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OPINION

Water resources and trade: A research vision

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Abstract

Water is an increasingly scarce resource in our globalized economy. At the same time, it is an essential input in the production of most goods and services enmeshed in an interconnected world economy. A rich literature has examined how water is used both *directly* in production and *indirectly* through supply chains and international trade (e.g., virtual water trade). There is now an opportunity to build on our understanding of *who* is using *what* water and *where*, with research that aims to understand *why* and *how* it is used. Such research should enlighten the mechanisms driving societal relations with water and inform decision-makers on how to increase water's productivity, improve its allocation, and enable us to do more with less water. In this essay, we lay out our vision for research on the relationship between water and international trade.

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What are the causal relationships between trade and water?

Tony Allan [1] introduced the term "virtual water," and Arjen Y. Hoekstra documented how our global society uses water [2]. Allan realized that arid countries in the Middle East rely on agricultural imports to feed their populations. The "water consumed by imported commodities" was a substitute for the scarce water that was available for local agricultural production. Hoekstra and others developed sophisticated accounting methods for measuring the water footprint of products and virtual water trade. Their work highlighted the importance of indirect water use in supply chains. This literature started by evaluating water use in agriculture (the most water-intensive economic sector), but soon encompassed water use throughout the economy, sparking water efficiency improvements in practice (e.g., such as those implemented at PepsiCo, https://www.pepsico.com/sustainability-report/water).

However, to better understand how trade and globalization impact water use (see Fig 1), it is essential to conduct research with the explicit goal of discovering the causal impact of trade on water use and/or what drives virtual water trade. Studies that quantify the water embodied in the production, trade, and consumption of goods do not uncover those causal links. This is because accounting procedures are about existing correlations between trade and water resources [3]. To assess the causal relations between trade and water, researchers should turn to inference methods from econometrics. Econometrics has developed a wealth of tools to

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tease out causal impacts in complex human systems. It bears emphasizing that causal inference in systems with humans is necessarily different from that in physical systems. Humans make discrete decisions and have specific motivations that have to be explicitly accounted for [4]. The decision to trade or produce a water-intensive good may be affected by factors other than water, or may be influenced by a conscious societal decision to limit (and not deplete) this valuable open-access resource, such as by pricing water for productive uses [5].

Water is just one among many factors of production. Trade also involves capital, labor, land, and nutrients, for example. Moreover, the factors that are more costly than water tend to be much stronger determinants of international trade flows than the availability of water [6]. Phenomena outside the water sphere often have a much larger impact on water use. For example, the changing economic structure of countries (e.g., becoming more service-oriented) reduces domestic water use and influences the balance of virtual water trade, as does technological change [7]. Inferring the impact of trade on water use is thus more complex than evaluating the volume of water embodied in imports and exports. In fact, studies that use econometrics actually show that trade openness in some instances can *reduce* water use [8]. Similarly, trade openness does not necessarily impact the nutrient use of nations (which is also a major input in agriculture) [9]. We need to deepen our knowledge of the causal interaction between water and trade and study the mechanisms that allow for global water savings through international trade, as documented in the virtual water literature.

How does agricultural trade interact with water hazards?

Water is increasingly scarce, and its sustainable use in a world with a changing climate is a growing concern. Since agriculture is by far the most dominant user of water, it is especially important to investigate how trade shapes agricultural production: including where crops are produced, the physical and economic productivity of agriculture, and the potential interactions with national agricultural policies at the micro and macro levels. For example, crop insurance may lead farmers to use more water [10], potentially counteracting the influence of trade on water use. This makes it important—but necessary—to untangle the varied policies influencing the agricultural system. Going forward, we need to figure out how countries that have the most abundant water resources, and/or produce crops with the greatest water use efficiency, can contribute more to global trade, and as such raise water's global productivity.

In addition, the increasingly variable and extreme hydrological cycle raises vexing questions. Does trade openness make countries more resilient to adverse water shocks? How will more droughts and floods impact international trade? The econometric studies discussed above quantify the impact of trade on water use *on average*. As the climate and the hydrological cycle become increasingly variable, it is important to determine how water and trade interact *in the extremes*. Recent work highlights that certain crops are more exposed to climate shocks than others [11]. Does trade mitigate or exacerbate climate shocks in these crops? Does irrigation enable farmers to buffer rainfall shortfalls and thereby buffer supply chains and trade? Do water markets have a role to play, in that they can capture and value explicitly a country's water cost, thereby shifting production to higher-value crops? [5]. How and where are water hazards transmitted through rather than mitigated by global trade?

A research frontier

The answers to the above questions will be complex and context dependent, but they are urgently needed. The 2010 drought in Russia is often cited as an example of a drought that propagated through the global wheat trade to Northern Africa, sparking the bread price riots that triggered the Arab Spring [12]. Yet the ability to trade within India reduced the

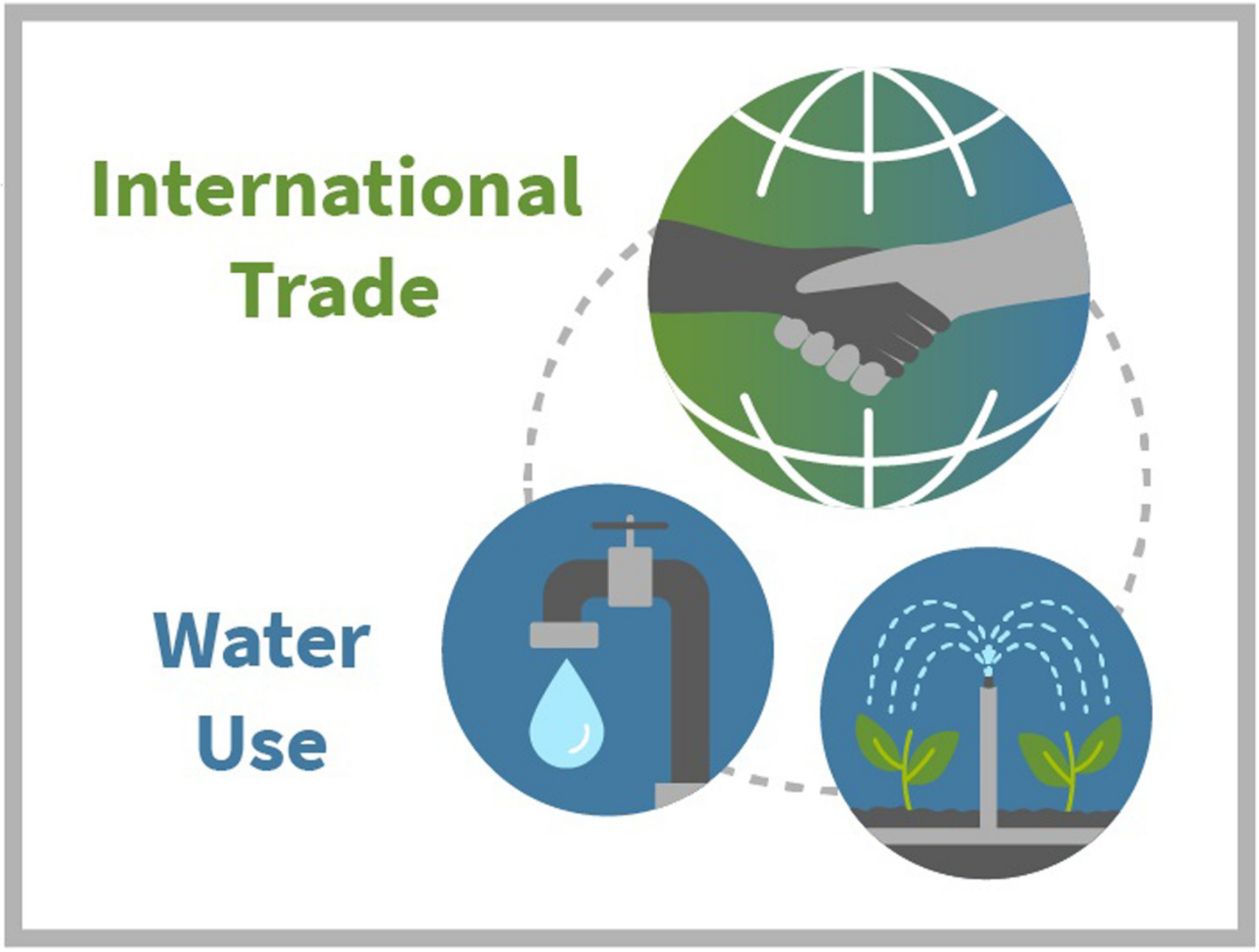

Fig 1. The relationship between international trade and water use is an important area of research.

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occurrence of famine following harvest failures in colonial India [13]. Groundwater pumping helped buffer crop production and international exports during the 2012–2015 drought in the Central Valley of California [14], although this contributes to risks from unsustainable virtual water flows in the long run [15]. Going forward, research that seeks to untangle *why* and *how* water resources and international trade interact will clarify our understanding and aid decision-makers.

Author Contributions

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Visualization: Peter Debaere, Megan Konar.

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