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# Export and import of virtual water from different states of India through food grain trade

Vijay Kumar and Sharad K. Jain

## ABSTRACT

The geographical area of India is $3.29 \times 10^6$ km$^2$ and the annual average precipitation is about 4000 km$^3$ (about 1215 mm depth over the country). Large variations in agricultural practices, climate and land productivity result in large variations in agricultural productivity between states. Virtual water refers to the water required in the production of goods or services; exchange of water through goods and services is virtual water trade. This paper quantifies virtual water export/import from/to various states of India to/from a central pool related to trade of two major food grains, wheat and rice, during the years 2003–04 to 2005–06. Virtual water contents of wheat and rice were estimated for different states using the data pertaining to that state. It was found to vary from 745 to 9405 m$^3$/t for wheat and from 2502 to 9562 m$^3$/t for rice. Punjab, Haryana, Chattisgarh and Uttarakhand are net exporters of virtual water to the central pool; all other states are net importers. Among the virtual water exporters, Punjab and Haryana are water-stressed areas and some virtual water importing states have adequate water resources. Analysis shows that besides water availability, other factors are also important in determining virtual water export from a region.

**Key words** | export, food grain, import, states of India, virtual water

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## INTRODUCTION

Water is required for the production of food such as cereals, vegetables, meat and dairy products. The amount of water consumed in the production process of an agricultural or industrial product is called the "virtual water" associated with the product. The adjective "virtual" is used because water is not currently contained in the product. The concept of virtual water was introduced by Professor J. A. Allan in the early 1990s (Allan 1993). This concept is also referred to as "embedded water" or "exogenous water" (Verma *et al.* 2009).

The virtual water concept has some practical uses. Virtual water trade can be an instrument in solving geopolitical problems and even preventing wars over water (Allan 1993, 2003). Further, the virtual water associated with a product tells something about the environmental impacts of consuming this product. The amount of water we drink each day, and use for washing, sanitation and other household tasks seem small when compared with the amount of water associated with the food that we consume.

Virtual water trade takes place during trade of various goods and services. Some countries of the world do not have adequate water to meet their current and projected water needs while in some other countries, available water is surplus to the demands for uses including municipal and industrial, agricultural, environmental and ecology, recreation, navigation, etc. Further, in large countries, there are regions of both surplus and deficient water availability. A possible approach to overcome this spatial mismatch between water availability and demand is to transport water from surplus regions to deficient regions. A viable option for water-scarce countries is to import water-intensive products rather than produce them domestically. By the year 2000, the Middle East and North Africa (known as MENA) region was

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importing 50 million tonnes of grain annually (Allan 2002). The flow of virtual water through this trade is equivalent to 50 billion ($10^9$) $m^3$, which is nearly the annual flow of the Nile River into Egypt (Allan 2002). Allan (2002) noted that this has been a major factor in averting conflict over water in the region because, since the early 1970s, local water resources have been insufficient for the production of food for local needs. In the similar vein, water-rich countries could reap benefits from their abundant water resources by producing and exporting products that consume large quantities of water. Of course, in reality things are not so simple and additional questions of food security, energy security, employment, etc., enter the picture. Virtual water trade is becoming an important concept of water management at the global as well as regional level, particularly in regions where water is scarce. Many studies (Hoekstra & Hung 2002; Oki *et al*. 2003; Renault 2003; Chapagain & Hoekstra 2004) have estimated the virtual water content of different products and the magnitude of virtual water trade between various countries.

Employing the concept of ecological footprint, Chapagain & Hoekstra (2004) advanced the concept of "water footprint" to indicate volume of water use and pollution by various nations. The water footprint of an individual, community or business can be defined as the total volume of freshwater that is used to produce the goods and services consumed by the individual or community or produced by the business (http://www.waterfootprint.org). Water use is measured in terms of water volumes consumed (evaporated) and/or polluted per unit of time. The water footprint is a geographically explicit indicator that not only shows volumes of water use and pollution, but also their locations. Broadly, "footprint" is a quantitative measure of the use/consumption of natural resources. For instance, ecological footprint is a measure of human demand on the Earth's ecosystems (Wikipedia) and the carbon footprint measures energy use in terms of the total volume of carbon dioxide emissions. The water footprint measures water use (volume/year).

Falkenmark & Rockström (2006) argued that the focus of conventional water-resource planning and management is on liquid water, or *blue water* (surface water and ground water) which served the needs of engineers who were primarily concerned with water supply and infrastructure projects. However, blue water only represents one-third of the real freshwater resource – the rainfall over the continents. Most rain flows back to the atmosphere as a vapor flow, dominated by consumptive water use by the vegetation. Falkenmark & Rockström (2006) estimated that global food production consumes approximately 6800 $km^3$ a year of water worldwide. Of this amount, 1800 $km^3$ a year is consumed through allocation of blue water in irrigated crop production, whereas the remaining 5000 $km^3$ a year is consumption of the green-water resource. According to NRC (1986), the precipitation on land and oceans is 107000 $km^3$ a year and 398000 $km^3$ a year respectively while evapotranspiration from land mass is 71000 $km^3$ a year.

When analyzing food production, it is necessary to incorporate a second form of water resource, the *green-water* which is the moisture present in soil and plants. Aldaya *et al*. (2010) have evaluated the strategic importance of green water in relation to international commodity trade and have concluded that "the importance of international green virtual water 'trade' and its contribution to water and food security in the future will, though, depend on factors such as the productivity of blue and green water, international trade agreements, the costs of engaging in trade, and the nature of domestic economic objectives and political considerations".

The total water footprint of a nation or individual is made up of two components: the blue and the green water footprint. The blue water footprint is the volume of water withdrawn from the global blue water resources to fulfill the national or individual demand for goods and services. The green water footprint is the volume of water used from the global green water resources to fulfill the demand for goods and services (Chapagain & Hoekstra 2004).

## Major crops of India and virtual water trade

India occupies the south-central peninsula of the Asian continent. The Republic of India is a Union consisting of 28 states and 7 union territories; New Delhi is the capital of India (Figure 1). In terms of area, Rajasthan (342,239 $km^2$) is the largest state followed by Maharashtra. Traditionally, India is an agriculture-based country; the agriculture sector has a vital place in the economic development of India as it contributes 23% of GDP and employs about 64% of the workforce. India has mainly two agricultural seasons. The Kharif is the monsoon crop season (June to October) whose crops include rice, millets, maize, groundnuts, jute, cotton, and pulses. The Rabi Season crops are sown in November

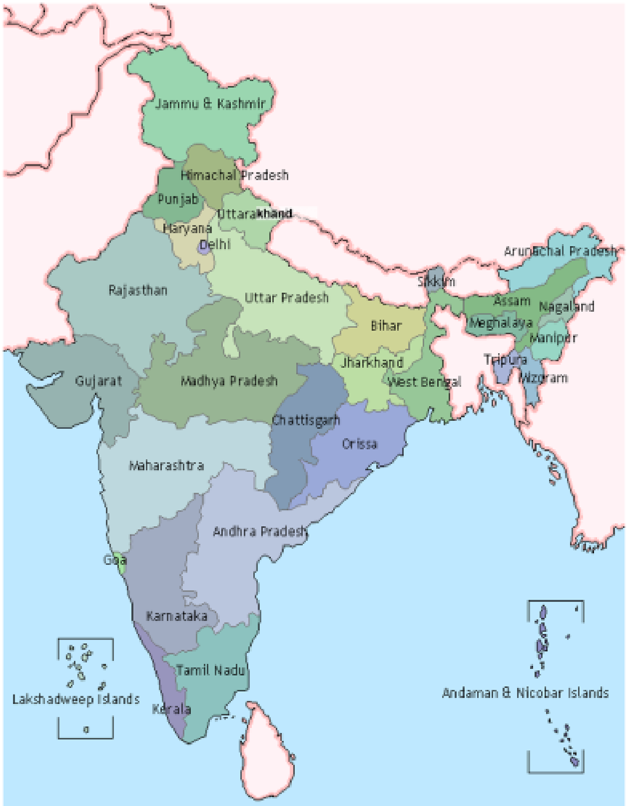


**Figure 1** | Map of India showing different states.

and are harvested in April. The major crops of this season are wheat, gram (chickpea), and oil seeds. Besides these two, farmers in irrigated areas are able to reap a third harvest during May to July, which is known as the hot weather or Jayad season. In addition to food crops, India also produces a large number of non-food or cash crops like, sugarcane, tea, coffee, cotton, tobacco, rubber, and spices (Jain *et al.* 2007).

The virtual water trade for India has been estimated by various authors (Hoekstra & Hung 2002; Zimmer & Renault 2003; Chapagain & Hoekstra 2004). Kumar & Jain (2007) reviewed the status of virtual water trade from India. According to the latest estimate by Chapagain & Hoekstra (2004), India has exported $42.5 \times 10^9$ m$^3$ a year of virtual water with net export of $25.4 \times 10^9$ m$^3$/yr. Out of the total export of $42.5 \times 10^9$ m$^3$ a year, crop trade contributed 76%, livestock 8% and industrial products 16%, whereas out of the total import, 81% trade was related to crop, 2% to livestock and the remaining 17% to industrial products. Soybean and palm oil were the major crops for virtual water export and import, respectively. During the period 1997–2001, India was among the top 15 gross virtual water exporters and among the top 10 net virtual water exporters. Chapagain *et al.* (2005) calculated virtual water export from India related to export of cotton products as $25.66 \times 10^9$ m$^3$ a year, which consists of $16.83 \times 10^9$ m$^3$ of green water, $5.75 \times 10^9$ m$^3$ of blue water and the remaining $3.08 \times 10^9$ m$^3$ for dilution water (it is the volume of water required to dilute waste, produced during the growth and processing of cotton, to such an extent that the quality of water remains within the agreed water quality standards).

In this paper, the virtual water associated with wheat and rice for different states of India has been calculated. The paper then quantifies the volume of virtual water export and import for various states of India related to trade of major food grains, i.e., wheat and rice.

## METHODOLOGY

The virtual water content of a product is the quantity of water that is used to produce it. The quantity depends upon the technology and conditions of production. The virtual water associated with various primary and processed crop products, livestock products and industrial products for different countries including India was estimated by Chapagain & Hoekstra (2004). In this study, the virtual water associated with various crop and crop products was calculated considering the country's average climate data. For example, to calculate the virtual water associated with crop products for India, the climate data used corresponds to the capital city of the country (New Delhi). Like any other large country, the climate in India significantly varies spatially and hence the virtual water for various crops and crop products will also have large spatial variations depending upon the place of production. Keeping this in view, virtual water for wheat and rice for different states of India has been estimated using the data pertaining to that state.

The methodology described in Chapagain & Hoekstra (2004) and Hoekstra & Chapagain (2007) has been used to calculate the virtual water for the crops. The FAO Penman–Monteith method has been used to calculate the reference evapotranspiration, which is the evapotranspiration of grass given an abundance of water (Allen *et al.* 1998). Reference evapotranspiration for different crops have been calculated using the CROPWAT 8.0 model of FAO (http://www.fao.org/nr/water/infores_databases_cropwat.html).

The green revolution in India in the mid-1960s resulted in a quantum jump in food grain production from $51 \times 10^6$ t in 1950–51 to $203 \times 10^6$ t in 1998–99. But there is large disparity between various states in their production of food grain. Various central and state agencies purchase food grains from different states for a central pool and sell these under the Targeted Public Distribution System and under various welfare programs in different states. The Food Corporation of India (FCI) is the nodal government agency that purchases, stores, transports, and sells food grains. It keeps records of purchases and sales of food grains for different states (FCI 2003–04, 2004–05, 2005–06). In some states, procurement is more than sales (a positive contribution of food grain to the central pool), and in other states it is the reverse (a negative contribution). The amount of virtual water export/import is calculated by multiplying the amount of food grain export/import by the virtual water associated with the respective food grain in the particular state. Note that, besides FCI, food grains are also transported across state boundaries by private traders and retailers but the data of such transport were not available. However, the quantities involved in this transport are comparatively small and are not likely to materially impact the inferences drawn here.

### Data used

The data for the calculation of the reference evapotranspiration are taken from the climate database CLIMWAT 2.0 (http://www.fao.org/nr/water/infores_databases_climwat.html) of the FAO. In this database information on humidity, mean maximum and mean minimum temperature, wind speed, daily sunshine, rainfall and location (altitude, latitude and longitude) of the weather station is available from 167 weather stations across India. The climate data for the capital city of the state or the nearby station in the state (if climate data of the capital city is not available) was used. Subsequently, the reference evapotranspiration was multiplied by crop parameter ($K_c$) to calculate the crop evapotranspiration. The crop parameters have been taken from Tyagi *et al.* (2000*a*, *b*). The crop water requirement is the summation of this potential crop evapotranspiration over the growth period. For rice, an amount of 300 mm of water was added to the crop water requirement to account for percolation during the plantation period (Chapagain & Hoekstra 2004). The virtual water content ($m^3$/tonne or $m^3$/t) of a crop in a state is calculated as the ratio of volume of water ($m^3$/ha) used during the entire period of crop growth in that state to the corresponding crop yield (tonne/ha) in the corresponding state. The state-wise average crop yield data for the period 1999–2000 to 2006–07 were taken from the Ministry of Agriculture (2008), Government of India.

## RESULTS

The average reference evapotranspiration calculated by CROPWAT 8.0 for different states of India are given in Table 1. $ET_o$ varies from 2.71 mm/day (Jammu and Kashmir) to 5.14 mm/day (Rajasthan). The average crop yield, calculated on the basis of eight years (1999–2000 to 2006–07) shows wide variation from state to state. Wheat yield varies from a maximum of 4351 kg/ha in Punjab to a minimum of 736 kg/ha in Karnataka, whereas the rice yield is again maximum in Punjab (3659 kg/ha) and is minimum in Madhya Pradesh (862 kg/ha). Due to variation in crop water requirement and crop yield, the virtual water associated with wheat and rice also varies widely from state to state (Figure 2). Virtual water associated with wheat is lowest in the high wheat crop yield states of Punjab (745 $m^3$/t) and Haryana (989 $m^3$/t), whereas it is very high in the low wheat crop yield states of Karnataka (9405 $m^3$/t) and Andhra Pradesh (8800 $m^3$/t). Virtual water associated with wheat is also high in the states of Chattisgarh, Kerala and Tamil Nadu. The virtual water associated with rice varies from 2502 $m^3$/t in Punjab to as high as 9562 $m^3$/t in Madhya Pradesh.

Table 2 shows the net purchases (purchases minus sales) of wheat and rice for different states of India for the years 2003–04, 2004–05 and 2005–06. Out of the 21 states listed in Table 2 only two states, Punjab and Haryana, were net exporters of wheat to the central pool and all other states were net importers of wheat for all the years. Rajasthan followed by Maharashtra in years 2003–04 and 2005–06 and Maharashtra followed by Rajasthan in year 2004–05 were the biggest net importer of wheat. The amount of wheat imported by Rajasthan, Maharashtra and West Bengal were almost the same during the year 2005–06. For rice, Punjab, Haryana, Uttar Pradesh, Uttarakhand and Chattisgarh were the net exporters and other states were net importers for the years 2003–04 and 2005–06.

For the year 2004–05, Punjab, Haryana, Uttarakhand, Chattisgarh, Andhra Pradesh, and Rajasthan were net exporters and all other states were net importers of rice.

The states having positive contribution of food grains to the central pool effectively export the virtual water whereas the states having negative contribution are importers of virtual water (Table 3). During the year 2003–04, Haryana with a net export of $5706 \times 10^6$ $m^3$ is the biggest exporter of virtual water related to wheat, whereas Maharashtra is the biggest importer with an import of $9559 \times 10^6$ $m^3$ (Figure 3). In this year, Punjab was the biggest exporter of wheat followed by Haryana, whereas Rajasthan imported the maximum quantum of wheat followed by Maharashtra. But due to low virtual water associated with wheat in Punjab (745 $m^3$/t) (as compared to 989 $m^3$/t for Haryana) and Rajasthan (2101 $m^3$/t) (as compared to 4793 $m^3$/t for Maharashtra), these states have exported/imported less virtual water as compared to Haryana and Maharashtra, respectively. Punjab was the biggest net exporter ($22434 \times 10^6$ $m^3$) of virtual water related to export of rice whereas Tamil Nadu ($11236 \times 10^6$ $m^3$) was the biggest importer of virtual water related to rice import (Figure 3). Considering both food grains, Punjab was the biggest net exporter of virtual water and Maharashtra was the biggest net importer of virtual water. All states except Chattisgarh, Uttar Pradesh and Uttarakhand were either net exporters or net importers of virtual water related to both wheat and rice. Chattisgarh, Uttar Pradesh and Uttarakhand were net importers of virtual water related to wheat and net exporters of virtual water related to rice; they were net exporters of virtual water considering both the food grains.

During the year 2004–05, Punjab was the biggest net exporter of virtual water and Maharashtra was the biggest net importer of virtual water related to wheat. Again Punjab was the biggest exporter of virtual water related to rice and Tamil Nadu was the biggest importer of virtual water related to this crop. Punjab has exported the largest amount of virtual water related to wheat ($6659 \times 10^6$ $m^3$) and rice ($20968 \times 10^6$ $m^3$) during the year 2005–06. Maharashtra has imported the biggest amount of virtual water ($9259 \times 10^6$ $m^3$) related to wheat and Tamil Nadu the biggest importer of virtual water ($11082 \times 10^6$ $m^3$) related to rice (Table 3).

It is also seen that the virtual water associated with wheat and rice is the smallest for Punjab and Haryana, the two major contributors of food grain to the central pool. Among the importer states, the virtual water associated with rice is of the same order but it is many times more for wheat. Thus, there is considerable saving of water due to food grain trade at the national level.

## DISCUSSION

Examination of the data given in Table 1 reveals some interesting facts. The yield of wheat in Punjab is nearly six times that of Karnataka while the yield of rice in Punjab is

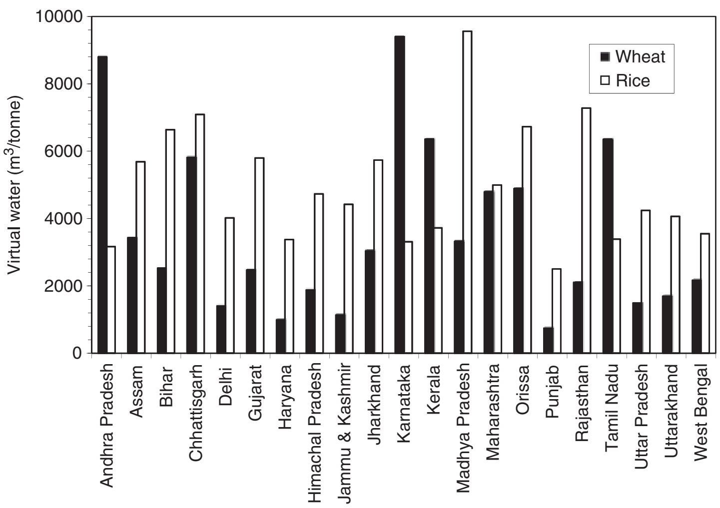


**Figure 2** | Virtual water associated with wheat and rice for different states of India.

**Table 1** | Reference evapo-transpiration (ETo), crop yield and virtual water associated with wheat and rice for different states of India

| | | | Crop Yield (kg/ha)** | | Virtual Water ($m^3$/t) | |
|---|---|---|---|---|---|---|
| S No | State | ETo (mm/day)* | Wheat | Rice | Wheat | Rice |
| 1 | Andhra Pradesh | 4.77 | 751 | 2638 | 8800 | 3166 |
| 2 | Assam | 3.32 | 1140 | 1396 | 3431 | 5684 |
| 3 | Bihar | 4.28 | 1900 | 1327 | 2532 | 6639 |
| 4 | Chattisgarh | 4.51 | 987 | 1139 | 5815 | 7089 |
| 5 | Delhi | 4.83 | 3512 | 2392 | 1402 | 4017 |
| 6 | Gujarat | 4.83 | 2393 | 1541 | 2474 | 5798 |
| 7 | Haryana | 4.33 | 4043 | 2787 | 989 | 3374 |
| 8 | Himachal Pradesh | 2.81 | 1492 | 1466 | 1878 | 4730 |
| 9 | Jammu & Kashmir | 2.70 | 1583 | 1873 | 1135 | 4422 |
| 10 | Jharkhand | 3.78 | 1545 | 1326 | 3036 | 5737 |
| 11 | Karnataka | 4.43 | 736 | 2477 | 9405 | 3309 |
| 12 | Kerala | 3.95 | 1000 | 2162 | 6357 | 3723 |
| 13 | Madhya Pradesh | 4.60 | 1674 | 862 | 3323 | 9562 |
| 14 | Maharashtra | 4.24 | 1318 | 1572 | 4793 | 4996 |
| 15 | Orissa | 4.86 | 1390 | 1259 | 4892 | 6728 |
| 16 | Punjab | 3.84 | 4351 | 3659 | 745 | 2502 |
| 17 | Rajasthan | 5.14 | 2699 | 1299 | 2101 | 7280 |
| 18 | Tamil Nadu | 4.93 | 1000 | 2897 | 6353 | 3389 |
| 19 | Uttar Pradesh | 3.91 | 2685 | 1995 | 1492 | 4242 |
| 20 | Uttarakhand | 3.30 | 1891 | 1910 | 1696 | 4062 |
| 21 | West Bengal | 3.89 | 2254 | 2261 | 2170 | 3546 |

*Based on long-term climate data set of Capital City of State (CLIMWAT 2.0)
**State average crop yield over the period 1999–2000 to 2006–07 (Ministry of Agriculture 2008).

more than four times that of Madhya Pradesh and 1.5 times that of Karnataka. Thus foodgrains are generally being exported from high to low water productive zones. Table 1 also shows that the states that are advanced in industry and services need not be advanced in agriculture (as reflected in productivity). It may be noted that agriculture is labor intensive in India and hence high agricultural growth leads to more equitable social development.

Considering the data pertaining to wheat and rice for three years, Punjab, Haryana, Uttarakhand and Chattisgarh were the net exporters of virtual water, with the largest export from Punjab. Among the net importers, Maharashtra was at the top, closely followed by neighboring state Karnataka. Other major virtual water importing states were Tamil Nadu, Madhya Pradesh, and Assam. A graphical representation of net exporters and importers is shown in Figure 4.

The concept of virtual water trade was advanced as a means of overcoming water scarcity. Since agriculture is the main consumer of fresh water, countries that face water scarcity can and should meet their water demand for food through cereal imports from water-rich countries. Within a large country, the same logic could be advanced to different administrative units. However, the analysis presented here shows that this logic alone fails to explain the reality. The annual rainfall of the top four virtual water exporting states is: Punjab 649 mm, Haryana 617 mm, Uttarakhand 1100 mm, and Chattisgarh 1338 mm. Further, in the virtual water importing states, the annual rainfall is: Maharashtra 901 mm, Karnataka 900 mm, Tamil Nadu 998 mm, Madhya Pradesh 1017 mm, and Assam 2818 mm. Thus rainfall in the largest exporter states is much less than the rainfall in importing states and hence renewable

**Table 2** | Net purchases (purchases minus sales) of wheat and rice (tonnes) from different states of India for year 2003–04, 2004–05 & 2005–06 (FCI 2003–04, 2004–05, 2005–06)

| | | 2003–04 | | 2004–05 | | 2005–06 | |
|---|---|---|---|---|---|---|---|
| **S No** | **State** | **Wheat** | **Rice** | **Wheat** | **Rice** | **Wheat** | **Rice** |
| 1 | Andhra Pradesh | −85472 | −1425232 | −78848 | 262782 | −106522 | −237578 |
| 2 | Assam | −289089 | −1367325 | −435902 | −1531649 | −310869 | −1612437 |
| 3 | Bihar | −1000154 | −233285 | −1032122 | −454518 | −822844 | −368948 |
| 4 | Chattisgarh | −183976 | 956842 | −195381 | 1841122 | −188427 | 2737572 |
| 5 | Delhi | −469572 | −78169 | −443181 | −157369 | −499908 | −115994 |
| 6 | Gujarat | −880641 | −254249 | −809032 | −248196 | −861693 | −286806 |
| 7 | Haryana | 5769621 | 1153087 | 5019638 | 1627161 | 4115458 | 2004753 |
| 8 | Himachal Pradesh | −150634 | −175787 | −177151 | −187690 | −189486 | −208495 |
| 9 | Jammu & Kashmir | −318787 | −451846 | −340109 | −467654 | −348314 | −486165 |
| 10 | Jharkhand | −348407 | −266801 | −394377 | −405551 | −495631 | −531822 |
| 11 | Karnataka | −454033 | −2881368 | −487822 | −2547666 | −629357 | −2098690 |
| 12 | Kerala | −224013 | −778371 | −333941 | −798610 | −452066 | −641645 |
| 13 | Madhya Pradesh | −1876339 | −339655 | −1693220 | −365871 | −1653055 | −372131 |
| 14 | Maharashtra | −1994213 | −897211 | −2343489 | −1006408 | −1931655 | −1093933 |
| 15 | Orissa | −292907 | −693655 | −201955 | −323088 | −216279 | −222491 |
| 16 | Punjab | 7366431 | 7141157 | 10253694 | 8829469 | 8941566 | 8381869 |
| 17 | Rajasthan | −2954588 | −9201 | −1885365 | 9228 | −1945085 | −36494 |
| 18 | Tamil Nadu | −159465 | −3035025 | −123507 | −3197624 | −270115 | −3269977 |
| 19 | Uttar Pradesh | −1475187 | 862812 | −1370637 | −4628 | −1636237 | 345293 |
| 20 | Uttarakhand | −72364 | 60589 | −68530 | 126534 | −90166 | 162448 |
| 21 | West Bengal | −1294123 | −679061 | −1803850 | −781946 | −1921739 | −552063 |

water availability does not correlate well with virtual water trade.

A partial explanation of this can be given by noting that farmers in many states of India including Punjab and Haryana receive subsidized energy to pump ground water. On account of this, large quantities of ground water are withdrawn in these states for irrigation. This largely insulates the farmers from the vagaries of monsoon and water does not become a constraint in agriculture production. A negative fallout of this is that the number of blocks (administrative units) where annual ground water withdrawal exceeds the recharge, is increasing with time. For example, out of 138 blocks (the ground water assessment units) in Punjab, 81 are over-exploited and 12 are severely over-exploited (CGWB 2006). In over-exploited blocks annual groundwater withdrawal exceeds annual recharge and in severely over-exploited blocks annual withdrawal is more than 85% of the annual recharge. In Haryana, 30 blocks out of 111 are over-exploited and 13 are in the severely over-exploited category. In view of this, the sustainability of Punjab and Haryana to contribute large quantity of food grains to the central pool is uncertain.

Kumar & Singh (2005) opined that virtual water flow dynamics is controlled more by the access to arable land than access to renewable freshwater. An analysis of the Indian context shows that factors such as land availability and productivity, infrastructure to support agricultural activities, and farmers' entrepreneurship, land reforms, and rural credit system are the key factors that impact crop production. These factors can be aggregated to create a regional productivity index that determines the surplus quantity of good that can be exported.

**Table 3** | Virtual water export (+ve)/import (−ve) ($10^6$ $m^3$) related to purchase and sale of wheat and rice from different states of India for different years

| S No | State | Wheat 2003–04 | Rice | Total | Wheat 2004–05 | Rice | Total | Wheat 2005–06 | Rice | Total | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Andhra Pradesh | −752 | −4513 | −5265 | −694 | 832 | 138 | −937 | −752 | −1690 | −6816 |
| 2 | Assam | −992 | −7772 | −8764 | −1495 | −8706 | −10202 | −1066 | −9166 | −10232 | −29198 |
| 3 | Bihar | −2532 | −1549 | −4081 | −2613 | −3017 | −5630 | −2083 | −2449 | −4533 | −14244 |
| 4 | Chattisgarh | −1070 | 6783 | 5714 | −1136 | 13053 | 11916 | −1096 | 19408 | 18312 | 35942 |
| 5 | Delhi | −658 | −314 | −972 | −621 | −632 | −1253 | −701 | −466 | −1167 | −3392 |
| 6 | Gujarat | −2179 | −1474 | −3653 | −2001 | −1439 | −3441 | −2132 | −1663 | −3795 | −10888 |
| 7 | Haryana | 5706 | 3891 | 9597 | 4965 | 5490 | 10455 | 4070 | 6764 | 10835 | 30887 |
| 8 | Himachal Pradesh | −283 | −831 | −1114 | −333 | −888 | −1221 | −356 | −986 | −1342 | −3677 |
| 9 | Jammu & Kashmir | −362 | −1998 | −2360 | −386 | −2068 | −2454 | −396 | −2150 | −2545 | −7360 |
| 10 | Jharkhand | −1058 | −1531 | −2588 | −1197 | −2327 | −3524 | −1505 | −3051 | −4556 | −10668 |
| 11 | Karnataka | −4270 | −9535 | −13805 | −4588 | −8430 | −13018 | −5919 | −6945 | −12864 | −39687 |
| 12 | Kerala | −1424 | −2898 | −4322 | −2123 | −2973 | −5096 | −2874 | −2389 | −5263 | −14681 |
| 13 | Madhya Pradesh | −6235 | −3248 | −9483 | −5627 | −3499 | −9126 | −5493 | −3558 | −9052 | −27661 |
| 14 | Maharashtra | −9559 | −4483 | −14041 | −11233 | −5028 | −16261 | −9259 | −5466 | −14724 | −45027 |
| 17 | Orissa | −1433 | −4667 | −6100 | −988 | −2174 | −3162 | −1058 | −1497 | −2555 | −11816 |
| 18 | Punjab | 5486 | 17865 | 23351 | 7636 | 22088 | 29725 | 6659 | 20968 | 27628 | 80703 |
| 19 | Rajasthan | −6208 | −67 | −6275 | −3961 | 67 | −3894 | −4087 | −266 | −4352 | −14521 |
| 20 | Tamil Nadu | −1013 | −10285 | −11298 | −785 | −10836 | −11621 | −1716 | −11082 | −12798 | −35717 |
| 21 | Uttar Pradesh | −2201 | 3660 | 1459 | −2045 | −20 | −2065 | −2441 | 1465 | −976 | −1582 |
| 22 | Uttarakhand | −123 | 246 | 123 | −116 | 514 | 398 | −153 | 660 | 507 | 1028 |
| 23 | West Bengal | −2808 | −2408 | −5216 | −3914 | −2773 | −6687 | −4170 | −1958 | −6128 | −18031 |

## Limitations of the study

The study has some data-related limitations. Only data for purchases/sales of food grains from different states to/from central pool were available. If the data on trade of food grains between different states were available, the virtual water trade between different states could also be estimated. Moreover, transportation of food grains through means other than FCI could not be taken into account (due to non-availability of data) although this quantity is not likely to be very large (probably less than 5% of the total transport). Also data of only two major food grains have been considered. Virtual water is also being traded among the states through vegetables, fruits and other food grains but that has not been considered here.

Another limitation of the study is that the virtual water content of crops is estimated based on crop water requirement. In states where actual water availability is lower than crop water requirement, this may have led to over-estimation of virtual water content.

For calculation of water requirement of wheat and rice, climatological data of the capital city of the state or the nearby station in the state (if climate data of the capital city are not available) were used. In some cases, the capital city is located in one corner or one side of the state. This data may not be representative of all the area in the state. To improve this calculation further, a GIS approach as used by De Silva *et al.* (2007), to estimate the water requirement of rice in Sri Lanka, could be used.

## CONCLUSIONS

Virtual water trade is still a fairly new concept which is slowly receiving attention. This paper reports the virtual water

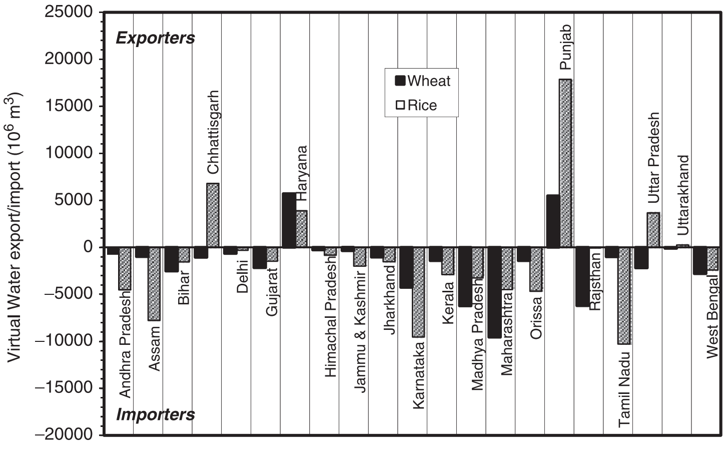


**Figure 3** | Net export/import of virtual water related to trade of wheat and rice from different states during year 2003–04.

export/import from/to different states of India to/from central pool related to trade of major food grains during the years 2003–04, 2004–05 and 2005–06. Punjab and Haryana are the two states which are net exporters of both the food grains (wheat and rice) and so are net exporters of virtual water to the central pool during all the three years. Chattisgarh and Uttarakhand are net exporters of virtual water related to export of rice in all the years. Uttar Pradesh is also the exporter of virtual water related to rice in the years 2003–04 and 2005–06. Andhra Pradesh and Rajasthan have also exported some virtual water embedded in rice in the year 2004–05. All other states are net importers of virtual water through food grains in all the years. Considering all the three years and both the food grains, Punjab ($80703 \times 10^6$ $m^3$) is the net exporters of virtual water along with Chattisgarh ($35942 \times 10^6$ $m^3$), Haryana ($30887 \times 10^6$ $m^3$), and Uttarakhand ($1028 \times 10^6$ $m^3$). Among the net importers, Maharashtra ($45027 \times 10^6$ $m^3$) was at the top followed closely by neighboring Karnataka ($39687 \times 10^6$ $m^3$).

Analysis of rainfall data shows that the virtual water concept alone is not able to explain the patterns of trade in major foodgrains. Currently, virtual water is not being exported from the regions which have a surplus of water to the regions that are facing water deficiency. Rather, it is the other way round for food grain trade. When the viewpoint is further widened, one can see that there are numerous examples of countries which are facing water shortage but are still involved in production of goods that consume large quantities of water. Within the countries also, there are regions of water deficit in which crops that use large amounts of water are being produced. Although virtual water is a useful concept which is likely to gain more attention, export of virtual water

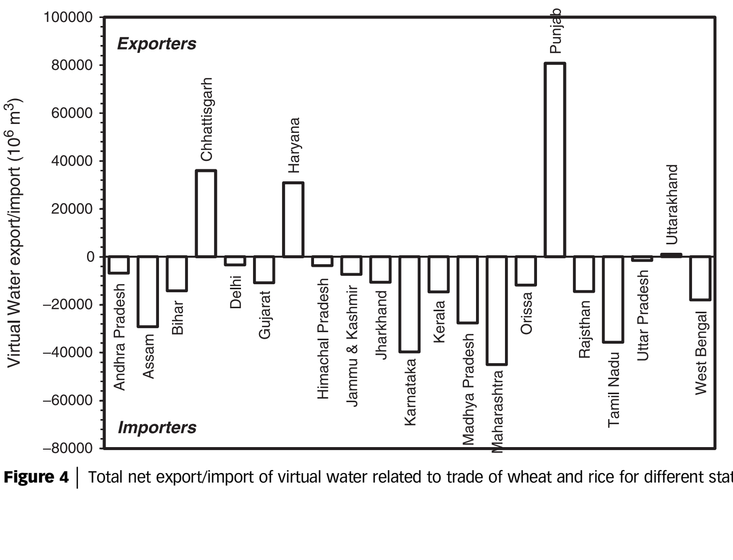


**Figure 4** | Total net export/import of virtual water related to trade of wheat and rice for different states during year 2003–04, 2004–05 and 2005–06.

can be better explained by considering a "regional productivity index" which is a group of factors that determine the surplus quantity of goods that can be exported. In formulating country policies for foodgrain production and its import, other factors besides water, such as food security, employment, socio-political lobbies, skills of the people and traditional professions, etc. are equally and at times more important.

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