

# Addressing India's Water Challenge 2050: The Virtual Water Trade Option<sup>1</sup>

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## **Food Security and Water Transfers**

The Government of India, on directions from the Supreme Court in 2002 and advice from the National Water Development Agency (NWDA), proposed an estimated US\$120 billion National River Linking Project (NRLP) which envisages linking 37 Himalayan and Peninsular rivers (Figure 1; NCIWRD 1999). Doing this will form a gigantic South Asian water grid which will annually handle  $178 \times 10^9$  m<sup>3</sup>/yr of interbasin water transfer; build 12,500 km of canals; generate 34 gigawatts of hydropower; add 35 million hectares (Mha) to India's irrigated areas; and generate inland navigation benefits (IWMI 2003; NWDA 2006; Gupta and van der Zaag 2007).

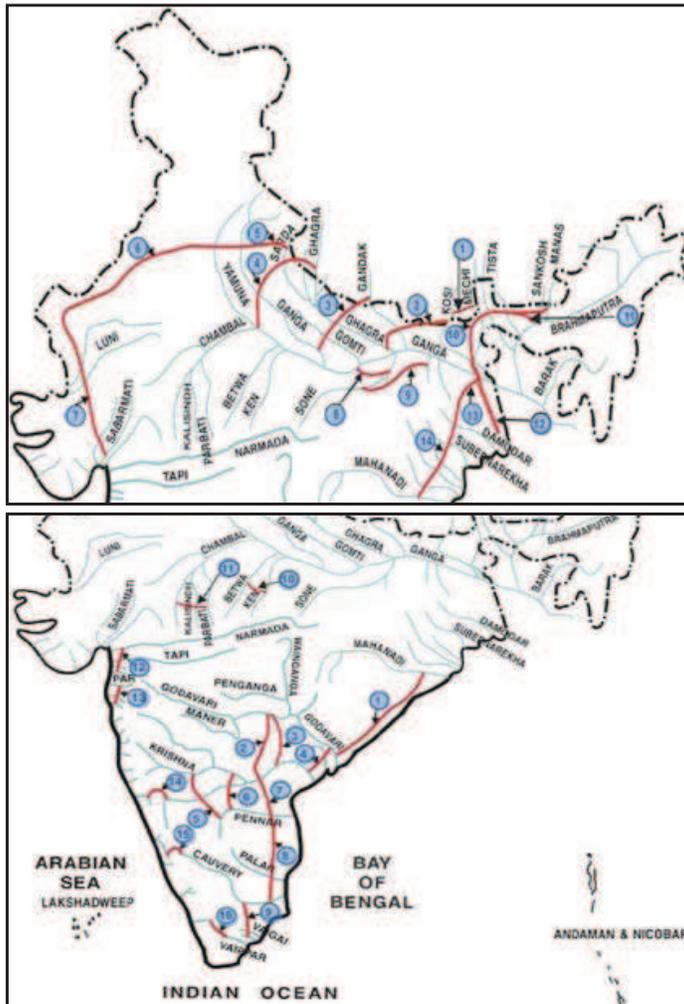
The prime motivation behind this grand plan is India's growing concern about the need to produce additional food for its large and rapidly increasing population. The NWDA cites that India will require about 450 million tonnes of food grains per annum to feed a population of 1.5 billion in the year 2050 (NCIWRD 1999) and to meet this requirement, it needs to expand its irrigation potential to 160 Mha, which is 20 Mha more than the total irrigation potential without NRLP. This follows India's long-standing, unwritten policy of food self-sufficiency.

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Figure 1. India's proposed National River Linking Project (NRLP), with the Himalayan component (left) and the Peninsular component (right).



Source: Reproduced from NCIWRD 1999.

Considering that large parts of the Ganga-Brahmaputra-Meghna Basin face recurring floods and a number of western and peninsular states face severe droughts, the NWDA (2006) contends that “one of the most effective ways to increase the irrigation potential for increasing the food grain production, mitigate floods and droughts and reduce regional imbalance in the availability of water is the Inter Basin Water Transfer (IBWT) from the surplus rivers to deficit areas.

However, representatives from civil society, the media and academia have strongly criticized the plan (Iyer 2002; Vombatkere 2003; Vaidyanathan 2003; Bandyopadhyay and Perveen 2004; Patkar 2004). Besides voicing concerns about the potential negative environmental impacts of the mega-project, critics have argued that the decision to go ahead with the plan has been hasty. They argue that NRLP is only one of the alternatives to ensure India's food and water security and alternative—local, cheaper and greener—options should have been given more serious consideration. A number of alternatives have been suggested including decentralized water harvesting and artificial recharge of aquifers, improving the

productivity of agriculture in water-scarce regions (which, it is claimed, continue to waste precious water resources), improving the efficiency of India's public irrigation systems through involvement of stakeholders in the management of irrigation, and using virtual water trade, instead of physical water transfers, to tackle the high spatial variation in water availability across the country.

While a number of these options seem plausible, all of them require further scientific exploration and study before any one of them (or a combination of several of them) can form a feasible answer to India's impending and formidable water crisis. While the Government of India has failed to share with the public its detailed studies and plans for the proposed interbasin transfers, the opponents of NRLP also do not have a studied program of action to present. The lack of such analyses has led to a polarized and opinionated debate which is preventing the nation from forming a scientific opinion about NRLP and its various alternatives (Verma and Phansalkar 2007).

One of the alternatives to NRLP that has been discussed is virtual water trade within the country. Proponents of this alternative have argued that instead of physically transferring large quantities of water from the flood-prone east to the water-scarce west and south, it would be desirable to transfer virtual water in the form of food grains. This paper explores the factors that influence interstate virtual water trade in India; provides a preliminary assessment of the potential of virtual water trade to act as an alternative to the proposed IBWT; and assesses policy options for promoting and enhancing water-saving trade within the country.

## **Virtual Water Trade and International Trade Theories**

The term 'virtual water' was introduced by Professor Tony Allan (1993, 1994) referring to the volume of water needed to produce agricultural commodities. The same concept has differently been referred to as 'embedded water' (Allan 2003), 'exogenous water' (Haddadin 2003) or 'ultraviolet' water (Savenije 2004). When a commodity (or service) is traded, the buyer essentially imports (virtual) water used in the production of the commodity. In the context of international (food) trade, this concept has been applied with a view to optimize the flow of commodities considering the water endowments of nations. Using the principles of international trade, it suggests that water-rich countries should produce and export water-intensive commodities (which indirectly carry embedded water needed for producing them) to water-scarce countries, thereby enabling the latter to divert their precious water resources to alternative, higher productivity uses.

The concept was later expanded to include other commodities and services (Allan 1998; Hoekstra 2003). Several researchers (Hoekstra and Hung 2002; Hoekstra 2003; Chapagain and Hoekstra 2003; Oki et al. 2003; Renault 2003; Zimmer and Renault 2003; De Fraiture et al. 2004; Chapagain et al. 2005; Chapagain 2006; Hoekstra and Chapagain 2007a,b) have investigated the role that international trade in virtual water can play in attaining global water saving and in ensuring food security in regions facing acute physical and economic water scarcity, especially in the Middle East, North Africa region and southern Africa.

Chapagain and Hoekstra (2004) employed the concept of 'water footprint' to compute nations' dependence on virtual water in the global trade system. Hoekstra and Hung (2002, 2005) quantified the scale and extent of virtual water crop trade globally while Chapagain and Hoekstra (2003) developed the methodology for similar calculations in the context of trade in

livestock and livestock products. The two results were then combined to get a comprehensive picture of the total agricultural virtual water trade (Hoekstra and Chapagain 2007a, b). Global water saving from this trade was estimated to be about 455 giga cubic meters ( $Gm^3$ ) per annum (Oki et al. 2003; Oki and Kanae 2004). However, policy conclusions from these results were suitably moderated by De Fraiture et al. (2004) who noted that global water savings are caused as a result of productivity differences between importing and exporting countries and are only an unintended by-product of international trade in agricultural commodities. Following the same logic, it is also possible to argue that virtual water trade can lead to wastage of water in the situation where countries with low water productivity export virtual water to high water productivity regions.

While a lot has been said about the scope, benefits and limitations of virtual water trade between countries, studies on virtual water movement within countries are, at best, sparse. As mentioned above, for countries such as India and China, it might be misleading to account for them as single entities. This is because even within these huge countries, there are wide disparities in water endowments. In addition, they demand special attention since they are big players in the international food trade, as the percentage of their domestic consumption trade is negligible and both countries are close to food self-sufficiency (De Fraiture et al. 2004). Further, virtual water trade within countries like India sidesteps the debate around food self-sufficiency—which is often used to negate any suggestion of letting the virtual water trade logic to influence India's food trade policies.

Ma and others (Ma 2004; Ma et al. 2006) quantified the virtual water trade within China in the backdrop of the south-north transfer project. The study found that north China exports  $52 \times 10^9$   $m^3/yr$  of virtual water to south China, a volume which is more than the maximum proposed water transfer volume along three routes ( $38\text{--}43 \times 10^9$   $m^3/yr$ ) in the south-north Transfer Project. The study therefore concludes that if the “perverse” direction of virtual water trade in China can be reversed, it can act as a better alternative to physical transfer of water across basins. It is with a similar logic that the idea of interstate virtual water trade in India is being proposed as an alternative to NRLP.

## **The Economic Logic behind Virtual Water Trade**

### ***Theory of Comparative Advantage***

Hoekstra (2003) referring to Wichelns (2001) observed that “the economic argument behind virtual water trade is that, according to international trade theory, nations should export products in which they possess a relative or comparative advantage in production, while they should import products in which they possess a comparative disadvantage.” Thus the logic of virtual water trade follows Ricardo's theory of comparative advantage which focuses on trade based on differences in production technologies and factor endowments. It states that each country should specialize in the production of such goods and services and export them to other countries and that in the production of these each country enjoys a comparative advantage by virtue of its factor endowments.

### ***Heckscher–Ohlin (H–O) Model of International Trade***

The direction and patterns of virtual water trade should be predictable and in agreement with the Heckscher-Ohlin (H-O) model of trade. Developed by Eli Heckscher and Bertil Ohlin, the Heckscher-Ohlin (H-O) model builds on Ricardo's theory to predict patterns of trade and production based on the factor endowments of trading entities. Broadly, the model states that countries (or regions) will export products that require high quantities of abundant resources and import products that require high quantities of scarce resources. Thus, a capital-rich (and relatively labor-scarce) country would be expected to export capital-intensive products and import labor-intensive products or services and vice versa (IESC 2007; Antras 2007; Davis 2007). In the context of virtual water trade, this translates to water-rich regions exporting water-intensive products and vice versa.

### ***Leontief Paradox***

However, even in trade of goods and services, the H-O model has been found wanting in terms of empirical evidence to support its logic. In 1954, Prof. W.W. Leontief attempted to test the H-O model by studying trade patterns between countries. To his surprise, he found that the US, perhaps the most capital-abundant country in the world, exported labor-intensive commodities and imported capital-intensive commodities. This was seen to be in contradiction to the H-O model and came to be known as the Leontief paradox.

### ***Linder Effect***

Several economists have, ever since, tried to resolve this paradox. In 1961, Staffan Burenstam Linder proposed the Linder hypothesis as a possible resolution to the Leontief paradox. Linder argued that demand, rather than comparative advantage, is the key determinant of trade. According to him, countries (or entities) with similar demands will develop similar industries, irrespective of factor endowments; and that these countries would then trade with each other in similar but differentiated goods. For example, both the US and Germany are capital-rich economies with significant demand for capital goods such as cars. Rather than one country dominating the car industry (by virtue of factor-endowment based comparative advantage), both countries produce and trade different brands of cars between them. This Linder effect has also been observed in other subsequent examinations. However, it does not account for the entire pattern of world trade (see Linder 1961; Bergstrand 1990).

### ***New Trade Theory***

Similarly, proponents of the New Trade Theory (Paul Krugman, Robert Solow and others) argue that factors other than endowments determine trade. New trade theorists base international trade on imperfect competition and economies of scale—both of which are realistic but assumed away in the H-O model. Gains from increasing returns to scale at the entity level are understood intuitively but gains from industry-level scale economies (external economies of scale) often get ignored. Such gains are particularly important in the case of agriculture where the scale of production of an individual farmer is very small compared to the size of the market. However, several factors such as agricultural extension services, specialized

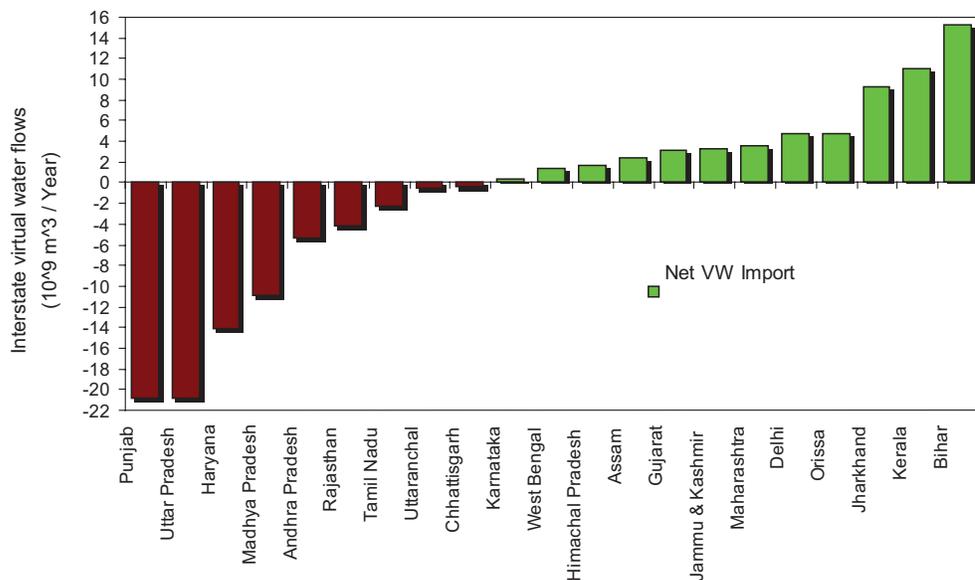
machinery markets and fertilizer markets, marketing channels for outputs, etc., contribute significantly in determining where agricultural commodities are produced.

## Interstate Virtual Water Trade in India: Quantum and Direction

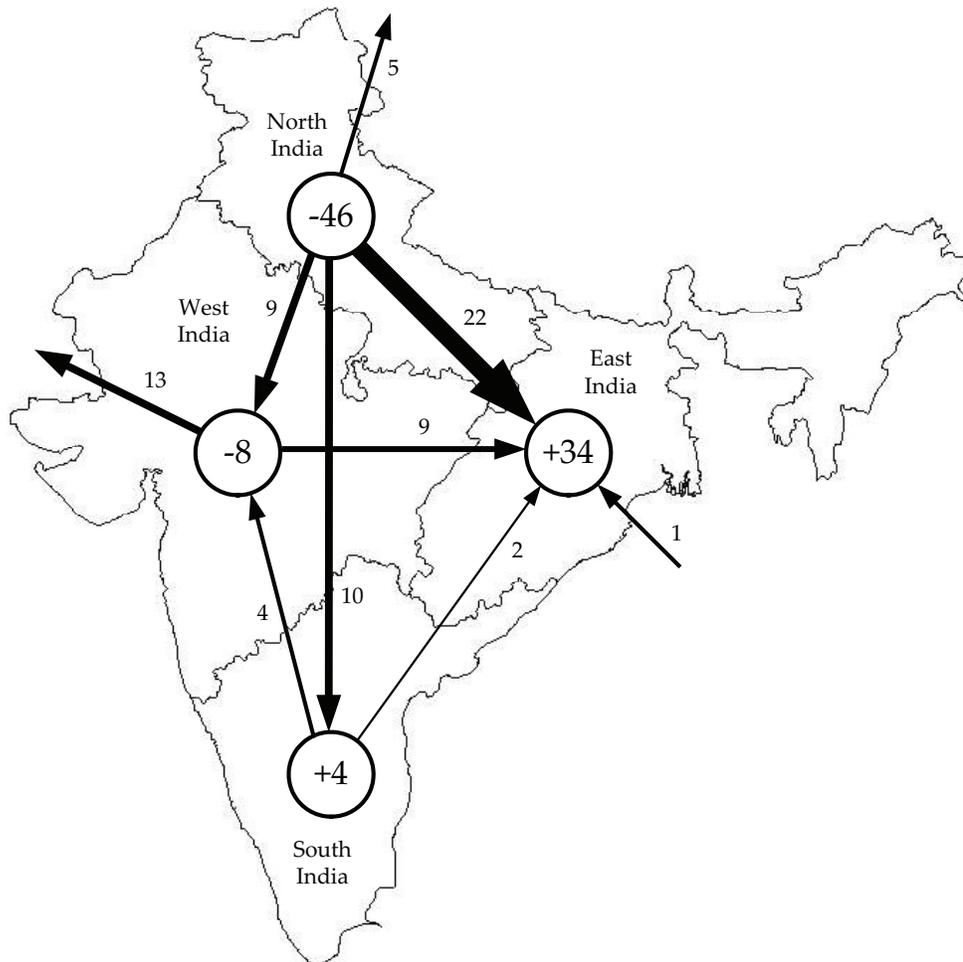
Kampman (2007) estimated that the virtual water flow as a result of interstate crop trade in India is  $106 \times 10^9$  m<sup>3</sup>/yr or 13% of the total water use. This estimate covers virtual water flows as a result of trade in 16 primary crops which represent 87% of the total water use, 69% of the total production value and 86% of the total land use. The estimates do not include virtual water flows as a result of trade in fodder, milk and milk products. Verma (2007) estimated that, at the current level of production and consumption, milk and milk products are unlikely to significantly add to the interstate virtual water flows since India as a whole is milk-surplus and consumption levels in states that produce less milk are much below the prescribed standards for nutritional security. However, if we consider a scenario of nutritional security (where minimum nutritional standards are met in every state), we can expect interregional virtual water flows of around  $40 \times 10^9$  m<sup>3</sup>/yr. Under such a scenario, the interstate virtual water flows will be still higher since there would also be some interstate flows within each of the four regions (North, East, West and South).

Based on certain assumptions about interstate movements of agricultural products, Kampman (2007) estimated the mean annual import (or export) of virtual water between states (see Figure 2). According to these estimates, the Punjab,<sup>3</sup> Uttar Pradesh and Haryana are the largest exporters of virtual water while Bihar, Kerala, Gujarat, Maharashtra, Jharkhand and Orissa are the key importers. Aggregating the flows at the regional level, Kampman (2007) found that eastern India, India's wettest region and prone to annual floods, imports large quantities of virtual water not only from the north, west and south but also from the rest of the world (Figure 3).

Figure 2. Interstate virtual water flows ( $10^9$  m<sup>3</sup>/yr), as estimated by Kampman (2007).



<sup>3</sup>In this paper by "Punjab" we mean the Indian Punjab.

Figure 3. Interregional virtual water flows ( $10^9 \text{ m}^3/\text{yr}$ ), as estimated by Kampman (2007).

The key virtual water importers—the eastern Indian states of Bihar, Jharkhand and Orissa—enjoy a comparative advantage over the key virtual water exporters—the northern states of Punjab, Uttar Pradesh and Haryana—if we look at the per capita water availability. The per capita water availability in all the three eastern Indian states is significantly higher than that in the northern states (see Table 1). Thus, we can see that the states which enjoy a natural comparative advantage (in terms of water endowments) actually have a net import of virtual water.

The NRLP proposes to transfer excess floodwater from the eastern states such as Assam, Bihar, West Bengal, Chattisgarh, etc., to the water-scarce regions which produce the bulk of the food thereby ensuring India's national food security. However, the proponents of the virtual water trade argument have repeatedly claimed that such a transfer would only accentuate what they term as the "perverse" direction of virtual water trade in India. They argue that going by theories of trade, water-rich states in eastern India should be producing much of India's food requirements and exporting food grains to the water-scarce states. However, as we can also see from the figures above, at present, the reverse is happening. Rather than having surplus produce to export to relatively water-scarce regions, the deficit in eastern India is so high that it even requires imports from outside India.

Table 1. Virtual water trade balances and water endowment.

States	Per capita water resources				Total (B+G)	Net virtual water import  10 <sup>9</sup> m <sup>3</sup> /yr
	Green (G)	Blue (B)		Total		
		Internal	External			
						m <sup>3</sup> /capita/yr
<i>Major virtual water exporters</i>						
Punjab	1,102	193	2,260	2,452	3,554	20.9
Uttar Pradesh	863	575	1,485	2,059	2,922	-20.8
Haryana	1,121	391	663	1,055	2,176	-14.1
<i>Major virtual water importers</i>						
Bihar	789	628	5,482	6,109	6,898	15.3
Jharkhand	2,082	1,970	528	2,498	4,580	9.3
Orissa	3,446	3,079	2,185	5,264	8,710	4.8

Critics of the NRLP argue that such a “perverse” direction is the result of food and agriculture policies that have been biased in favor of states like the Punjab and Haryana where farmers receive highly subsidized agricultural inputs (including water for irrigation) and are assured high prices for the wheat and rice they produce through the procurement policies of the Food Corporation of India (FCI). The proponents of the virtual water trade argument contend that if these policies were to be revised in favor of the wetter states, the so-called “perverse” direction of food trade would get “rationalized” and the water-rich states would no longer have to import virtual water from water-scarce states.

## Determinants of Interstate Virtual Water Trade in India

Why do water-rich states import even more water (in virtual form) from relatively water-scarce states? In order to test the relationship between the water resources endowments of states and their behavior in the virtual water trade arena we checked whether the type of water endowment mattered. Figures 4 (a) to 4 (d) plot net virtual water imports (or exports) against per capita green water availability: (a) per capita internal blue water availability, (b) per capita total blue water availability, (c) per capita total [internal blue + external blue + (internal) green] water availability, and (d) as estimated by Kampman (2007). We use Figure 2 as a starting point but omit states with net inflow or outflow less than  $2 \times 10^9$  m<sup>3</sup>/yr, given the approximate nature of Kampman’s (2007) estimates.

If water endowments were to influence virtual water trade as hypothesized by the virtual water theorists, we would expect that as we move along the plots from left to right, moving from the largest exporters to the largest importers, the water resource endowments would show a declining trend. The four trend lines do not depict strong correlations ( $R^2$  in the range of 0.004 to 0.060) or point to any such trend. Thus clearly, in the case of interstate virtual water flows, better water endowments do not lead to higher virtual water exports.

International trade in agricultural commodities depends on a lot more factors than differences in water scarcity in the trading nations, such as differences in availability of land, labor, knowledge and capital and differences in economic productivities in various sectors. Also the existence of domestic subsidies, export subsidies or import taxes in the trading nations

may influence the trade pattern. As a consequence, international virtual water transfers cannot be explained at all, or can only be partially explained on the basis of relative water abundances or shortages (De Fraiture et al. 2004; Wichelns 2004). Yang et al. (2003) demonstrated that it was only below a certain threshold in water availability that an inverse relationship can be established between a country's cereal import and its per capita renewable water resources. As shown here, trade of agricultural commodities between Indian states is not governed by water-scarcity differences between the states.

Figure 4a. Virtual water trade and per capita green water availability ( $R^2 = 0.004$ ), as estimated by Kampman (2007).

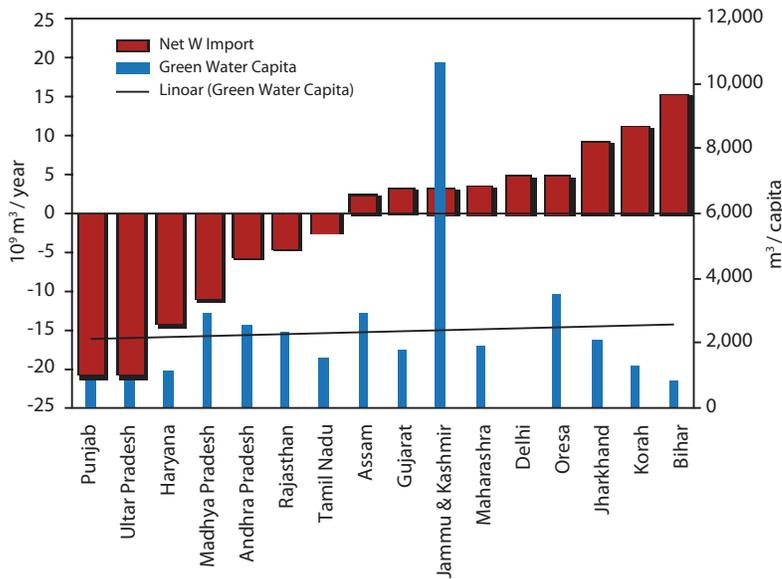


Figure 4b. Virtual water trade and per internal blue water availability ( $R^2 = 0.058$ ), as estimated by Kampman (2007).

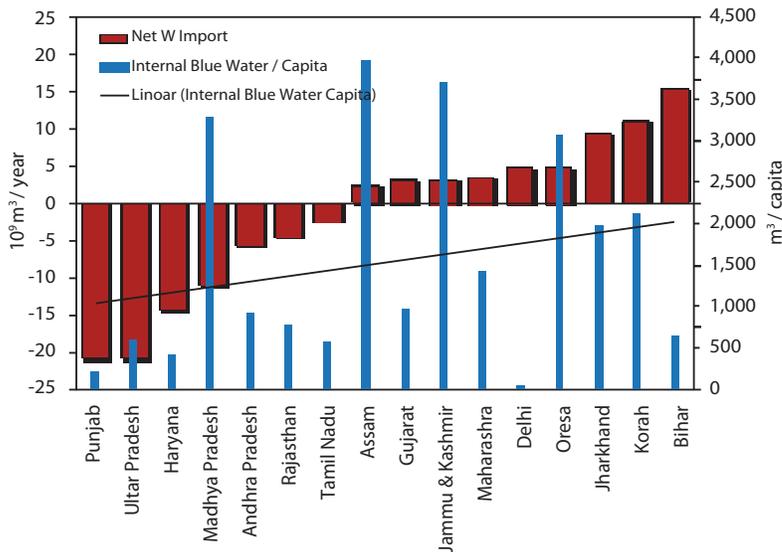


Figure 4c. Virtual water trade and per capita total blue water availability ( $R^2 = 0.004$ ), as estimated by Kampman (2007).

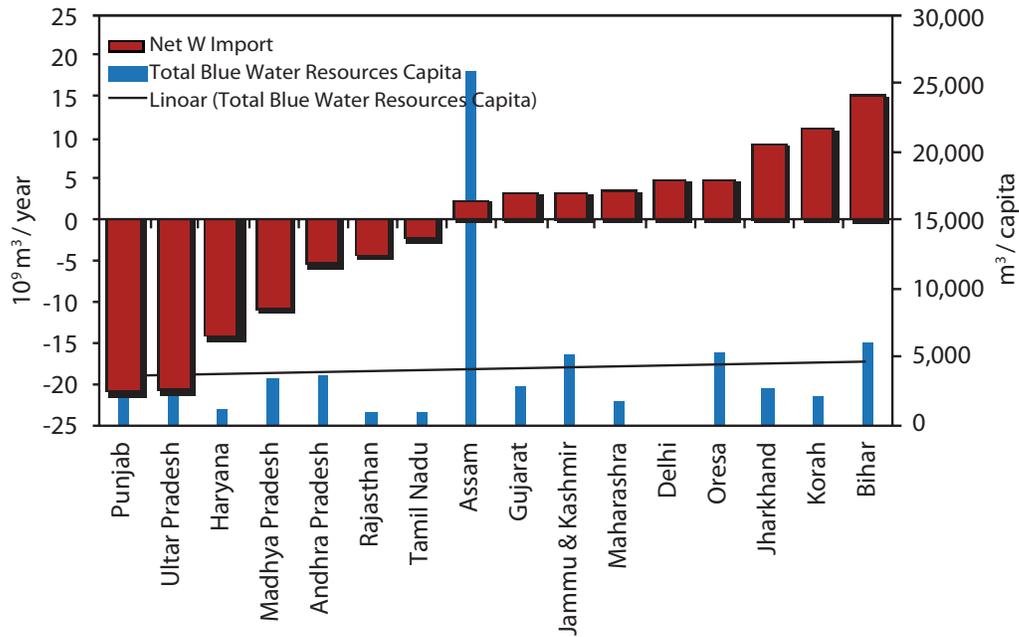
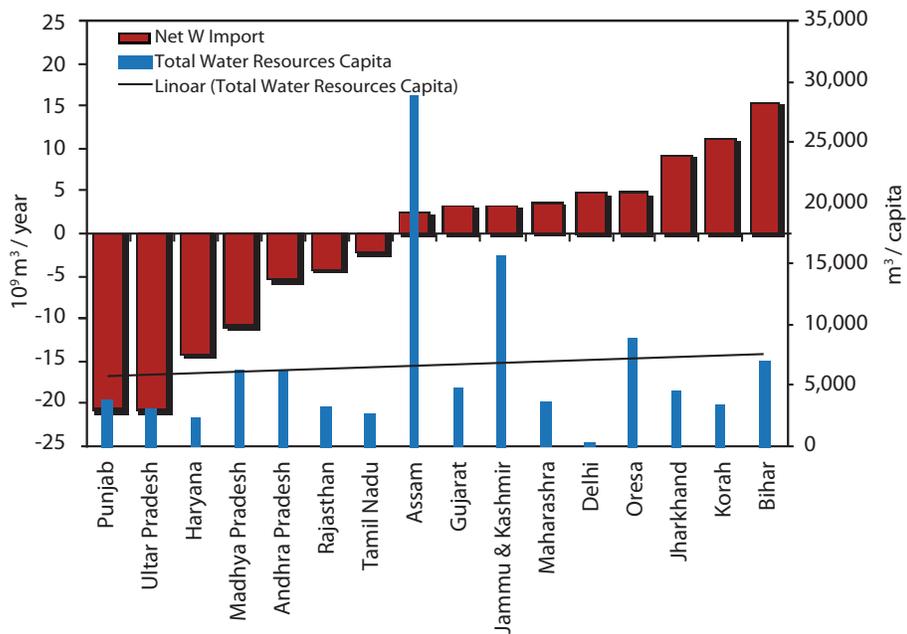


Figure 4d. Virtual water trade and per capita total resource water availability ( $R^2 = 0.006$ ), as estimated by Kampman (2007).



Source: Verma et al. 2009.

Figure 5. Virtual water trade, as estimated by kampman (2007) and per capita Gross Cropped Area (GCA) ( $R^2 = 0.39$ ). Data Source : Ministry of Agriculture, Government of India; accessed from www.indiastat.com.

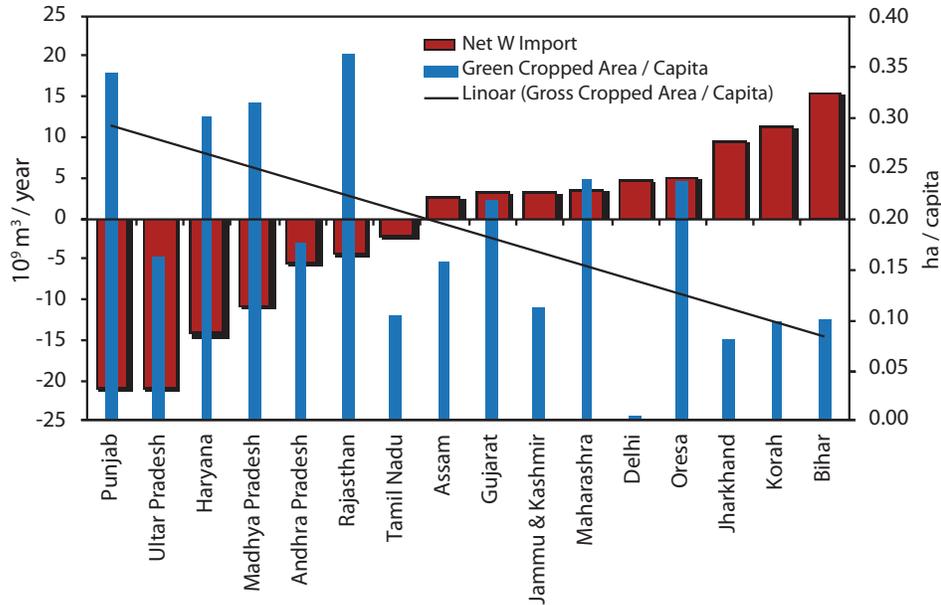
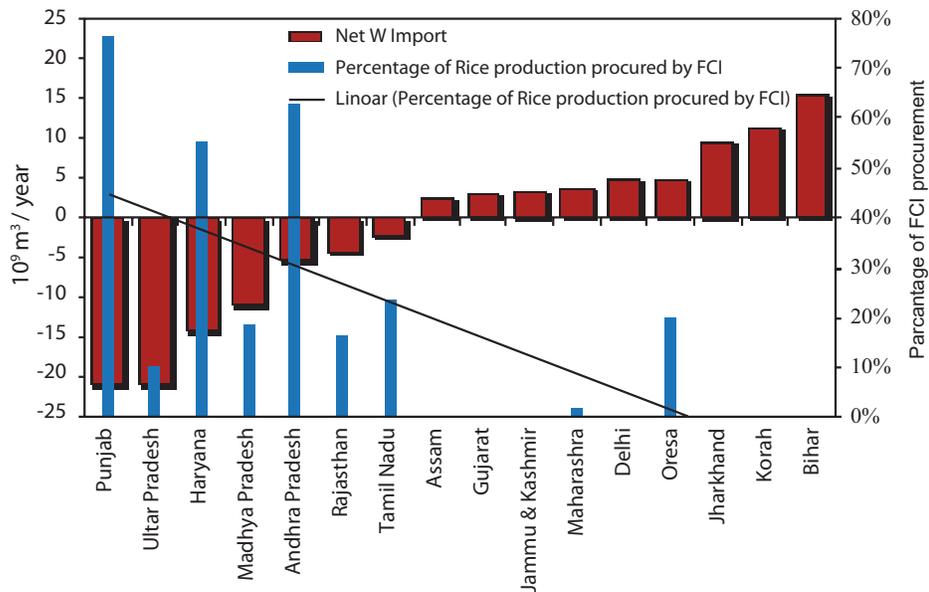


Figure 6. Virtual water trade, as per Kampman (2007) and percentage of rice production procured by Food Corporation of India (FCI) ( $R^2 = 0.47$ ). Data Source: Ministry of Agriculture, Government of India; accessed from www.indiastat.com.



Source: Verma et al. 2009.

If it is not water endowment that determines the direction of virtual water flow, then what does? In a recent paper analyzing data for 146 countries across the globe, Kumar and Singh (2005) have argued that a country's virtual water surplus or deficit is not determined by its water situation. They concluded that no correlation exists between relative water availability in a country and virtual water trade or the volume of water embedded in the food and food products traded. Several water-rich countries including Japan, Portugal and Indonesia have recorded high net virtual water imports.

Further analysis of 131 countries in the same paper showed that "access to arable land" can be a key driver of virtual water trade. We test this "access to arable land" hypothesis using per capita gross cropped area data for the Indian states (Figure 5). As can be seen from Figure 5, per capita gross cropped area does seem to assert a strong influence on net virtual water exports. The correlation coefficient ( $R^2 = 0.39$ ) is much higher than that related to water endowment.

In our analysis of high food exports from the northern Indian states, it was suggested that "access to secure markets" could be a key determinant of why the Punjab continues to produce food grains. We therefore also test "access to secure markets" across virtual water importing and exporting states by using the proxy variable of 'percentage of rice production procured by the Food Corporation of India' (Figure 6). We find that this percentage correlates well with net virtual water exports ( $R^2 = 0.47$ ). Thus we see that while the correlation between water endowments and virtual water surplus/deficit is very weak, access to arable land and access to secure markets are much more strongly correlated with virtual water exports.

### **Discussion: Why H-O Does Not Work for H<sub>2</sub>O?**

If the H-O model of international trade was able to explain the quantum and direction of trade, we would have expected water endowments to be strongly and positively correlated with a region's virtual water exports. However, our estimates of interstate virtual water trade clearly do not match with such a pattern. One of the reasons for this could be the method Kampman (2007) applied for estimating interstate trade. Kampman assumed that trade (import or export) is equal to the difference between production and consumption within a state. Thus, only surplus states export and only deficit states import. Such an estimation procedure implicitly assumes that all traded agricultural goods are undifferentiated commodities. But we know that products such as basmati rice, branded dairy products and other differentiated (or branded) agricultural commodities negate this assumption. However, in comparison to the total volume of virtual water traded, the proportion of virtual water embedded in branded products is perhaps small.

Another reason that the H-O model fails to apply is that it requires pre-trade resource prices to be in relation to resource endowments. In the case of water, this does not happen, especially at the farm level. Farmers in water-rich states such as Bihar face a much steeper price for using water for irrigation compared to water-scarce states like the Punjab. This can be attributed to the public policy biases in favor of regions such as the Punjab. Thus while a region might be facing physical water scarcity, the farmers do not face any economic scarcity while the reverse is true for wetter regions.

Thus, though intuitively appealing as a concept, the idea of using virtual water as a tool for water saving, or as an alternative to physical water transfers, has limited applicability

in the current scenario. Virtual water trade theorists have often implicitly and erroneously assumed that water-abundant countries (or regions) necessarily enjoy comparative advantage in the production of water-intensive commodities. The patterns of interstate virtual water trade in India and global food trade trends discussed by De Fraiture et al. (2004) show that water endowments alone are unable to explain the direction and magnitude of trade. The Leontief paradox holds as much in the case of virtual water trade as it does for other goods. The implicit assumption behind measuring every commodity by its virtual water content is that water is the most critical and scarcest resource input. However, this assumption does not always hold. There are several key inputs that go into the production of food and these other 'factors of production' might tilt the balance of decisions against the logic of virtual water which dictates water saving as the sole criterion.

Thus, the H-O model will work to efficiently allocate water resources if and only if they constitute the most critical resource in the production process. If, on the other hand, another resource such as land becomes the critical constraint, efficient allocation will optimize land use and not water use. By importing food grains from a land-rich state, a land-scarce region is economizing on its land use. Following the virtual water trade logic, this can be termed as *virtual land trade* (see Würtenberger et al. 2006). A land-scarce region (such as Bihar) would import crops from regions where land productivity is higher (for instance, the Punjab). In order to produce the same amount of food as in the Punjab, Bihar would have to employ more land than Punjab (Aggarwal et al. 2000). If, and as long as, land is the critical constraining resource, Bihar would like to economize on its land use, even at the cost of inefficient or incomplete utilization of its abundant water resources.

## Conclusions and Implications for India's River Linking Project

The mean annual interstate virtual water trade in India has been estimated to be  $106 \times 10^9$  m<sup>3</sup>/yr for the years 1997–2001 (Kampman 2007). While these estimates are neither precise nor comprehensive (for instance, Kampman's estimates do not include virtual water trade through trade in milk and milk products), they do illustrate that the quantum of interstate virtual water trade is comparable to the proposed interbasin water transfers proposed by the Government of India under the NRLP ( $178 \times 10^9$  m<sup>3</sup>/yr). Significantly, the estimates also show that the direction of virtual water trade runs opposite to the proposed physical transfers. While physical water transfers are proposed from 'surplus' to 'deficit' basins, interstate virtual water flows move from water-scarce to water-rich regions.

The existing pattern of virtual water trade is exacerbating scarcities in already water-scarce regions and our analysis has shown that rather than being dictated by water endowments, trade patterns are influenced by factors such as per capita availability of arable land and, more importantly, by biases in food and agriculture policies of the Government of India as indicated by the FCI's procurement patterns. Given that the desperation of the 1960s and 1970s with respect to national food security no longer persists, there is a strong case for reversing this trend through changes in food procurement and input subsidy policies.

According to international trade theory, there are five basic reasons why trade takes place between two entities: (1) differences in technological abilities, as explained by the Ricardian model of comparative advantage; (2) differences in resource endowments, as explained by the H-O model; (3) differences in demand, which partly explain trade between surplus entities, as explained by the Linder effect; (4) existence of economies of scale, as enumerated by the new

trade theory; and (5) existence of government policies which might create new comparative advantages and disadvantages that are different from natural advantages and disadvantages (Suranovic 2007).

Much of the literature on virtual water trade, just as the H-O Model of international trade, focuses almost entirely on differences caused by factor (in this case, water) endowments or on the Ricardian logic of trade. However, this paper argues that in order to have a comprehensive understanding of the behavior of agents in trade, all other reasons including endowments of non-water factors of production (such as land) need to be taken into consideration. Further, it is *economic* rather than *physical* water scarcity/abundance that influences trade and economic scarcity as defined by government policies on agricultural inputs, extension services, access to assured markets and minimum support prices.

Finally, while our analysis based on estimates of trade balances at the state level provides a conceptual picture of the conflict between the two alternatives of virtual water trade and physical interbasin water transfers, the same can more accurately be evaluated by carrying out an empirical study of the potential of virtual water trade in a particular proposed river link. Three of the 30 odd links proposed under the NRLP are independent links and the first one most likely to be implemented is the Ken-Betwa link between two adjoining subbasins in central India. Carrying out such an analysis at that scale with data on actual (as opposed to estimated) trade and better estimates of water resources in the donor and recipient basins will be a useful exercise to further our understanding of virtual and physical transfers across river basins, and their possible trade-offs.

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## References

- Aggarwal, P.K.; Talukdar, K.K.; Mall, R.K. 2000. *Potential yields of rice-wheat system in the Indo-Gangetic plains of India*. Rice-Wheat Consortium Paper Series 10. New Delhi, India: Rice-Wheat Consortium for the Indo-Gangetic Plains p.16.
- Allan, J.A. 1993. Fortunately there are substitutes for water otherwise our hydro-political futures would be impossible. In: *Priorities for water resources allocation and management*, ed. ODA, London: Overseas Development Administration pp. 13-26.
- Allan, J.A. 1994. Overall perspectives on countries and regions. In: *Water in the Arab World: Perspectives and prognoses*, ed. Rogers, P.; Lydon, P. Cambridge, Massachusetts: Harvard University Press, pp.65-100.
- Allan, J.A. 1998. Virtual water: A strategic resource, global solutions to regional deficits. *Groundwater* 36 (4): 545-546.
- Allan, J.A. 2003. Virtual water - the water, food, and trade nexus: Useful concept or misleading metaphor? *Water International* 28 (1): 106-113.
- Antras, P. 2007. Lecture notes on international economics I. MIT 14.581 (graduate), Spring 2007. Cambridge, MA: Massachusetts Institute of Technology (MIT). Available online (last accessed in May 2007) [stellar.mit.edu/S/course/14/sp07/14.581/materials.html](http://stellar.mit.edu/S/course/14/sp07/14.581/materials.html)
- Bandyopadhyay, J.; Perveen, S. 2004. *The doubtful science of interlinking*. India Together, February. Available online (last accessed on 7 October 2006). [www.indiatogether.org/2004/feb/envbadsci-p1.htm](http://www.indiatogether.org/2004/feb/envbadsci-p1.htm)
- Bergstrand, J. H. 1990. The Heckscher-Ohlin-Samuelson model, the Linder hypothesis and the determinants of bilateral intra-industry trade. *Economic Journal* 100 (403): 1216-1229.
- Chapagain, A.K. 2006. *Globalisation of water: Opportunities and threats of virtual water trade*. PhD dissertation, UNESCO-IHE, TU Delft, University of Twente. The Netherlands: A.A. Balkema Publishers.
- Chapagain, A.K.; Hoekstra, A.Y. 2003. *Virtual water flows between nations in relation to trade in livestock and livestock products*. Value of Water Research Report Series # 13. Delft, the Netherlands: UNESCO-IHE.
- Chapagain, A.K.; Hoekstra, A.Y. 2004. *Water footprint of nations*. Value of Water Research Report Series # 16. The Netherlands: UNESCO-IHE, Delft.
- Chapagain, A.K.; Hoekstra, A.Y.; Savenije, H.H.G. 2005. *Saving water through global trade*. Value of Water Research Report Series # 17. Delft, the Netherlands: UNESCO-IHE.
- Davis, D.R. 2007. Notes on competitive trade theory. Lecture notes from Columbia University, New York. Available online [www.columbia.edu/~drd28/Text.pdf](http://www.columbia.edu/~drd28/Text.pdf) (last accessed in May 2007).
- De 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. Colombo, Sri Lanka: Comprehensive Assessment Secretariat.
- Gupta, J.; Van der Zaag, P. 2007. Interbasin water transfers and integrated water resources management: Where engineering, science and politics interlock. *Physics and Chemistry of the Earth* 33: 28-40.
- Haddadin, M.J. 2003. Exogenous water: A conduit to globalization of water resources. In: *Virtual water trade: Proceedings of the International expert meeting on virtual water trade*, ed. Hoekstra, A.Y. Value of Water Research Report Series # 12. Delft, the Netherlands: UNESCO-IHE.
- Hoekstra, A.Y. 2003. Virtual water: An introduction. In: *Virtual water trade: Proceedings of the International expert meeting on virtual water trade*, ed. Hoekstra, A.Y. Value of Water Research Report Series # 12. Delft, the Netherlands: UNESCO-IHE.

- Hoekstra, A.Y.; Chapagain, A.K. 2007a. *Globalization of water: Sharing the planet's freshwater resources*. Oxford, UK: Blackwell Publishing.
- Hoekstra, A.Y.; Chapagain, A.K. 2007b. Water footprints of nations: Water use by people as a function of their consumption pattern. *Water Resources Management* 21(1): 35-48.
- Hoekstra, A.Y.; Hung, P.Q. 2002. *Virtual water trade: A quantification of virtual water flows between nations in relation to international crop trade*. Value of Water Research Report Series # 11. Delft, the Netherlands: UNESCO-IHE.
- Hoekstra, A.Y.; Hung, P.Q. 2005. Globalisation of water resources: International virtual water flows in relation to crop trade. *Global Environmental Change* 15 (1) : 45-56.
- IESC (International Economics Study Center). 2007. Website of the International Economics Study Center (IESC) (last accessed in May 2007). [internationalecon.com/Trade/T-toc.php](http://internationalecon.com/Trade/T-toc.php).
- IWMI (International Water Management Institute). 2003. Strategic Analyses of India's National River Linking Project (NRLP). Proposal submitted to the CGIAR Challenge Program on Water and Food. Available online (last accessed on 9 October 2006).
- Iyer, R. 2002. Linking rivers: Vision or mirage. *Frontline* 19 (25), December 7. Available online (last accessed on 8 October 2006). [www.frontlineonnet.com/fl1925/stories/20021220001504900.htm](http://www.frontlineonnet.com/fl1925/stories/20021220001504900.htm)
- Kampman, D.A. 2007. Water footprint of India: A study on water use in relation to the consumption of agricultural goods in the Indian states. Masters' thesis. Enschede: University of Twente.
- Kumar, M.D.; Singh, O.P. 2005. Virtual water in global food and water policy making: Is there a need for rethinking? *Water Resources Management* 19: 759-789.
- Linder, S.B. 1961. *An essay on trade and transformation*. Stockholm: Almqvist and Wiksell.
- Ma, J. 2004. Assessment of virtual water trade as a tool in achieving food security in China. MS thesis. Delft, the Netherlands: UNESCO-IHE.
- Ma, J.; Hoekstra, A.Y.; Wang, H.; Chapagain, A.K.; Wang, D. 2006. Virtual versus real water transfers within China. *Phil. Trans. R. Soc. B*, 361: 835-842.
- NCIWRD (National Commission for Integrated Water Resource Development). 1999. *Integrated water resource development: A plan for action*. Report of the National Commission for Integrated Water Resource Development (NCIWRD). Volume I. Government of India: Ministry of Water Resources.
- NWDA (National Water Development Agency). 2006. Inter basin water transfer: The need. National Water Development Agency. Available online (last accessed on 7 October 2006). [nwda.gov.in/index2.asp?sublinkid=46&langid=1](http://nwda.gov.in/index2.asp?sublinkid=46&langid=1)
- Oki, T.; Kanae, S. 2004. Virtual water trade and world water resources. *Water Science & Technology* 49 (7): 203-209.
- Oki, T.; Sato, M.; Kawamura, A.; Miyake, M.; Kanae, S.; Musiake, K. 2003. Virtual water trade to Japan and in the world. In: *Virtual water trade: Proceedings of the International expert meeting on virtual water trade*, ed. Hoekstra, A.Y. Value of Water Research Report Series # 12. Delft, the Netherlands: UNESCO-IHE.
- Patkar, M. 2004. *River linking: A millennium folly?* India: National Alliance of Peoples' Movements (NAPM) and Initiative, 131p.
- Renault, D. 2003. Value of virtual water for food: Principles and features. In: *Virtual water trade: Proceedings of the International expert meeting on virtual water trade*, ed. Hoekstra, A.Y. Value of Water Research Report Series # 12. Delft, the Netherlands: UNESCO-IHE.

- Savenije, H.H.G. 2004. The role of green water in food production in sub-Saharan Africa. Article prepared for the Food and Agriculture Organization of the United Nations (FAO). Available online (last accessed on 7 October 2006). [www.wcainfonet.org/cds\\_upload/documents/1352.Role\\_of\\_green\\_water.pdf](http://www.wcainfonet.org/cds_upload/documents/1352.Role_of_green_water.pdf)
- Suranovic, S.M. 2007. International trade theory and policy. Online textbook on International Trade (last accessed in April 2007), International Economics Study Center. [internationalecon.com/Trade/tradehome.php](http://internationalecon.com/Trade/tradehome.php)
- Vaidyanathan, A. 2003. Interlinking of peninsular rivers: A critique. *Economic and Political Weekly*, July 5, pp. 2865-2871.
- Verma, S. 2007. Can H-O work for H<sub>2</sub>O? Interstate virtual water trade as an alternative to inter basin water transfers in India. MSc thesis. Delft: Institute for Water Education, UNESCO-IHE.
- Verma, S. 2009a. Addressing India's water challenge 2050: the virtual water trade option. Paper presented at "Strategic Issues in Indian Irrigation", National Workshop: International Water Management Institute and Challenge Program for Water and Food Project on "Strategic Analyses of India's National River Linking Project," New Delhi, Apr 7-8.
- Verma, S. 2009b. Securing India's water future 2050: Can domestic virtual water trade play a role? Keynote address, "Securing access to water-related goods through trade." Selected for publication in "The Best of World Water Week 2009." Stockholm World Water Week, 16-22 August.
- Verma, S.; Phansalkar, S. 2007. India's water future 2050: Potential deviations from 'business-as-usual'. *International Journal of Rural Management*. Sage Publications.
- Verma, S.; Van der Zaag, P. 2007. Virtual water trade and India's water future 2050. Paper presented at the EGU General Assembly, session "Water resources assessment with special focus on developing countries". Vienna, 18 April. *Geophysical Research Abstracts* Vol. 9, No. 05601
- 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. Paper presented at the International Forum on Water and Food (IFWF2), Addis Ababa, Ethiopia, Nov 10-14.
- Vombatkere, S.G. 2003. Interlinking: Salvation or folly? India Together, February. Available online (last accessed on 7 October 2006). [www.indiatogether.org/environment/water/wtrsgvintlink.htm](http://www.indiatogether.org/environment/water/wtrsgvintlink.htm)
- Wichelns, D. 2001. The role of 'virtual water' in efforts to achieve food security and other national goals, with an example from Egypt. *Agricultural Water Management* 49: 131-151.
- Wichelns, D. 2004. The policy relevance of virtual water can be enhanced by considering comparative advantages. *Agricultural Water Management* 66(1): 49-63.
- Würtenberger, L.; Koellner, T.; Binder, C.R. 2006. Virtual land use and agricultural trade: Estimating environmental and socio-economic impacts. *Ecological Economics* 57: 679-697.
- Yang, H.; Reichert, P.; Abbaspour, K.C.; Zehnder, A.J.B. 2003. A water resources threshold and its implications for food security. In: *Virtual water trade: Proceedings of the International Expert Meeting on Virtual Water Trade*, ed. A.Y. Hoekstra. Value of Water Research Report Series No. 12. Delft: UNESCO-IHE, pp. 111-117.
- Zimmer, D.; Renault, D. 2003. Virtual water in food production and global trade: Review of methodological issues and preliminary results. In: *Virtual water trade: Proceedings of the International expert meeting on virtual water trade*, ed. Hoekstra, A.Y. Value of Water Research Report Series # 12. Delft, the Netherlands: UNESCO-IHE.