices and challenges. *Environ Sci Technol* 43, 240-244 (2009).
5. Hubacek K., Guan, D., Barrett, J., Wiedmann, T. Environmental implications of urbanization and lifestyle change in China: Ecological and water footprints. Journal of Cleaner Production 17, 1241-1248 (2009).
6. Liu, J., Yang, W. Water sustainability for China and beyond. *Science* **337**, 649-650 (2012).
7. Seckler, D., Barker, R., Amarasinghe, U. Water scarcity in the twenty-first century. *Int J Water Resour D* **15,** 29-42 (1999).
8. Sorooshian, S., Witaker, M. P. L., Hogue, T.S. Regional and global hydrology and water resource issues: The role of international and national programmes, water policy article. *Aquat Sci* **64,** 317–327 (2002).
9. Arnell, M.W. Climate change and global water resources. *Global Environ Chang* **9**, S31-S49 (1999).
10. Postel, S.L. Entering an era of water scarcity: the challenges ahead. *Ecol Appl* **10**, 941–948 (2000).
11. Allan, J.A. Virtual water: A strategic resource. Global solution to regional deficits. *Ground Water* **36**, 545-546 (1998).
12. Yang, H., Zehnder, A. Virtual water: An unfolding concept in integrated water resources management. *Water Resour Res* **43,** W12301 (2007).
13. Chapagain, A. K., Hoekstra, A. Y. The global component of freshwater demand and supply: an assessment of virtual water flows between nations as a result of trade in agricultural and industrial products. *Water Int* 33, 19-32 (2008).
14. Fraiture, C., Cai, X., Amarasinghe, U., Rosegrant, M., Molden, D., 2004. Does International Cereal Trade Save Water? The Impact of Virtual Water Trade on Global Water Use. Comprehensive Assessment Research Report 4, International Water Management Institute, Colombo, Sri Lanka.
15. Hoekstra, A., Hung, P. Globalization of water resources: International virtual water flows in relation to crop trade. *Global Environ Chang* 15, 45-56 (2005).
16. Chen, Z.M., Chen, G.Q., Xia, X.H., Xu, S.Y. Global network of embodied water flow by systems input-output simulation. Frontiers of Earth Science 6, 331-344 (2012).
17. Chen, Z.M., Chen, G.Q. Virtual water accounting for the globalized world economy: National water footprint and international virtual water trade. Ecological Indicators 28, 142-149 (2013).
18. Hoekstra, A.Y. and Chapagain, A.K. *Globalization of water: Sharing the planet's freshwater resources.* Blackwell Publishing. Oxford, UK (2008).
19. Konar, M. et al. Water for food: The global virtual water trade network. *Water Resour Res.* **47,** W0552 (2011).
20. Dalin, C., Konar, M., Hanasaki, N., Rinaldo, A., Rodriguez-Iturbe, I. Evolution of the global virtual water trade network. *Proc. Nat. Acad. Sci.* **109,** 5989-5994 (2012).
21. Wichelns, D. The virtual water metaphor enhances policy discussions regarding scarce resources. *Water Int* **30**, 428–437 (2005).
22. Hoekstra, A. Y. Virtual water trade between nations: a global mechanism affecting regional water systems. *Glob. Change News Lett*. **54,** 2–4 (2003).
23. Sadek, A.E. Virtual water: an effective mechanism for integrated water resource management. *Agricultural Sciences* **2(3),** 248-261 (2011).
24. Wichelns, D. The role of virtual water in efforts to achieve food security and other national goals, with an example from Egypt. *Agr Water Manage* **49**, 131-151 (2001).
25. Oki, T., Kanae, S. Virtual water trade and world water resources. *Water Sci Technol* **49,** 203-209 (2003).
26. Kumar, M. D., Singh, O. P. Virtual Water in Global Food and Water Policy Making: Is There a Need for Rethinking? *Water Resour Manag* **19,** 759-789 (2005).
27. Yang, H., Wang, L., Abbaspour, K. C., Zehnder, A. J. B. Virtual water trade: an assessment of water use efficiency in the international food trade. *Hydrol Earth Syst Sc* **10,** 443-454 (2006).
28. Mai, J. et al. Virtual versus real water transfers within China. *Phil. Trans. R. Soc. B* **361**, 835–842 (2006).
29. Guan, D., Hubacek, K. Assessment of regional trade and virtual water flows in China. *Ecol Econ* **61,** 159-170 (2007).

30. Kumar, V., Jain, S.K. Status of virtual water trade from India. *Curr. Sci*., **93**, 1093-1099 (2007).
31. Chapagain, A.K., Hoekstra, A.Y., Water footprints of nations. Value of Water Research Report Series No. 16, UNESCO-IHE, Delft, The Netherlands (2004) (date of access 05/03/2014).
32. Mekonnen, M.M., Hoekstra, A.Y. The green, blue and grey water footprint of crops and derived crop products. *Hydrol Earth Syst Sc* **15**, 1577-1600 (2011).
33. FAOSTAT Division (http://faostat.fao.org/site/291/default.aspx).
34. AQUASTAT, Food and Agriculture Organizations of the United Nations (http://www.fao.org/nr/water/aquastat/data/query/index.html).
35. Ramesh, K. V. and Goswami, P. Reduction in temporal and spatial extent of the Indian summer monsoon. *Geophys Res Lett* **34**, L23704 (2007).
36. Transport Information Services (http://www.tis-gdv.de/tis_e/ware/inhaltx.htm#13).
37. Agricultural Research Service, United States Department of Agriculture (http://ndb.nal.usda.gov/ndb/foods#).
38. Verhulst, P.-F.Recherches mathématiques sur la loi d'accroissement de la population. *Nouv. mém. de l'Academie Royale des Sci. et Belles-Lettres de Bruxelles* **18**, 1-41 (1845).
39. United Nations Population Division World Population prospects the 2012 revision. Department of Economic and Social affairs, United Nations, Newyork (2013).
40. Valin et al. The future of food demand; understanding differences in global food models. Agricultural Economics 45, 51-67 (2014).
41. Kalnay, E. et al. The NCEP/NCAR 40-Year Reanalysis Project. *Bull. Amer. Meteor. Soc.* **77**, 437–471 (1996).
42. Kitoh, A. Monsoons in a changing world: A regional perspective in a global context. *J Geophys Res* **118**, 3053–3065 (2013).
43. Ramesh, K.V., Goswami, P. Assessing reliability of regional climate projections: the case of Indian monsoon. *Nature Sci. Reports* **4**, 4071 (2014).
44. Alcamo, J.; Döll, P.; Henrichs, T.; Kaspar, F.; Lehner, B.; Rösch, T. & Siebert, S. (2003). Development and testing of the WaterGAP 2 global model of water use and availability. *Hydrological Sciences*, 48(3), 317–337.
45. Allan, J. A., 2003b, 'Virtual water-the water, food, trade nexus, useful concept or misleading metaphor? Discussion paper,' *Water International*. **28**(1), 4–10.
46. Allan, J.A. (2003). Virtual Water – the water, food, and trade nexus useful concept or misleading metaphor? Water International, 28, 4-11.
47. Allan, J.A. Virtual water: A strategic resource. Global solution to regional deficits. *Ground Water* **36**, 545-546 (1998).
48. Allan, J.A., 1997. Virtual water: A long term solution for water short Middle Eastern economies? : Occasional paper, no. 3. Water Issues Study Group, School of Oriental and African Studies, University of London.
49. Allan, J.A., 2003. Virtual water-the water, food, and trade nexus: useful concept or misleading metaphor? Water International 28, 106-112.
50. Ansink, E., 2010. Refuting two claims about virtual water trade. Ecological Economics 69, 2027-2032.
51. B Orlowsky1, A Y Hoekstra2, L Gudmundsson1 and Sonia I SeneviratneToday's virtual water consumption and trade under future water scarcity. Environ. Res. Lett. 9 (2014) 074007.
52. Brown, L. R. & Halweil, B. 1998 China's water shortage could shake world food security. World Watch Mag. 11, 10–21.
53. Chapagain, A. K. & Hoekstra, A. Y. 2003 Virtual water trade: a quantification of virtual water flows between nations in relation to international trade of livestock and livestock products. In Virtual water trade proc. int. expert meeting on virtual water trade—Value of water research report series No.12 (ed. A. Y. Hoekstra), pp. 49–76. Delft: IHE.
54. Chapagain, A. K., A. Hoekstra, and H. Savenije (2006), Water saving through international trade of agricultural products, Hydrol. Earth Syst. Sci., 10, 455–468.
55. Chapagain, A. K., Hoekstra, A. Y. The global component of freshwater demand and supply: an assessment of virtual water flows between nations as a result of trade in agricultural and industrial products. *Water Int* **33,** 19-32 (2008).
56. Chapagain, A.K. & Hoekstra, A.Y. (2004).*Water footprints of nations*. UNESCO-IHE, Delft, the Netherlands.
57. Chapagain, A.K., Hoekstra, A.Y., Water footprints of nations. Value of Water Research Report Series No. 16, UNESCO-IHE, Delft, The Netherlands (2004) (date of access 05/03/2014).
58. Chapagain, A.K.; Hoekstra, A.Y. & Savenije, H.H.G. (2006a). Water saving through international trade of agricultural products. Hydrology and Earth System Sciences, 10: 455–468.

59. Chen, Z.M., Chen, G.Q. Virtual water accounting for the globalized world economy: National water footprint and international virtual water trade. Ecological Indicators 28, 142-149 (2013).
60. Chen, Z.M., Chen, G.Q., Xia, X.H., Xu, S.Y. Global network of embodied water flow by systems input-output simulation. Frontiers of Earth Science 6, 331-344 (2012).
61. Dabo Guan, Klaus Hubacek, Assessment of regional trade and virtual water flows in China. Ecol. Econ. 61 (2007), 159–170.
62. Dalin, C., Konar, M., Hanasaki, N., Rinaldo, A., Rodriguez-Iturbe, I. Evolution of the global virtual water trade network. *Proc. Nat. Acad. Sci.* **109,** 5989-5994 (2012).
63. Earle, A. and Turton, A., 2003, 'The virtual water trade amongst countries of the SADC, Virtual water trade,' in A. Y. Hoekstra (ed.), *Proceedings of the International Expert Meeting on Virtual Water Trade*, Value of water research report series # 12.
64. Esther Velázquez Water trade in Andalusia. Virtual water: An alternative way to manage water use. Ecol Econ 63 (2007) 201 – 208.
65. Falkenmark, M. & Rockström, J. (in press). Integrating agricultural water use with the global water budget. In: A. Garrido & H. Ingram (eds.), *Water for Food in a Changing World*. Routledge.
66. Falkenmark, M. (1995). Coping with water scarcity under rapid population growth. Paper presented at Conference of SADC Ministers, Pretoria, South Africa, 23–24 November 1995
67. FAO (2006). FAOSTAT: FAO statistical databases. Food and Agriculture Organization of the United Nations, Rome, Italy. [Available at http://faostat.fao.org/default.aspx].
68. FAOSTAT Division (http://faostat.fao.org/site/291/default.aspx).
69. Fraiture, C., Cai, X., Amarasinghe, U., Rosegrant, M., Molden, D., 2004. Does International Cereal Trade Save Water? The Impact of Virtual Water Trade on Global Water Use. Comprehensive Assessment Research Report 4, International Water Management Institute, Colombo, Sri Lanka.
70. Guan, D., Hubacek, K. Assessment of regional trade and virtual water flows in China. *Ecol Econ* 61, 159-170 (2007).
71. Hoekstra A Y and Mekonnen M M 2012 The water footprint of humanity Proc. Natl Acad. Sci. USA 109 3232–7
72. Hoekstra, A. Y. & Hung, P. Q. 2003 Virtual water trade: a quantification of virtual water flows between nations in relation to international crop trade. In Virtual water trade proceedings of the international expert meeting on virtual water trade—Value of water research report series No.12 (ed. A. Y. Hoekstra), pp. 25–48. Delft: IHE.
73. Hoekstra, A. Y. 2003 Virtual water trade between nations: a global mechanism affecting regional water systems. Glob. Change News Lett. 54, 2–4.
74. Hoekstra, A., 2010. The relation between international trade and freshwater scarcity. World Trade Organization staff working paper ERSD-2010-05.
75. Hoekstra, A., Hung, P. Globalization of water resources: International virtual water flows in relation to crop trade. *Global Environ Chang* **15,** 45-56 (2005).
76. Hoekstra, A.Y. & Chapagain, A.K. (2008). *Globalization of water: Sharing the planet's freshwater resources*. Blackwell Publishing. Oxford, UK.
77. Hoekstra, A.Y., Hung, P.Q., 2003. Virtual water trade: a quantification of virtual water flows between nations in relation to international crop trade. Virtual water trade. Proceedings of the International Expert Meeting on Virtual water Trade. Value of Water Research Report Series, vol. 12. IHE, Delft, Holanda
78. Hubacek, K., Sun, L., 2005. Economic and societal changes in china and their effects on water use: a scenario analysis. In: Hertwich, E. (Ed.), consumption and the Environment. Journal of Industrial Ecology, vol. 9, pp. 1–2
79. Jeffrey J. Reimer. 2012. "On the Economics of Virtual Water Trade." *Ecological Economics* 75:135-139.
80. Konar, M. et al. Water for food: The global virtual water trade network. *Water Resour Res.* **47,** W0552 (2011).
81. Kumar MD, Singh O.P. Virtual Water in Global Food and Water Policy Making: Is There a Need for Rethinking? Water Resources Management (2005) 19: 759–789
82. Kumar, M. D., Singh, O. P. Virtual Water in Global Food and Water Policy Making: Is There a Need for Rethinking? *Water Resour Manag* **19,** 759-789 (2005).
83. Kumar, V., Jain, S.K. Status of virtual water trade from India. *Curr. Sci.*, **93**, 1093-1099 (2007).
84. Kuylenstierna, J.; Destouni, G. & Lundqvist, J. (2008). Feeding the future world – securing enough food for 10 billion people. In: Swedish Research Council Formas (ed.), *Water for Food*. Formas, Stockholm, Sweden: 9–22.

85. Leontief, W., 1954. Domestic production and foreign trade: the american capital position reexamined. Economia Internatiozionale 7, 3–32 (February).
86. Liu J., Yang H. Global agricultural green and blue water consumptive uses and virtual water trade. Chapter 2, pp-23-32
87. Liu, J. &Yang, H. (2010). Spatial explicit assessment of global consumptive water uses in cropland: green and blue water. *Journal of Hydrology*, 384: 187–197.
88. Liu, J.; Zehnder, A.J.B. &Yang, H. (2009). Global consumptive water use for crop production: the importance of green water and virtual water.*Water Resources Research*, 45: W05428
89. Mai, J. et al. Virtual versus real water transfers within China. *Phil. Trans. R. Soc. B* **361**, 835–842 (2006).
90. Mekonnen, M.M., Hoekstra, A.Y. The green, blue and grey water footprint of crops and derived crop products. *Hydrol Earth Syst Sc* **15**, 1577-1600 (2011).
91. Merrett, S., 1997. Introduction to the economics of water resources: An international perspective. Rowman & Littlefield Publishers, Lanham, Maryland.
92. Merrett, S., 2003. Virtual water and Occam's razor. Water International 28, 103-105.
93. Novo, P.; Garrido, A. & Varela-Ortega, C. (2009). Are virtual water "flows" in Spanish grain trade consistent with relative water scarcity? *Ecological Economics*, 68: 1454–1464.
94. Ohlin, B., 1933. Interregional and international trade. Harvard University Press, Cambridge, Massachusetts.
95. Oki, T. & Kanae, S. (2004). Virtual water trade and world water resources. *Water Science and Technology*, 49 (7): 203–209.
96. Oki, T., Kanae, S. Virtual water trade and world water resources. *Water Sci Technol* **49,** 203-209 (2003).
97. Paolo D'Odorico, Joel Carr, Francesco Laio and Luca Ridolfi Spatial organization and drivers of the virtual water trade: a community-structure analysis. Environ. Res. Lett. 7 (2012) 034007
98. Rosegrant, M.; Cai, X. & Cline, S. (2002). *World water and food to 2025*. International Food Policy Research Institute (IFPRI). Washington, D.C., USA.
99. Roth, D. & Warner, J. (2008). Virtual water: Virtuous impact? The unsteady state of virtual water. *Agricultural and Human Values*, 25: 257–270.
100. Sadek, A.E. Virtual water: an effective mechanism for integrated water resource management. *Agricultural Sciences* **2(3),** 248-261 (2011).
101. Seekell D A, D'Odorico P and Pace M L 2011 Virtual water transfers unlikely to redress inequality in global water use Environ. Res. Lett. 6 024017
102. Verma, S.; Kampman, D.A.; van der Zaag, P. & Hoekstra, A.Y. (2008). Going against the flow: A critical analysis of inter-state virtual water trade in the context of India's National River Linking Program. *Physics and Chemistry of the Earth*, 34(4–5): 261–269.
103. Wang, L., Davis, J., 2000. China's Grain Economy: the Challenge of Feeding More than a Billion. Ashgate, Aldershot.
104. Wheida E., Verhoeven R. The role of "virtual water" in the water resources management of the Libyan Jamahiriya Desalination, 205, 312-316 (2007).
105. Wichelns, D. (2004). The policy relevance of virtual water can be enhanced by considering comparative advantages. *Agricultural Water Management*, 66: 49–63.
106. Wichelns, D. The virtual water metaphor enhances policy discussions regarding scarce resources. *Water Int* **30**, 428–437 (2005).
107. Yang, H. & Zehnder, A.J.B. (2007). Virtual water: An unfolding concept in integrated water resources management. *Water Resources Research*, 43, W12301.
108. Yang, H., Wang, L., Abbaspour, K. C., Zehnder, A. J. B. Virtual water trade: an assessment of water use efficiency in the international food trade. *Hydrol Earth Syst Sc* **10,** 443-454 (2006).
109. Yang, H., Zehnder, A. Virtual water: An unfolding concept in integrated water resources management. *Water Resour Res* **43,** W12301 (2007).
110. Yang, H.; Wang, L.; Abbaspour, K.C. & Zehnder, A.J.B. (2006). Virtual water trade: an assessment of water use efficiency in the international food trade. *Hydrol Earth Syst Sc*, 10: 443–454.

Per capita total annual renewable water resources (TARWR) by country-population data from 2009



Source: FAO AQUASTAT database

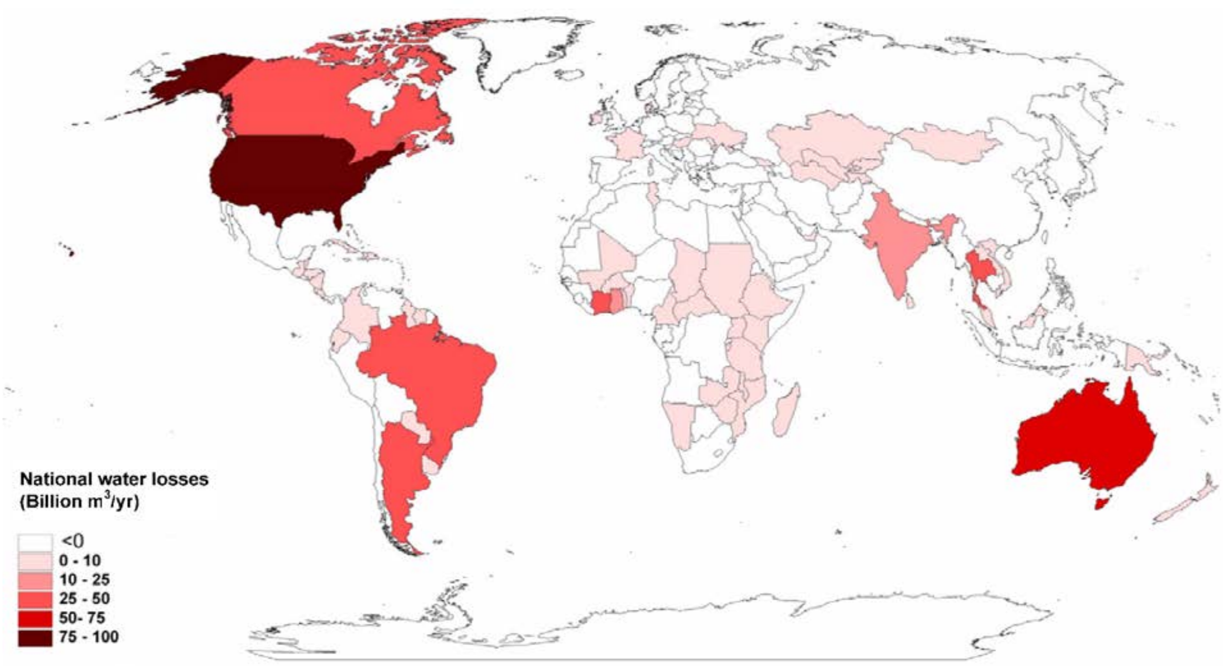


Figure National water losses related to international trade of agricultural products. Period 1997-2001.

Source: Chapagain A.K. et al. (2015)