Water as a Global Public Good: Assessing the Cost of Inaction.

LITERATURE REVIEW

F. Roscioli [1,2]

[1] *University of Rome Tor Vergata*
[2] *Fondazione Tor Vergata*

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1 Introduction

Water scarcity can be expressed as physical or economic scarcity (D. W. Seckler et al., 1998). Physical scarcity is when the water supply cannot meet all needs (including environmental flows), a situation that arises regardless of, or due to, the global system's hydroclimatic interconnectedness (Alcamo et al., 2008). Economic scarcity is characterized by the inability of the socio-economic system to use existing water to meet all demands, irrespective of physical scarcity (Ahopelto et al., 2019). This can occur due to a lack of storage, appropriate distribution and infrastructure for access (Nairizi, 2017), or when human, institutional, and financial capital restrict water access (Molden, 2013; D. Seckler et al., 1999). Water has been declared an economic commodity (Kim, 1995; Nations, 1992; Secretariat, 1992) and is viewed as a production element in Computable General Equilibrium (CGE) modelling (Calzadilla et al., 2017), where the non-substitutability condition can be circumvented through the trade of virtual water (Allan, 1997; d'Odorico et al., 2019) goods. In the past, water consumption was on the rise and typically associated with low total and marginal social costs, and a flexible long-term supply of impounded water. Concurrently, the demand for delivered water was small but increasing, and flexible at low prices—rigid at high prices, with little competition and externalities (Booker & Trees, 2020; Randall, 1981), while agriculture was in a phase of traditional development (Booker & Trees, 2020). The current phase is marked by increasing total and marginal social costs, a high and escalating demand for delivered water, flexibility at low prices and rigidity at high prices, fierce competition and significant externalities (Booker & Trees, 2020; Randall, 1981), while agriculture is in a phase of commercial development (Booker & Trees, 2020). Ignoring integrated technology levels results in severe externalities; for instance, globally, one of the main examples is the loss of over 50% of irrigation water due to technical shortcomings, as evidenced in Guarino, 2017; Jägermeyr et al., 2015. Another issue is the allocation of water to primary users—agriculture and industry—in terms of value and pricing policy, as in a model for agricultural water use, water is considered a given input (Liu et al., 2013), which evidently favors agriculture over industry (Zisopoulou et al., 2022).

The purpose of this paper is to ...

2 Literature review

Water is a dynamic entity, demonstrating both water flows (serving various water roles) and water functions, which collectively establish the global circulatory system. Throughout its cycle, water takes on three roles: in its governing role, it is essential for sustaining all forms of life, generating ecosystem services and functions in terrestrial and aquatic systems; in its state role, it is prone to change, responding, for example, to modifications in land use and contamination; and in its driving role, it can induce societal upheavals through floods and droughts, or serve as a trigger for conflict. These three roles coexist and interact dynamically (Falkenmark, 2020).

2.1 Types of water

There are numerous classifications of water in the scholarly literature, based on their functions. This paper specifically concentrates on two categories: green and blue water. There are several interpretations for both green and blue water (Sood et al., 2014). Falkemark's initial definition suggests that the incoming rainfall is divided into vertical and horizontal flows, leading to aquifers and rivers, which make up "blue water". On the other hand, "green water" is the water found in the root zone, a crucial part of the upper vadose zone that partitions rain and irrigation water into evaporation, transpiration, runoff, and deep drainage (Lazarovitch et al., 2018), acting as a source of plant nutrition (Falkenmark, 1995). A subsequent, more accurate definition (Falkenmark & Rockström, 2006) was provided in the context of resource supply: blue water is the water in aquifers, lakes, and dams, while green water is the soil's moisture; these are associated with the liquid blue-water flow through rivers and aquifers and the green water vapor flow returning to the atmosphere. Green water is bifurcated into two segments, one part stored in the soil as moisture and another part in motion through the evapotranspiration process (Zisopoulou et al., 2022).

Green water has three functions: regulatory, which includes all the functions of soil moisture, evaporation, and transpiration flows to manage the Earth's energy balance and climate system, for example, carbon sequestration and water's capacity as a greenhouse gas; productive, such as evaporation and transpiration to support food, biomass, and bioenergy production; and moisture feedback, controlling the water cycle over land by evaporation. Water also has five distinct blue water functions: water for societal supply, available for withdrawal; water as a carrier of nutrients and pollution, and for transport; water as state, involving the function of water masses and storages; the productive function, for irrigation to produce food, and water to sustain aquatic growth; and the control function, managing the Earth's energy balance, sea levels, and geological processes, such as subsidence (Falkenmark, 2020).

Both blue and green water flows are utilized productively for human needs. Blue water is employed for industrial and domestic purposes and for irrigation in agriculture. Green water supports crop production, grazing lands, forestry, and terrestrial ecosystems (Gerten et al., 2005; Rockström et al., 1999). These systems supply food, fibres, biofuels, timber, and livestock products, along with other ecosystem services that humans derive benefits from (Assessment, 2005; Gordon et al., 2010).

The quality of green water is distinct from that of blue water, with the former's quality being influenced by soil characteristics like the availability and retention capacity of nutrients, as well as the presence of salts and harmful substances. However, there is a close relationship with the quality of blue water. For instance, when blue water, which may be brackish or saline, is utilized for irrigation, it can lead to an increase in soil salinity and also remove surplus nutrients and other materials (Schyns et al., 2015).

The usage of green and blue water has varying socioenvironmental impacts, particularly in relation to competition for other water needs and costs, despite the fact that these two distinct water reserves are interconnected. Primarily, blue water usage tends to face more competition than green water usage. This competition can be especially intense for water resources held in reservoirs, rivers, and lakes, which can be used not only for irrigation but also for hydropower generation, potable water, energy production and extraction, mining, among other industrial uses (D'Odorico et al., 2018). The main competition for the use of green water is essentially linked to the land. Without crops, the fate of soil moisture would vary based on the type of land use (forest, grassland, or developed land), but once crops are planted, there are no other potential uses for green water. In fact, green water is made available at no charge through rainfall, although its productive use by crops necessitates indirect costs for preparing the soil (for example, plowing, mulching, seeding, and weed removal) for rainfed agriculture. On the other hand, the use of blue water incurs a direct cost, which includes the construction, maintenance, and operation of irrigation infrastructure such as canals, pumps, wells, and drip or sprinkler irrigation systems (d'Odorico et al., 2019).

2.2 Water scarcity

As per Falkenmark, 1995, the absolute scarcity of water is defined as the situation where the water supply is insufficient to meet the overall demand, even after all viable strategies to increase supply and manage demand have been executed, usually set to less than 500 m3 per capita of renewable water (Xu & Wu, 2017). However, Winpenny, 1997 notes that "scarcity" is not a singular concept but has various levels, including ”need”, which is the lower limit of the scarcity spectrum. This ”need” has two interpretations: the actual physical need, which signifies the reduction of the discrepancy between the current state and the desired state from an objective perspective, and the ”felt need”, which is based on individuals’ subjective perceptions and anticipated scenarios (Zisopoulou & Panagoulia, 2021).

The Organization on Economic Co-operation and Development (OECD) and the Dublin Water Principles had to officially designate water as an economic commodity. The OECD characterized water as an ’economic good’ because scarce economic resources (such as human, capital, knowledge) were required to ensure the availability of water in the necessary form, quality, location, and time for users (Herrington, 1987). From an economic standpoint, water is considered a scarce commodity because it involves opportunity costs, which are the missed benefits from potential alternative uses of water (Turner, 2004). This is a type of ”relative scarcity” that assumes the interchangeability of goods (Baumgärtner et al., 2006). Indeed, water can also be relatively scarce in regions with abundant water, as allocating water to one purpose means it cannot be allocated to another (Schyns et al., 2015). Thus, water scarcity is driven by demand (Cui et al., 2018; Nechifor & Winning, 2018), assuming the optimal physical and managerial infrastructure for water resources, as it is influenced by:

- The growth of population and Gross Domestic Product (GDP), which escalates the demand for irrigation water to fulfill food production needs and residential and industrial water demand (Rosegrant et al., 2002);
- The efficiencies of water use, which, when achieved in the form of irrigation efficiencies (IE), seldom lead to the public good benefits of increased water availability Grafton et al., 2018, as yield increases are directly proportional to irrigation increases (Perry et al., 2009) and water recycling technology (Shen et al., 2008) or climate-driven (Rossing et al., 2010).

Considering that water is a fundamental element in key sectors of the economy, including agriculture, mining, and industry, its shortage is likely to hinder economic growth, as evidenced in (Dasgupta, 2001), and specifically in Africa (Sachs et al., 2004), according to an in-depth analysis by the World Bank Group (Bank, 2016) and in various economic development initiatives (Blignaut & Van Heerden, 2009). Similarly, there is a direct correlation between rainfall variability and real GDP growth in Zimbabwe (Sanctuary et al., 2007), with a negative impact observed due to a decrease in rainfall. In China, stable industrial development is contingent on the ratio of water resources and human capital growth rates being lower than the ratio of human capital and water output flexibility (Zhang et al., 2017). However, Damania does not find any significant obstacles (Damania, 2020).

It should be noted that water scarcity is determined not only by the volume of the water resource in comparison to demand, but also by the quality of the resource in relation to the quality required for its intended use (Pereira et al., 2002). If there is an adequate amount of water for a specific purpose, but it is so polluted that it cannot be used for that purpose, then the water can be deemed scarce as long as there are no means to purify the water to an acceptable level. Therefore, water resource pollution can exacerbate water scarcity (FAO, 2012a).

2.3 Climate change

Climate change, with its rising temperatures and altered precipitation patterns, poses severe threats to global water security, particularly in arid and semi-arid regions. Studies have shown that global warming will exacerbate water scarcity, leading to significant reductions in snow cover and glaciers, increased saline intrusion into groundwater, and heightened demand for irrigation (Gosling & Arnell, 2016; Zakar et al., 2020). In Saudi Arabia and other Middle Eastern and

North African regions, water mismanagement and increased consumerism have led to critical groundwater depletion, worsening the impact of climate change on water resources (DeNicola et al., 2015).

In terms of broader socioeconomic impacts, climate change is expected to aggravate property damage, health threats, and economic instability, particularly in developing countries. Increased expenditures on damage repair and health maintenance will detract from living standards and economic growth (Stern & Stiglitz, 2023). Advanced models integrating climate change with economic variables reveal that water scarcity will significantly affect irrigation and land use, with trade mitigating some adverse impacts on food security in affected regions (Taheripour et al., 2015).

Overall, the interplay between climate change, water scarcity, and economic growth underscores the urgent need for comprehensive adaptive strategies. Effective water management, combined with robust economic policies, is essential to mitigate the adverse effects of climate change and to ensure sustainable development in the face of increasing climatic variability and uncertainty (Schewe et al., 2014).

Recent research has delved into the impacts of rainfall and water availability on economic growth, highlighting the significant yet variable effects of climate change on economic and agricultural productivity. Canonical studies by Dell et al., 2012 and Burke et al., 2015 examine the combined influence of rainfall and temperature on economic outcomes, consistently finding that while temperature negatively impacts economies, precipitation effects are inconsistent due to spatial aggregation of data at the country level (Lobell & Asseng, 2017). Recent studies have demonstrated that highly aggregated models often underestimate the economic impact of rainfall, which is spatially heterogeneous compared to temperature, resulting in a concave relationship between rainfall and GDP growth, particularly in arid regions (Damania et al., 2020).

Despite these findings, the literature assessing overall agricultural productivity is limited by its focus on cereal crops, which only represent 20% of global net production value, and by its failure to account for input adjustments in response to weather changes, resulting in divergent impacts on total and agricultural GDP (Ortiz-Bobea et al., 2021). Agricultural Total Factor Productivity (TFP), which measures aggregate output per unit of input, reveals that higher temperatures have become increasingly detrimental, yet there is no persistent effect of weather on TFP growth. Neglecting input responses tends to exaggerate the global impacts of climate change on agricultural productivity.

2.4 Global vs Local perspectives

As water is consumed by everyone both directly and indirectly, via agricultural goods and meat, it is a necessity as seen in Varian and Varian, 1992, one with perhaps greatest scope and at a greater scale than any other good. Beyond the ‘need’ concept as seen above there is another impact: a form of an economic aspect of ‘need’ in terms of maintaining or augmenting a particular sectoral economy . This is seen on two levels (Zisopoulou et al., 2022):

1. At global level, water is needful in both agriculture and industry. Through its use measured by footprints in agriculture and industry, it represents additively a sizeable segment of the global tangible economy in terms of capital, both installations and monetary flow, as well as in terms of labor. Reduction of these sectors will have a global negative economic effect. Moreover, the competition between the agricultural and the industrial sectors constrained by the limits on quantity available will place a stress on the global economy. Considering that the 2030 U.N. hunger targets will not be attained, agricultural needs will be fueled and the increase in population and affluence projected by the Food and

Agricultural Organization (FAO) (FAO, 2012b) will fuel the needs of both agriculture and industry.

2. At country level, the situation above is exacerbated as water resources and availability are unequally distributed and so is increase in population and affluence. A good example is Sub-Saharan Africa (Malmberg, 2008), where water resources and availability are low, population increase is high and affluence is low.

The nature of water as an economic asset at the national level is influenced by factors such as the availability of blue water and rainfall, per capita income, the structure of national production, exchange rates, international loans, and external balances. Furthermore, while the global hydrological cycle, as seen above (Koutsoyiannis, 2020), tends towards a state of equilibrium, the hydrological cycles at the country level are diverse and vary significantly from one country to another. In nations where water availability is low or regionally irreparable, the public and social good aspects of water become increasingly prominent. The only viable solution in such circumstances is a centralized state water policy, as the necessary expansion of water infrastructure will be substantial, requiring resources and expertise at the state level, and its distribution can only be optimized at a national scale, leading to greater state control over its provision. This is exemplified by the countries of the Southern African Development Community (SADC) (Loehman & Dinar, 1992), where the Human Development Index (HDI) rankings among 177 countries range from 121 to 168, annual per capita freshwater withdrawals are all below 1000 m3/year, and water distribution prioritizes agriculture over domestic consumption and industrial use. The primary cause is believed to be the inequitable allocation of water across sectors (Bohm, 1987), with the government being the main source of funding for water infrastructure in South Africa (Sukharev, 2012).

Water plays a significant role in national social welfare, influencing poverty reduction, employment, and food security (Rogers et al., 1998), as demonstrated in a study on MENA countries (Hussein, 2011). However, social policy should be viewed as a state intervention that operates in conjunction with economic policy to achieve national social and economic objectives (Mkandawire, 2006). This policy imposes limitations on the extent and methods of mitigation measures related to a country's water policy, both generally and at the regional level, as elements such as basic needs, government debt, and economic growth are interconnected (Irons & Bivens, 2010). This social policy's implications include the stabilization of rural agricultural prices through government intervention, which is not deemed distortionary in the context of impoverished countries (a study on Kenya investigates the impact of allocating 10% of the government budget to this cause (Boulanger et al., 2018)), and a policy objective of self-sufficiency, which is not deemed a case of "poor economics", as outlined in a 2009 FAO report (Chang, 2012).

Countries that are rich in available water have a Ricardo type comparative advantage in the international trade of goods with medium/large water footprint over countries which are not, and according to the Heckser–Ohlin Model (H–O) (Leamer et al., 1995), this leads to a degree of specialization in these goods within their production distribution. The need for water at national level gave birth to a substantial global scale virtual water trade network with strong plasticity (the ability to change structurally and functionally in time). In the period 1986–2008 the number of inter-country connections increased by 70%. From the point of view of exporters, this remained constant after 1991, and doubled in volume (Carr et al., 2012). This enhances the mobility of water as a factor in the exporting country, which, as per the general equilibrium theory, contributes to growth by boosting water productivity. Furthermore, agri-foods do not adhere to Vernon's product cycle (Vernon, 1966) for low-income countries, despite the ongoing advancements in agricultural technology (Khan et al., 2021). Concurrently, the amalgamation of per capita GDP growth, population growth and GDP growth for water-stressed countries like India, Sub-Saharan Africa (SSA) and Near East and North Africa (NENA) is unfavorable when compared to Europe and North America, the primary agri-food exporters, as evident from World Bank Data.

Indeed, it is observable that blue and green water and landmass rainfall do not constitute a closed system in the context of hemispheres. There is a transfer of rainfall to the northern hemisphere in a region north of the equator, owing to the northward energy redistribution beyond the equatorial ocean through heat transport, as the meridional overturning circulation also transports energy, carrying heat northwards across the equator (Frierson et al., 2013). This, along with moisture, may decrease due to global warming (Weaver et al., 2012). Additionally, the melting of Arctic ice results in prolonged deviations from typical precipitation during autumn and winter in densely populated northern hemisphere regions (Walsh, 2013). This delineates water-abundant countries, with the U.S. as the export hub, in contrast to water-scarce countries. Even when relative, not absolute, water abundance is present among a group of countries and their neighbors, the H–O model is proven accurate, for instance, for MENA countries and exporting countries like Greece and Turkey (Sayan, 2003). In this scenario, Greece and Turkey only partially specialized their production with comparative advantage (opportunity costs and comparative advantage are dependent on production levels, and Greece is bound to the costly euro while Turkey employs the cheap lira), and the other countries showed the significance of relative water resources. This sensitivity can be traced back to the Lerner-Pearce diagram (Sayan, 2003), which compares a necessity and a normal good in a two-good economy. It is worth noting that countries abundant in water are also, for the most part, countries with a competitive advantage in Porter's sense, which amplifies their comparative advantage created by water abundance and vice versa.

2.5 Virtual water trade

As illustrated previously, there exist two contrasting perspectives on the economic characteristics of water, which vary based on whether the viewpoint is global or national (Zisopoulou et al., 2022). In the global perspective, the world's population is seen as a single, idealised consumer body. Conversely, in the national perspective, the population is divided into competitive entities delineated by sovereign nations. This latter perspective, which is arguably more grounded in reality, presents water at the inter-country level as a rival and excludable commodity, thereby not an impure public good. The principles of non-rivalry and non-excludability are implemented at the intra-country level as integral components of national economic strategies, and within the financial capacity of the specific nation, where the state serves as the local player. This division establishes a structure of 'haves' and 'have nots'. It positions inter-country virtual water trade as a global actor in transforming water into an impure public good at the national level, in partnership with the sovereign state actor (Zisopoulou et al., 2022). Consequently, an 'international water market' emerges where water, in the guise of virtual water, is traded as a private commodity at the national level and moves towards the actual consumers (as per the global perspective) under the rules and regulations set by the participating state in the international water market.

The concept of 'virtual water' was initially introduced in 1994 by Allan, 1994. It is characterized as the water incorporated into products during their manufacturing process (Hoekstra, 2003). The aggregate amount of water utilized in the production of traded goods significantly surpasses (and covers more extensive distances) than the quantity of water that is physically moved around the globe (Oki et al., 2017). In fact, water is predominantly a resource that is physically accessible for local consumption (Hoekstra, 2017), as it is substantially more straightforward to transport goods or crops than the water needed for their production. Over the past century, the escalation of trade has resulted in certain global regions becoming heavily reliant on food, energy, and materials that are produced or extracted using water resources located elsewhere. This situation provokes concerns regarding national water security and the governance of water resources essential for societal progression (Carr et al., 2012). Indeed, numerous countries lack self-sufficiency and rely on imports from other regions to satisfy their requirements (Carr et al., 2013; Hoekstra & Chapagain, 2011). For instance, the limited water resources available in the Middle East are currently inadequate to fulfill the food requirements of the local inhabitants (Allan, 1998). Virtual water is incorporated in products from agriculture, forestry, industry, and mining (D'Odorico et al., 2018). Water is also necessary for electricity production, as well as for the extraction and processing of minerals and both traditional (Carr & D'Odorico, 2017) and non-traditional fossil fuels (Rosa & D'Odorico, 2019). The majority of water scarcity indicators only consider local water consumption and availability (Liu et al., 2017), yet a significant portion of water consumption and pollution is attributable to global and regional trade (Vörösmarty et al., 2015).

One intriguing aspect of CGE models, particularly noticeable in the second set of simulations, is the capability to understand trade movements in the context of virtual water. Given the availability of industrial water consumption estimates, the conversion of international trade flows in agricultural commodities into virtual water flows becomes feasible (Calzadilla et al., 2017). Seen from this perspective, the virtual water trade is frequently acknowledged for its potential to enhance both physical and economic water accessibility in regions with water scarcity (Zhao et al., 2021), enabling these areas to conserve domestic water by importing products that require a lot of water (Kumar, 2017). It can be anticipated that countries with water scarcity may be at a comparative disadvantage in industries that consume a lot of water, implying that they should import more from these sectors, or in other words, that virtual water imports could partially offset water scarcity (Calzadilla et al., 2017). Moreover, as every simulation using a CGE model produces hypothetical trade flows, it's always feasible to interpret all simulation outcomes in terms of changes in virtual water trade patterns (Calzadilla et al., 2017).

There exist numerous factors that might cause the flow of virtual water not to align with our intuitive understanding in the real world (Reimer, 2012). However, virtual water continues to serve as a potent illustrative tool to underscore the potential efficiency gains from trade, as per the neoclassical theory (the foundation of CGE models), specifically in the context of managing water resources. It's important to remember though, given the often ambiguous nature of water property rights, virtual water trade doesn't necessarily result in a Pareto improvement (Calzadilla et al., 2017). The temporal rebuilding of the VWT network (Carr et al., 2012) has facilitated the study of shifts in the geographic spread of VWT and network characteristics over recent decades. These investigations have underscored that cereal grains generally constitute the largest share of virtual water movements, with soybeans, vegetable oils, and luxury items like coffee and chocolate also making up a significant part of the traded virtual water (Carr et al., 2013). Basic VWT balances indicate that countries such as the United States, Brazil, Argentina, India, and Australia consistently function as net exporters, while Germany, Italy, Russia, and Japan operate as net importers of virtual water (Carr et al., 2013). Certain regions, like the Middle East, have augmented their importation of virtual water resources, whereas other regions like Central Africa and China have transitioned from being net exporters to net importers of virtual water (Carr et al., 2013). Notably, the rise in exports from South America, particularly Brazil and Argentina, reduced the North American proportion of trade to both Asia and Europe from 1986 to 2007, mirroring historical shifts in global trade and the diminishing role of the US in agricultural exports (d'Odorico et al., 2019).

The virtual trade of blue and green water through crops occurs at a similar rate: it is estimated by Konar et al., 2012 that blue water contributes 12% to the global VWT, a ratio that has remained consistent over time, according to a study on five crops and three livestock products from 1986 to 2006 (Konar et al., 2012). Nevertheless, the proportions of blue and green water used in crop production vary significantly depending on the product and location. For example, regions like South Asia tend to use more irrigation compared to other parts of the world. This increased dependence on blue water is indicative of an arid climate with limited rainfall during the growing season. There are also notable differences between various sources of blue water, such as groundwater and surface water, both of which are utilized across all economic sectors, including irrigation, industry, and municipal uses. Virtual water transfers frequently serve as a means of providing relief during famines and alleviating the impact of regional food shortages. VWT helps avoid large-scale migrations from drought-prone areas of the world where water resources would be insufficient to satisfy the needs (food security) of the local population, and it is for this reason that they are believed to avert conflicts and wars (Allan, 1998). Virtual water trade is also linked with significant water savings, as the general trends in agricultural production and trade indicate that crops are grown in regions where they have a higher water use efficiency and are then exported to areas where their production would demand more water. This implies that Virtual water trade promotes a more efficient utilization of water resources, leading to water conservation. However, despite the fact that Virtual water trade can alleviate local water shortages by virtually redistributing water resources (Suweis et al., 2013), it does not offer a sustainable long-term solution to water scarcity (Jia et al., 2017; Suweis et al., 2013), as water continues to be a globally finite resource under increasing strain from agricultural, industrial, and municipal uses (d'Odorico et al., 2019).

3 Conclusion

This literature review provides a comprehensive examination of the multifaceted roles and classifications of water, its significance in sustaining ecosystems, and its intricate interplay with socio-economic and environmental factors. Water's three primary roles—governing, state, and driving—highlight its indispensable nature in sustaining life, responding to environmental changes, and influencing societal dynamics through events such as floods and droughts. These roles underscore the dynamic and interconnected nature of water within the global circulatory system, emphasizing its multifaceted impacts on both natural and human systems. The distinction between green and blue water, and their respective roles, is crucial for understanding water resource management. Green water, essential for soil moisture and plant growth, plays regulatory, productive, and moisture feedback roles. Blue water, found in aquifers, lakes, and rivers, supports societal supply, nutrient transport, irrigation, and geological processes. This classification provides a framework for managing water resources effectively, balancing the needs of agriculture, industry, and ecosystems.

Water scarcity, defined both in absolute and relative terms, poses significant challenges. The scarcity driven by increasing population and GDP growth, inefficient water use, and climate change threatens to hinder economic growth and stability, particularly in regions with limited water resources. Addressing water scarcity requires a multifaceted approach, incorporating both supply augmentation and demand management strategies. Climate change exacerbates water scarcity by altering precipitation patterns, reducing snow cover, and increasing the demand for irrigation. This not only impacts water availability but also has broader socioeconomic consequences, including property damage, health threats, and economic instability, particularly in developing countries. Effective adaptation strategies are essential to mitigate these impacts and ensure sustainable water management.

The global and local perspectives on water use highlight the complexity of managing water resources. While water is a global necessity, its distribution and usage are highly localized, leading to disparities in water availability and economic impacts across regions. The competition between agricultural and industrial water use, coupled with population growth and affluence, intensifies the need for efficient and equitable water management policies. The concept of virtual water trade illustrates the global interconnectedness of water resources. By importing products that require substantial water for production, water-scarce regions can alleviate local water shortages. However, the effectiveness of virtual water trade depends on numerous factors, including water property rights and the efficiency of trade networks . Understanding the dynamics of virtual water trade is essential for optimizing global water resource management.

This review highlights several key areas for future research and policy development:

1. **Integrated Water Management**: Developing comprehensive frameworks that consider the interconnected roles and classifications of water is essential for sustainable water management.
2. **Adaptive Strategies for Climate Change**: Policies must incorporate adaptive measures to address the impacts of climate change on water resources, focusing on both mitigation and resilience building.
3. **Equitable Water Distribution**: Ensuring fair and equitable distribution of water resources, particularly in regions with limited availability, is crucial for social and economic stability.
4. **Enhancing Virtual Water Trade**: Further research is needed to optimize virtual water trade networks, ensuring they effectively contribute to global water security and sustainability.

In conclusion, water's complex roles and functions, coupled with the challenges posed by scarcity and climate change, necessitate a multi-dimensional approach to water resource management. By integrating scientific insights with practical policy measures, it is possible to achieve sustainable and equitable water use that supports both human and ecological well-being.

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