Thirsty crops and virtual water flows – making sense of the economically invisible water flows

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Water for irrigation constitutes the highest freshwater demand in any country. For a monsoon-fed country like India, variations in precipitation lead to severe repercussions in the agricultural economy. Water security in India has historically been approached by creating more storage capacity and increasing the supply. Can managing the demand for water be an approach to the challenge of water security? What could be the basis for managing the demand? This article revisits the concepts of virtual water flow and water footprint, to examine their applicability in today's context. The present author has applied the concepts in a dip-stick manner on fruit and sugar export from Maharashtra, India. The quantity of water flowing out of Maharashtra from such exports was assessed. The results show a remarkable quantity of scarce water being diverted to foreign lands. This article also discusses the use of these concepts in water policies to nudge the farmers into making choices appropriate for the region.

Keywords: Agriculture, drought, virtual water flow, water footprint.

WATER and soil are by far, the most important factors of agricultural production. While most parts of India are blessed with rich soil, water is a relatively scarce resource. A large portion of the country depends largely on monsoon. Agriculture is the biggest consumer of water, and this makes water resource management a critically important agenda for every state government. To add to the woes, the effects of climate change are most seen in water resources. This manifests in the form of increasing uncertainty in rainfall and higher evaporation due to temperature rise. On the other hand, the demand for water has continued to grow. The report of the Standing Committee on Water Resources, Government of India[1] estimates the rise in water demanded for irrigation, drinking water, industry, energy and other sectors to be from 710 billion cubic metre (BCM) in 2010 to 843 BCM by 2025, and nearly 1180 BCM by 2050. On the other hand, the water availability will remain at 1123 BCM.

When monsoon fails in any part of the country, it triggers debates on water supply and heated political spats on rural–urban allocation. How much should cities consume and what quantity should be diverted for irrigation? The debates remain unresolved and the vagaries of Indian monsoon continue to hound every state government. The approach to addressing this problem has primarily been to enhance water storage capacity in the states. Relentless dam-building activities all over the country have resulted in over 5264 large dams[2]. However, by focusing on supply side water security, policies have ignored the potential of managing irrigation water demand.

Can managing the demand for water be an approach to the challenge of water crisis? What could be the basis for managing such demand? To answer these questions, the present author revisited the concepts of virtual water flow and water footprint, and examined their applicability in today's context. The present study has applied the concepts in a dip-stick manner on fruit and sugar export from Maharashtra, India. The quantity of water flowing out of Maharashtra from such exports was assessed. The results show a remarkable quantity of scarce water being diverted to foreign lands. On this basis, the study discusses the applicability of these concepts in water policies to nudge the farmers into making choices appropriate for the region.

Methods and data used

Many international organizations on water and agriculture have conducted research on virtual water and water footprints of farm produce in several countries. Some studies have compiled water footprint data of food crops. These publications were referred while conducting the present study. To assess the quantity of virtual water flowing out Maharashtra, data on export of finished sugar, bananas and grapes from state were used. The data were taken from the websites of the National Horticultural Board, MoSFI, APEDA and AgriXchange. Data on water footprint of crops were taken from the detailed compilation done by Mekonnen and Hoekstra[3].

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Considering the narrow scope of the study and absence of primary data, this article is intended to generate interest in deeper research on the applicability of the virtual water concept to water policy for rain-starved regions of India.

Literature review

Water scarcity is common across many regions of the world. While parts of India are severely affected, the Middle East and North African region (MENA) is one of the most arid regions in the world[4]. Freshwater is renewable but limited; and fundamental to social and economic development of any country. According to the World Water Council[5], climate change first affects water resources and thus water security forms an important agenda in governance and takes up a significant portion of state and national budgets. For the year 2018–19, the Central Government had allotted Rs 8860 crores to the Ministry of Water Resources, Riverfront Development and Ganga Rejuvenation and Rs 22,356 crores to the Ministry of Drinking Water and Sanitation. Some researchers have suggested that managing the demand of water is critical to achieve water security. John Allan proposed the concept of 'virtual water' while studying irrigation in arid countries. During the mid-1980s, he observed that water-intensive oranges and avocados were being exported from Israel. This, warned economists, was equivalent to exporting the embedded water in the crop[6]. This, according to Allan, was the 'virtual water' flowing out of Israel. He coined this term at a seminar in 1993. Bases on it, he argued that countries facing water scarcity should not use their water to grow thirsty crops. Instead, they would be better off by importing their requirements from water-rich countries. He defined virtual water as the volume of water required to produce a commodity or service[7]. It is also termed as 'embedded water'[8]. In explaining the concept of virtual water flow, Allan[9] notes that 'more water moves into the Middle East as food trade than flows down the Nile and the Jordan in a year'. Recent studies have mapped international trading of virtual water from import and export data[10], and evaluated the global crop water requirements. The concept is useful since it links water resources with food production and has the potential for ameliorating water deficits in water scarce regions through trade. Allan approaches water scarcity by looking outside the watershed region. Water-scarce countries like Jordan and Israel employ policies to reduce export of water-intensive crops. These countries use virtual water as an important source and are net importers of virtual water. The virtual water exported from here is largely related to crops that yield relatively high income per cubic metre of water consumed[11].

Related to the concept of virtual water is the measurement of 'water footprint', proposed by Hoekstra[12]. He defines the water footprint of a nation as the total volume of freshwater that is used to produce the goods and services consumed by people of that nation. Since not all goods consumed in a country are produced in that country, the water footprint consists of two parts: use of domestic water resources and of water outside the borders of the country[13]. Hoekstra and Chapagain[13] also propose a method of calculating the water footprint of crops and present a table of water footprints for the common crops for each country. There are three categories of virtual water: green, blue and grey. Green water is that which is available by precipitation. Blue water is the surface or groundwater that is extracted and used for farm irrigation crops, and grey water is the water used up in remediating water pollution to meet water standards[14].

The virtual water content, or the specific water demand (SWD, m^3/t) of a primary crop *c* in a country *n* is computed by dividing the crop water requirement (CWR, m^3/ha) by the crop yield (CY, t/ha) (ref. 12). In formula

$$SWD_{n,c} = CWR_{n,c}/CY_{n,c}.$$

This study[12] suggests that in absolute terms, India has the largest aggregate water footprint in the world (987 Gm^3/yr). However, while India contributes 17% to the global population, its people contribute only 13% to the global water footprint. On a relative basis, USA has the largest water footprint, with 2480 m^3/yr per capita, followed by south European countries such as Greece, Italy and Spain (2300–2400 m^3/yr per capita).

The concept has been used by several researchers and international think-tanks on water, including OECD, UNESCO-IHE and World Water Council, to illustrate the virtual water flows. Empirical studies have been conducted in India. For example, Singh *et al.*[15] applied the concept to the dairy economy of Gujarat and proposed its use for choice of fodder crop based on water requirements. Considering these studies, both the concepts have potential application for managing water demand in arid parts of the country. Since the last few years India has been experiencing erratic monsoon due to adverse climatic conditions[16]. There is a decline in the crop production in some areas. For example, wheat production declined in 2014–15 by about 10 million tonnes (mt), against the previous year's record of 95.85 mt, due to a monsoon deficit[17], while the Third Advance Estimates report of 2017–18 predicted a surplus wheat production of about 1.11 mt, citing a near normal monsoon for 2017 (ref. 18). In India, the spatial patterns of water use and grain production do not match the distribution of water resources, and it would be useful to apply the concepts of virtual water flows to better understand water usage.

Application and discussion

India's varied regional climate and diverse agrarian practices have significantly contributed to the global food basket. Indian spices and fruits have made their mark in

Table 1. Virtual water flowing out of Maharashtra, India, through three fruit and sugar exports

Commodity	Export (metric tonnes)	Water required per tonne of produce (m^3/t)	Virtual water exported (m^3)
Sugar (government target for exports in 2018–19)	620,000	1065	660,300,000
Grapes	140,000	319	44,660,000
Bananas	5,000	256	1,280,000
Total virtual water exported (m^3)			706,240,000

Source: Fruit export data taken from the National Horticultural Board and Maharashtra State Agricultural Marketing Board, Government of Maharashtra.

international markets and agri-horticultural exports have been encouraged by the government. During April–August 2017, exports of agricultural and processed food products totalled US$ 7.26 billion. The exports of fruits in the financial year 2018–19 was expected to be worth US$ 87.8 million. India exports its agricultural, horticultural and processed foods to more than 100 countries, including the Middle East, Southeast Asia, SAARC countries, EU and USA. Various agencies like the APEDA, and Coffee, Tea and Spice Boards of India actively seek to expand the export potential of Indian agricultural and food products. Horticulture production is estimated to have risen by 2.2% to 307.2 mt during 2017–18, according to the agriculture ministry[19]. Fruits output has estimated to be 2% higher at 94.4 mt, whereas the production of vegetables by 2.2% at about 182 mt in 2017–18 as against the previous year. The total horticulture production of the country was estimated to be 307.2 mt during 2017–18, which is 2.2% higher than the previous year and 8.6% higher than the past five year's average production. This indicates that India has been actively pushing exports of its agricultural produce[20].

By the virtual water concept, India's water resources flow out of the country with the exports and this stresses the water stock in water-scarce parts. To illustrate the amount of water exported through crops, the virtual water concept was applied to finished sugar, bananas and grapes exported from Maharashtra. Mekonnen and Hoekstra[14] have computed the data on green, blue and grey water footprints of crops, derived crop products, biofuels, livestock products and industrial products. All data are available at the national level and aggregated to the state level. The data are published under the creative commons BY-SA license and open to public for use. Using the 'green water' component of the water footprint for Maharashtra, the virtual water embodied in the sugar and fruits being exported was computed (Table 1). The virtual water flowing out of Maharashtra with these exports was 70.62 million cubic metres, which is nearly equivalent to the effective storage capacity of Walwan dam. This is Maharashtra's 118th dam in storage capacity, among over 1500 dams of the state.

Virtual water flow is sometimes viewed by the theory of comparative advantage of nations. The Heckscher–Ohlin theorem states that a nation will export a commodity whose production entails the intensive use of its relatively abundant and cheap factor of production; and import a commodity whose production requires intensive use of the nation's relatively scarce and expensive factor[21]. By this theorem it does not make sense to export water-intensive crops from a region which is facing water scarcity. However, the calculation for Maharashtra shows the enormous quantity of virtual water flowing out of a water-scarce region through agricultural exports. This affects the quantity of water supplied to other crops which contribute to the food security of the region.

In face of water scarcity, a state can apply the virtual water observations in two ways.

(i) Curtail the production of water-intensive farm produce being grown for exports. In this situation crop choice should be based on water footprints. While this is possible for agricultural produce, it may not be possible for horticultural products.
(ii) For its own consumption, a portion of the state's demand for thirsty crops like paddy and wheat can be sourced from states which have surplus water.

Both these actions can reduce the water stress during drought. However, this is easier said than done. Who will take these decisions and for which farmers? Who compensates the loss of income by planting cheaper priced crops? Is the dependence on other states for crops a compromise of food security? Questions like these are challenging and although methods and datasets for evaluating water footprints have advanced in recent years, the application of water footprint to water policy has clearly lagged. In India, water is a state subject and that places the responsibility of water management squarely on the shoulders of state governments. Especially in times of drought, supply of water is a deeply contested issue between political parties. Its resolution is loosely based on water demanded by a region and not on an assessment of water use. According to Hoekstra[11], the virtual water flow of agriculture is 'economically invisible and politically silent'. Due to this, water decisions are influenced by emotions rather than data, which can be unfair to some stakeholders.

Unless each state takes up a detailed water assessment of its crops, at the level of river basins, it is unlikely to be visible in water policy. Allan[22] mentions that the idea of computing virtual water flow has been rejected by water policy makers and water professionals '…with the same passion that fishing communities greet proposals that they should reduce their catches according to international collective action principles…'. He observes that in developing countries, virtual water calculations appear to threaten farming livelihoods and drawing attention to where national security lies is potentially controversial.

However, when all possible sources of water are already harnessed and diminishing returns set in for every additional increase in water storage, then managing the demand of the resource can offer to improve the situation. Using the water footprint, each state can quantify how the available water is appropriated for producing certain commodities for certain people. Furthermore, water footprint of crops can be effectively related to their nutrition. This could offer an alternate perspective to the problem of nutritional inequity in India. A study from California, USA[23] suggests linking water footprint of crops to the livelihood potential and to its impacts on the environments[23]. This has been effectively used in Beijing, China, where the environmental impact of water footprint was quantified[24].

Criticisms to the concept and its application

It is not surprising that both the concepts of virtual water and water footprint have their share of criticism. Applying them to agrarian markets would amount to substituting the 'invisible hand' with the 'Government hand', which challenges the classical free market thinking. Reimer[25] considers the virtual water concept as an 'inherently economic concept'. Others argue that the concept is not based on a legitimate conceptual framework and can lead to misleading policy recommendations[26]. The arguments to the recommendation of importing thirsty farm produce from other regions are about the dependency imposed by imports on food. Why should a region rely on importing its food when it can produce locally? Jia *et al.*[27] suggest that the mistake in theoretical basis of virtual water trade is to assume that water resources allocation may be optimized considering water as the sole production factor, while there are many other production factors. Furthermore, the conditions for optimal multi-factor allocation are much broader and more demanding than the unrealistic assumption of water alone. Iyer[28] cautions to be wary of presentations based on the virtual water concept, in international forums, but considers it a useful reminder of the water implications of an economic activity.

Researchers and think tanks on water will continue empirical studies on crop water and the accuracy of water footprints can be expected to improve significantly. This will perhaps encourage a more serious consideration from policy makers. However, the major limitation of virtual water flow as the only basis of crop decisions is that it does not consider the social and cultural implications of water in a society. For a climatically and culturally diverse country like India, this is an important consideration.

Conclusion

Arguably, water is the primary resource through which the impacts of climate change will reach society. Managing water resources will inevitably become a focus for adaptation. There are multiple ways in which water requirements of a crop can be reduced. Efficient use of water, reducing evaporative losses and timing irrigation is already widely known. These efforts lead to individual farm savings, which are important but not enough to reduce regional water stress in times of poor monsoon. The concepts of virtual water flow and water footprint have the potential to offer a perspective to improve the situation in a scarcity-affected region. The present author does not imply that virtual water flow can be the sole variable in any decision-making. While accepting the limitations of the concept and its applicability to farm decisions and policy, the present author considers virtual water concept as a useful indicator of water use. In face of the threats of climate change and the possible reduction in precipitation, virtual water flow offers an alternative approach to water-saving. Moreover, linking it to crop nutrition has huge potential in improving crop choice decisions in India.

A region's vulnerability to climate change depends on the biophysical and socio-economic characteristics[16], and virtual water flow can be one of the many indicators of water use. The arguments made here suggest that water footprint of a crop is a factor to consider when setting agricultural policies of a region. Moreover, the government's encouragement to agri-horticultural exports through subsidies, marketing efforts, insurance covers and credit security must be tested through the lens of water footprints. Is the encouragement justified when a scarce resource is used up for foreign markets? Considering the government's obsession with food exports, these concepts warrant at least a thought.

There is another remarkable potential of virtual water flow and water footprint. It is a powerful tool to improve public awareness. The water footprints of processed items like ready-to-eat food, snacks and breakfast cereals are huge compared to the grains used in its production. How many consumers are aware of this? The lack of complete information, or information asymmetry, prevents consumers from making an informed choice[29]. The changing dietary habits within Indian cities has manifested in changing crop regimes while ignoring the water availability[30]. Thus, a knowledge of the water footprint will serve the interests of the community.

Lastly, there is a potential for these concepts to be factored in the pricing of water in India. Water tariffs in the country are largely influenced by political considerations and are subject of debates. The application of these concept scan offer a quantitative basis for the calculation. Differential pricing can influence consumption, as seen from the experience of Singapore[31], and this offers a hope for water conservancy in India.

The virtual water flow and water footprint have a great potential for prioritizing water use of regional importance. The way ahead is for each state to establish the water footprints of crops according to their regional differences and link them to issues of regional importance, which could be water conservation, nutrition, livelihood or impacts on the environment. The concepts cannot provide a simple solution to the complex socio-economic problem of irrigation water distribution. However, they show a new aspect of water use, hitherto overlooked in water policy.

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