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Opinion

Can International Freshwater Trade Contribute to the SDG 6

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Abstract: Freshwater is fundamental for all aspects of human well-being and sustainable development. The supply of freshwater resource largely depends on the natural water cycle, leading to extremely unequal distribution over the world. This uneven distribution and increasing freshwater demand results in spatial and temporal physical freshwater shortage. By discussing the limitations of desalination techniques and the shortcomings of existing pathways for freshwater transfer including water transfer projects, bottled water market, and virtual water trade, we suggest that international freshwater trade as an additional pathway is necessary. The analysis of the cost structure of freshwater production and transportation and the hypothetical examples between potential exporting and importing countries show the feasibility of international freshwater trade. The establishment of a global freshwater market is confronted with six challenges, namely, natural sustainability, ecological safety, opinions of stakeholders, market access mechanism, pricing mechanism, and infrastructure system. We conclude that a global freshwater market is expected to make contributions to achieving SDG 6 by mitigating spatial and temporal freshwater scarcity and by resolving transboundary freshwater conflicts and managing local freshwater consumptions.

Keywords: water transfer project; virtual water trade; bottled water market; global freshwater market

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1. Global Water Crisis

The world's total water supply is about 1386 million cubic kilometers, of which only three percent is freshwater. Over 68 percent of total freshwater is locked up in glaciers and ice caps, while another 30 percent is buried in the ground. Thus, surface freshwater constitutes only two percent for most of human uses [1,2]. As a natural resource [3], freshwater is fundamental for all aspects of human well-being and sustainable development, such as human health, food security, industrial production, energy generation, and ecosystems resilience. This significant importance of freshwater resources is reflected by the Sustainable Development Goal 6, which requires "ensuring availability and sustainable management of water and sanitation for all" [4]. However, confronted with growing populations, expanding cities, rising incomes, and shifting consumption patterns, the world is predicted to experience a global water deficit of 40 percent by 2030. For instance, 1.6 billion people will lack safely managed drinking water, 2.8 billion people will lack safely managed sanitation, and 1.9 billion people will lack basic hygiene facilities [5].

Freshwater scarcity has long been deemed one of the major global crises in the 21st century [6]. Precipitation of the natural hydrological cycle is the main source of available freshwater (Figure 1a), leading to the fact that the spatial and temporal distribution of freshwater resources is extremely unequal in the world (Figure 1b). Such uneven distribution results in the spatial differences of freshwater stress among countries (Figure 1c). For example, more than 733 million people (ca. 10 percent of the global population) live in countries with high and critical levels of water stress in Northern Africa and Western Asia [5]. Global climate change is expected to worsen the situation of freshwater stress by aggravating the stress level of currently water-stressed regions and generating stress in regions with currently abundant water resources, in particular, extreme drought events have caused temporal freshwater scarcity in many regions [7]. The value of average annual precipitation, total renewable water resources, and water stress in individual countries can be found in Supplementary Table S1.

In total, 153 countries around the world share transboundary rivers, lakes, and aquifers, which would reshape national economies and geopolitical alliances and may even cause conflicts and wars as competition for water demands intensifies [8]. Only one quarter of reporting countries have more than 90 percent of their transboundary waters covered by operational arrangements [5]. A typical example is the transboundary Colorado River Basin is, which has undergone bitter international battles over water rights between the US and Mexico, leading to the decades-long drying-up of the Colorado River delta. Although water returned to the delta in 2014, the fundamental problem of basin-wide water shortages is finding more available water sources outside the river basin [9,10].

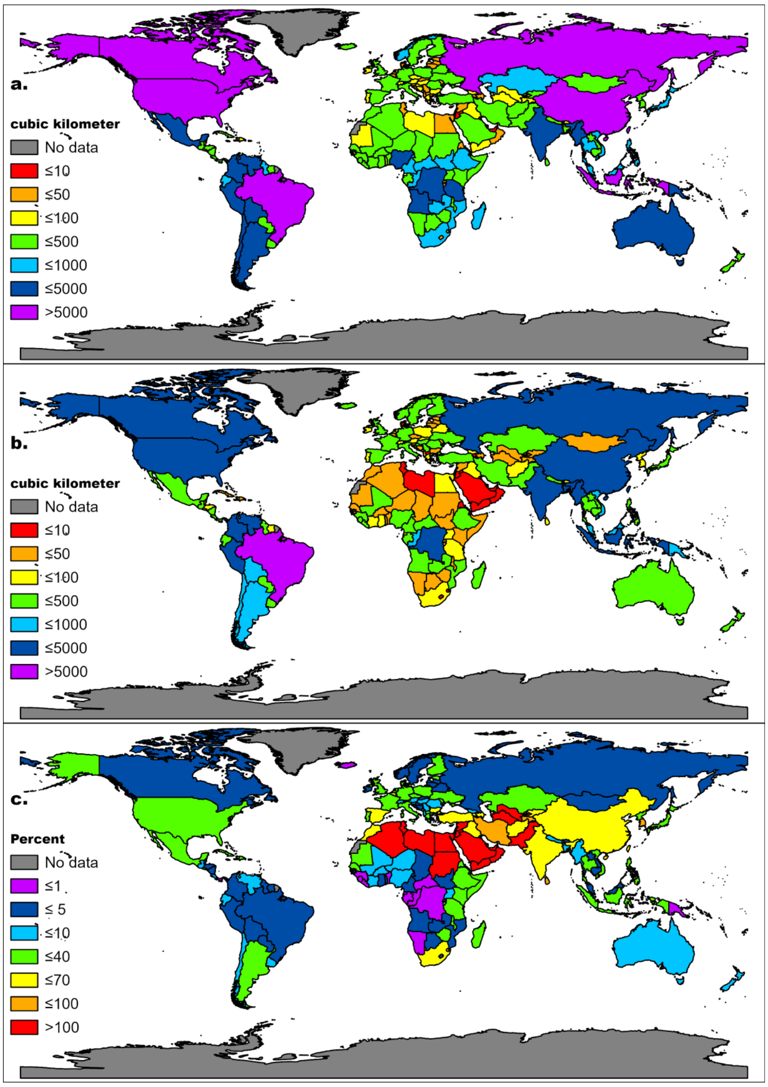

Figure 1. (**a**). Long-term average annual precipitation in volume (km^3). (**b**). Annual total renewable freshwater resources (km^3), which corresponds to the maximum theoretical yearly amount of freshwater available for a country at a given moment. (**c**). Freshwater stress (%), which is calculated as Total freshwater withdrawal/(Total renewable freshwater resources—Environmental flow requirements). Data sources: AQUASTAT [11].

2. Limitations of Desalination Techniques

Confronted with such a severe freshwater challenge, desalination of seawater is considered to be one of the most promising and viable techniques to satisfy the quickly increasing demand for high-quality freshwater [12]. The long history of desalination techniques can be dated back to ancient times and has rapidly developed over the past two decades [13]. There are currently approaching 20,000 desalination plants located in more than 180 countries worldwide, providing a daily capacity that exceeds 100 million m^3 [14]. However, the utilization of seawater is limited not only by the large economic costs [15] but also by the high energy consumption [16]. Desalination may also lead to prospective environmental consequences, such as decreasing quality of water and air, and groundwater and marine pollution [12]. Furthermore, the adoption and proliferation of desalination are strongly affected by a number of socio-political factors, including political stability, employment, health impacts, and legal challenges [17]. More importantly, although it is possible to balance the environmental impacts and economic costs of desalination, not every country (e.g., countries without coastlines) could benefit from desalination technologies, and the comparative advantages among different countries would make international trade of desalinized freshwater inevitable.

3. Existing Pathways for Freshwater Reallocation

Ensuring sufficient freshwater supply is not only an effective way to enhance regional resilience against climate change, but also an essential premise for the integrated management of freshwater demands and uses. Reallocating freshwater from water-abundant regions to water-scarce regions can provide external freshwater sources to the regions without sufficient available freshwater. Currently, there exit three pathways for interregional freshwater transfer.

3.1. Water Transfer Project

Water transfer projects have a long history that can be dated back to ancient times, when the Romans built waterworks for supplying freshwater to urban centers, mineral extraction, and irrigation fields [18]. Currently, there are ca. 155 inter-basin freshwater transfer projects distributed in 26 countries, with an annual total capacity of 490 billion m^3 [19]. The South-to-North Water Diversion project in China is by far the world's largest interregional water transfer project, which is planned to bring water from water-rich South to the water-scarce North. By the end of 2018, the eastern and middle routes have transferred accumulated 3 and 18 billion m^3 water, respectively, and about 85 million people in Northern China have benefited from this project. In its full capacity, this project is expected to annually transfer ca. 45 billion m^3 of water northward to meet the needs of almost half a billion people by 2050 [20]. However, most water transfer projects are national projects, implying that they are not capable of solving the problem of the internationally uneven distribution of freshwater resources.

3.2. Bottled Water Market

Bottled water refers to the drinking water that is filled into various types of containers (e.g., bottles, dispensers, and sachets, etc.) and is safe for direct individual and household use [21]. Bottled water originates from the 16th Century when natural mineral water was sold in glass bottles, which was considered a luxury beverage for special occasions [22]. The invention of polyethylene terephthalate plastic in the late 1970s and the entrance of big food and beverage corporations in the 1980s resulted in a rapid global market expansion and product diversification, even replacing tap water as the main drinking water in some countries where the public water supply and distribution systems are insufficient [23]. In 2021, the global bottled water market was estimated to be about 350 million m^3, with an increasing rate of 73% during the last decade [21], which accounted for 0.18% of global municipal water withdrawal and 0.02% of global total freshwater withdrawal (calculated based on AQUASTAT [11]). Obviously, the amount of freshwater transferred through the global bottled water market is tiny. Besides, bottled water serves only as drinking water in most cases and is usually so expensive that low-income households cannot always afford it [24]. Furthermore, it has been recognized that bottled water is often associated with resource depletion of groundwater and plastic pollution [21].

3.3. Virtual Water Trade

Virtual water trade is defined as the volume of freshwater that is consumed in the production of agricultural and industrial goods and then traded in the international market. The total international flow of virtual water amounted to approaching 1000 billion m^3 in 2010 and will amount to more than 3000 billion m^3 by the end of this century. Water-scarce regions have heavily relied on the import of water-intensive goods to offset insufficient domestic water supply [25]. As some economists argued, virtual water is only a "metaphor" because only those goods are actually traded rather than freshwater, which means that there is no additional water supply for real water demands [26]. Although virtual water trade can be interpreted as the trading of freshwater services, this strategy as a solution to physical freshwater scarcity is fallacious because many other production factors (e.g., land, labor, and facilities, etc.) in reality affect the agricultural and industrial production, for example, some water-scarce regions with the advantage of land resources export virtual water to water-rich regions with poor land resources [27].

4. International Freshwater Trade Provides an Additional Potential Pathway

Since all of the existing pathways for freshwater reallocation have their shortcomings, an additional feasible pathway is needed, which is international freshwater trade. Freshwater plays a vital role in the production of food and energy. The emergent water competition between the food and energy systems has been recognized as the "water-food-energy nexus" [28]. Analogous to food (e.g., arable land resources) and energy (e.g., petroleum resources) that are extremely uneven distributed and thus depend on trade-based international reallocation, international freshwater trade is expected to overcome the physical freshwater shortage and balance the spatial uneven distribution of freshwater resources.

4.1. Feasibility

From an economic perspective, two issues determine the economic feasibility of international freshwater trade, one is transportation costs, and the other is production costs. The potential and possibility of the international freshwater trade has been insufficiently discussed [29,30] because it is usually suggested that freshwater is too heavy and bulky to be transported long distance [2,20]. However, it has been reported that some companies have specialized in internationally transporting large amounts of freshwater. For example, Nordic Water Supply transported ca. 1.7 million m^3 of freshwater from Turkey to Cyprus in 2001. With the upgrade of transportation technology, such as a tugboat with a gigantic sack that can hold 35,000 m^3 of freshwater, the transportation cost has been reduced to 0.5 $\$/m^3$ [31]. Hence, this developed technology and its potential improvement have made transporting freshwater over long distance possible.

To estimate the costs of freshwater production, we refer to the cost structures of petroleum production in major petroleum-producing countries like Russia, the US and Saudi Arabia. Among multiple cost types, the most important ones are the costs for petroleum exploitation and refining, which average at 201 and 102 $\$/m^3$, respectively [32]. In order to avoid the depletion of groundwater, we only consider surface water as a freshwater source. In comparison to petroleum, we assume that the costs of freshwater production consists of an exploitation cost and a refining cost, which are further assumed to be 0.1% of the costs for petroleum production because the producing technology for freshwater would be significantly simpler. Thus, the cost of freshwater production is 0.303 $\$/m^3$, which is smaller than the cost of desalinated water (0.45–2.51 $\$/m^3$) [33] and the economic virtual water productivity (0.5–2.0 $\$/m^3$) [34].

We take some hypothetical examples between potential freshwater exporting countries and potential freshwater importing countries (Table 1). Brazil imported 4,500,846 tons of petroleum from Saudi Arabia in 2022, valuing ca. 3,205,478 thousand dollars [35]. If Brazil would export the same quantity of freshwater to Saudi Arabia, this would cost Saudi Arabia ca. 3614 thousand dollars, which accounts for 0.17% of the value of petroleum export. Similarly, Croatia imported 12,000 tons of petroleum (9336 thousand dollar) from Turkmenistan [35], while the export of the same quantity of freshwater would cost Turkmenistan ca. 10 thousand dollars, accounting for 0.10% of the value of petroleum export. Papua New Guinea imported 134,355 tons of petroleum (42,250 thousand dollar) from the United States of America [35], while the export of the same quantity of freshwater would cost the United States of America ca. 108 thousand dollars, accounting for 0.26% of the value of petroleum export. These three examples indicate a win-win situation for both freshwater exporting and importing countries because the value of freshwater import takes up a very small proportion of the value of petroleum export and the petroleum importing countries can partly benefit from the export of freshwater.

Table 1. Hypothetic freshwater trade between potential exporting countries and potential importing countries.

Potential Exporting Country	**Import Petroleum from**		**Potentially Export Freshwater to**		**Potential Importing Country**
	Ton	**Thousand Dollar**	**Ton**	**Thousand Dollar**	
Brazil	4,500,846	3,205,478	4,500,846	3614.18	Saudi Arabia
Croatia	12,000	9336	12,000	9.63	Turkmenistan
Papua New Guinea	134,355	42,250	134,355	107.89	United States of America

4.2. Challenges

From the perspective of costs, international freshwater trade provides a feasible pathway for global freshwater reallocation and shows the potential for the establishment of a global freshwater market. Several challenges or preconditions of the potential international freshwater trade should also be recognized. First of all is natural sustainability where the exploitation of surface freshwater for exportation should be sustainable by ensuring the basic ecological flow in rivers and lakes and the local demand for freshwater. Second is ecological safety where the exploited freshwater must be processed, not only avoiding the invasion of aquatic organisms in the exporting country to the importing country, but also being suitable for agricultural, industrial, and household use in the importing country. For this purpose, an internationally acceptable standard for traded freshwater should be established. Third is opinions of stakeholders where an emphasis should be put on the ethical concerns that decision-making on the implementation of freshwater export or import should take into account the opinions of stakeholders, which should be based on the clarification of the benefits and shortcomings of freshwater export or import. Fourth is the market access mechanism. Legal issues should not be neglected, namely the allocation of freshwater exploitation rights. Thus, a national market access mechanism should be established to ensure fair competition of freshwater exploitation rights. Fifth is pricing mechanisms. A profitable price of freshwater will ensure the feasibility of international trade. Thus, it is necessary to construct an effective pricing mechanism for the global freshwater market, which embodies the characteristic that the price of freshwater tends to rise if the available freshwater in a given region has become or is expected to become scarcer. The final consideration is the infrastructure system. An infrastructure system for transportation in exporting countries and for distribution in importing countries is necessary and associated with high investments.

4.3. Implications

The establishment of a global freshwater market has implications for achieving SDG 6 in the future. First, a global strategic stockpile of freshwater is of vital importance for overcoming spatial physical freshwater scarcity. More importantly, it will make the timeliest contributions to temporal freshwater scarcity induced by extreme climate events like long-term droughts. Second, an internationally acceptable freshwater price is helpful for resolving transboundary freshwater conflicts based on an economic approach and also for managing local freshwater consumption on the demand side by encouraging water harvesting in water-rich regions or water sparing in water-scarce regions. Finally, since freshwater provision is an essential service provided by water-related ecosystems, a global freshwater price is indicative of the valuation of this ecosystem service.

5. Conclusions

The uneven distribution of freshwater resources and the increasing demand for freshwater lead to a spatial and temporal physical freshwater shortage, which is being exacerbated by global climate change. The utilization of seawater by desalination technologies is limited for providing sufficient freshwater, while all of the existing pathways for global freshwater reallocation have their shortcomings, including water transfer projects, bottled water market, and virtual water trade. Therefore, in analogy to food and petroleum, international freshwater trade provides a potentially feasible and necessary pathway for solving the problem of physical freshwater shortage. From the perspective of costs, international freshwater trade becomes increasingly available thanks to the development of transportation technology. Three hypothetical examples show that international freshwater trade would generate win-win situations between freshwater exporting and importing countries, implying the possibility of establishing a global freshwater market. For this purpose, six challenges should be taken into account, namely, natural sustainability, ecological safety, opinions of stakeholders, the market access mechanism, the pricing mechanism, and the infrastructure system. The global freshwater market is expected to make contributions to the achievement of SDG 6 by mitigating spatial and temporal freshwater scarcity based on a global strategic stockpile of freshwater and by resolving transboundary freshwater conflicts and managing local freshwater consumptions based on an internationally reliable freshwater price.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w15213853/s1, Table S1: The value of average annual precipitation, total renewable water resources, and water stress in individual countries.

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