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Inequalities in the Networks of Virtual Water Flow

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The globalization of water associated with the trade of food commodities [*Hoekstra and Chapagain,* 2008] has often been acclaimed as a means to save water, mitigate the effect of regional- and local-scale water scarcity, and meet the demand for food in overpopulated and water-poor countries [*Allan,* 1998]. However, there are negative implications for water use from globalization of trade. For instance, globalization disconnects populations from local sustainable freshwater use [*Allan,* 1998; *D'Odorico et al.,* 2010]. This distance between societies and the resources on which they rely is a major obstacle to the emergence of behaviors that foster ecosystem stewardship [*Chapin et al.,* 2009] through a responsible management of the environment. The globalization of water is also expected to reduce societal resilience to drought by decreasing the redundancy of freshwater resources, thereby limiting opportunities to meet human needs during periods of crisis [*D'Odorico et al.,* 2010]. Overall, globalization enhances inequalities in the way different societies may have access to freshwater resources [*Chapin et al.,* 2009]. In fact, only a few countries control most of the water that is virtually exchanged—through food trade—in the global market.

Because food production requires adequate soils, climate, and water (neglecting trade), there exists a tight relationship between population and the sustainable use of local resources. With human societies employing approximately 85% of their freshwater use for food production, population growth has led to an increase in freshwater utilization, thereby enhancing the potential for local water stress. However, when food production is inadequate to meet the demands of a population, importation of food commodities from other regions allows societies to reduce stresses associated with limited water resources.

This trade of agricultural and industrial products creates a mechanism by which societies virtually transfer freshwater resources [*Allan,* 1998]. The virtual water of a commodity is the water required to produce that commodity. As such, virtual water trade is often considered as a solution to limited water availability in many regions. Virtual water trade can prevent societal water stress, malnourishment, and water wars [*Allan,* 1998; *Barnaby,* 2009]. Virtual water trade also provides a means to ameliorate regional changes in food production due to the impacts of climate change. Thus, global food security depends, in part, on virtual water trade [*Hanjra and Qureshi,* 2010]. However, differential resource and trade accessibility among countries introduces the potential for large inequalities to arise. Because of its important role in determining global food security, recent studies have begun to examine the major drivers of virtual water trade and how the global redistribution of (virtual) water has changed in the past few decades [*Suweis et al.*, 2011; *Carr et al.*, 2012].

Trade Changes Over the Past Few Decades

The networks of virtual water trade for 1986–2008 have been reconstructed [*Carr et al.*, 2012] using detailed trade data on agricultural plant and animal commodities from the statistics division of the Food and Agriculture Organization of the United Nations combined with estimates of the water footprint of those products [*Mekonnen and Hoekstra*, 2011a, 2011b]. Analyses of these data have found that virtual water networks have changed substantially over the past few decades. The total number of trade connections has more than doubled, while the total trade in virtual water has increased from roughly 1×10^{12} to about 2.2×10^{12} cubic meters. This doubling in virtual water trade exceeds the rate of population growth, with an increase in virtual water trade of 200 cubic meters per person between 1986 and 2008. The increase has not been uniformly distributed across the network. Most trade partnerships have limited durations [*Carr et al.*, 2012]; only 3964 connections (about 25% of the links existing in 2008) were permanent throughout the study period. These links tend to organize the network in communities that exhibit numerous internal connections between community members and connect to other communities with only a few external connections [*D'Odorico et al.*, 2012].

What causes this repeated appearance and disappearance of virtual water trade partnerships? The majority of the connections and fluxes in the network seem to depend on a multitude of factors, including geopolitical and socioeconomical

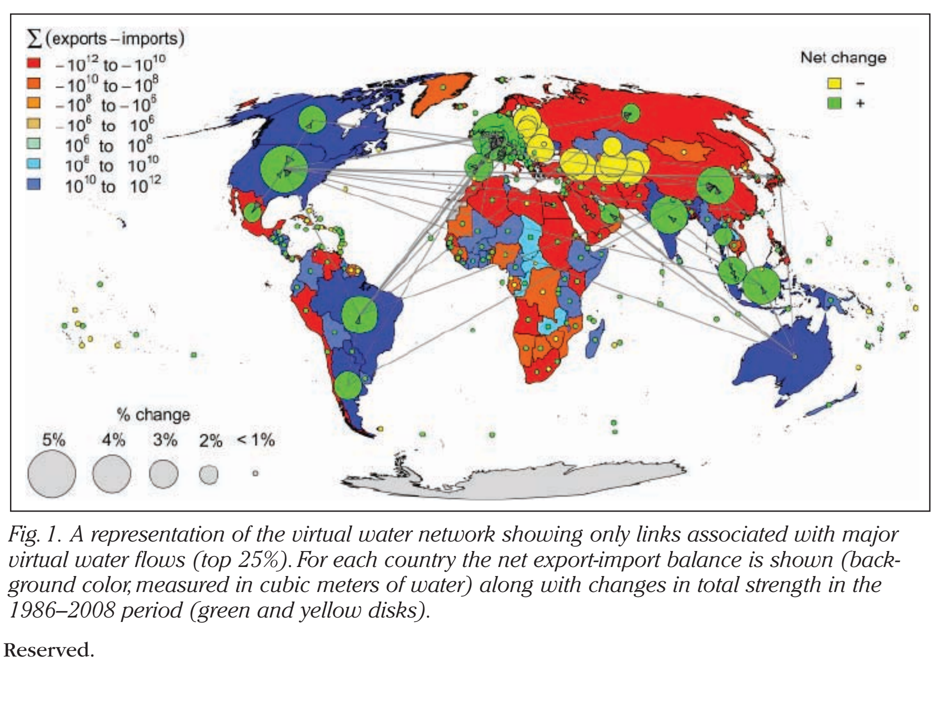

Fig. 1. A representation of the virtual water network showing only links associated with major virtual water flows (top 25%). For each country the net export-import balance is shown (background color, measured in cubic meters of water) along with changes in total strength in the 1986–2008 period (green and yellow disks).

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drivers, climate, fluctuations in crop yields, dietary changes, and conflicts. In some cases, factors controlling trade are readily identified, such as the lack of trade connection between Cuba and the United States. The increase in virtual water fluxes to the Russian federation in 1992 is attributed to post–Cold War subsidy reforms, associated decrease in livestock production (http://www.ers.usda.gov/publications/aer813/aer813c.pdf), and the corresponding increase in imports to the Russian federation. Similarly, the increase in soy trade between China and Brazil after 2000–2001 is explainable by changes (in 2000) in importation policies in China [*Dalin et al.,* 2012].

In other cases, however, drivers of trade are harder to discern, and the intermittent character of the virtual water network and its relatively low number of permanent links still needs to be elucidated. Moreover, it is unclear why the increase in total virtual water flow is not evenly distributed among all connections. Globally, most of the virtual water flux occurs through a small number of links (about 50% of the total flux is carried by 1.1% of the connections), and only a handful of countries control these fluxes. Approximately 40% of the net virtual water exports arise from Brazil, Argentina, and the United States—countries that in aggregate account for only 5.7% of the global population. Consequently, major changes in the network may be controlled by a relatively small number of trading partners [*Carr et al.,* 2012; *Konar et al.*, 2011].

A Few Countries Have a Large Impact

The total strength, i.e., the sum of imports and exports, of a node of the virtual water network can be used to examine the total impact each country has on the flow of virtual water in the network. Figure 1 shows (with circles) the change in strength for each of the trading countries between their first and the last reporting year. This change is shown superimposed on a map with the net export-import balance for each country for the year 2008 and the links that have carried the top 25% of all virtual water over the 23-year period. Of note is the paucity of countries that have a near-zero export-import virtual water balance: Most countries are either strong net importers or net exporters of virtual water. While most countries have increased their total strength over time, some of the major net exporters of virtual water, such as Australia, have maintained their total strength.

Of the countries that increased their total strength, Germany accounts for 6.7%, the Netherlands accounts for 6.5%, the United States accounts for 6.4%, and China accounts for 5.5% of the global increase. Altogether, these four countries account for a quarter of the global increase (3.15×10^{12} cubic meters) in the strength of virtual water trade through the study period. Ten countries account for about 51% and 25 countries account for 75% of this increase. Interestingly, these countries have access to large amounts of financial resources (Germany, United States, China), water (Brazil, Argentina, United States), and oil (United Arab Emirates, Iran), or they act as major trade hubs (Netherlands, United Arab Emirates). In contrast, the nodes undergoing a decrease in the strength of virtual water trade are dominated by former Soviet states and small island nations. Overall, the decrease found in Australia and Saudi Arabia, both large importers and exporters of products globally, is small (<1%). Africa remains only marginally affected by changes in virtual water trade.

Why Are There Inequalities in Virtual Water Trade?

This analysis reveals a select few countries dominating the changes in the network. The inequality in terms of access to resources appears to directly or indirectly drive the trade of virtual water. The relative distribution of freshwater resources and human populations opens important environmental and ethical questions. The existing inequality in the access to local water resources is mostly controlled by geography and climate conditions while access to virtual water resources depends more on gross domestic product [*Suweis et al.*, 2011].

Is this inequality unjust or only regrettable? While, by valuing environmental sustainability, many societies appear to have found an answer to a similar question in the time domain (i.e., it is unjust to deplete natural resources and reduce the availability of environmental goods and services for future generations), the assessment of what is just or unjust does not appear to be obvious in the space domain, when inequalities in per capita virtual water and resource availability exist among different countries and regions of the world. However, recent research may clarify some of the ethical implications of virtual water trade: Virtual water flows tend to be driven by gross domestic product and social development status rather than regional- and local-scale water scarcity and solidarity toward water-stressed populations [*Seekell et al.*, 2011; *Suweis et al.,* 2011]. As such, virtual water trade tends to further enhance inequality [*Seekell et al.*, 2011], and these socioeconomic drivers appear to prevail over the need to reduce inequalities associated with the global distribution of freshwater resources and people.

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