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DOI: https://doi.org/10.14195/2183-203X_56_3

Responding to the Global Challenges of 'Too Much, Too Little and Too Dirty' Water: Towards a Safer and More Just Water Future

Respondendo aos Desafios Globais de "Too Much, Too Little and Too Dirty Water': Rumo a um Futuro Mais Seguro e Justo

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Received for publication: May 31, 2023
Revision accepted for publication: June 30, 2023

ABSTRACT
The world water crisis is manifest through 'Too Much, Too Little and Too Dirty' water at multiple scales from the local to the global. Understanding the key drivers and consequences of this water crisis, and who bears the biggest costs, is necessary to develop appropriate responses, at scale and over time. Using four framings: one, water stocks and limits; two, water rights and responsibilities; three, water values and prices; and four, green and grey water infrastructure, we review the challenges and possible responses. Using a water justice lens, we highlight the transitional and transformational pathways towards a safer and more just water future.
Keywords: World water crisis; justice; floods; droughts; WASH; infrastructure.

JEL Classification: Q25; Q57; Q58.

Acknowledgement: This research was funded, in part, by the Australian Research Council grant FL190100164: 'Water Justice: Indigenous Water Valuation and Resilient Decision-making', the 'Hilda John Endowment' of the Australian National University and a subsidy from the Dutch Enterprise Agency. The authors also gratefully acknowledge insightful discussions with Joyeeta Gupta, Aromar Revi, Jagdish Krishnaswamy, Hilmer Bosh, Neha Sami, and Julia Schaef.

"We shall overcome because the arc of the moral universe is long, but it bends toward justice."

Dr. Rev. Martin Luther King Jnr, 31 March 1968

1. The World Water Crisis

In this review, we describe the world water crisis in its multiple dimensions and the consequences that manifest themselves as 'Too Much, Too Little, and Too Dirty' water (Chen, 2018; Fanaian, 2022). Too Much water is primarily associated with flooding events that expose at least 20 percent of humanity to flood risks (Tellman et al., 2021). In coastal areas, Too Much water from storm surges exacerbates saline intrusion associated with sea-level rise (Mohammed and Scholz, 2018). Too Little water is primarily about hydrological droughts that arise from both meteorological and human actions, such as excessive water withdrawals (Agha Kouchak, 2021). Too Little water also includes the limited water access of billions of people due to exclusion from formal piped water systems and/or from the high economic costs of access to safe water supplies (Rusca and Cleaver, 2022). Too Dirty water is about water pollution; most visible with inadequate Water Sanitation and Hygiene (WASH) for many vulnerable communities in the Global South[1] (Dados and Connell, 2012). All three dimensions will worsen with climate change (Flörke et al., 2018; IPCC, 2022; Pokhrel et al., 2021; Satoh, 2022).

Collectively, floods and droughts increase mortality and morbidity, contribute to declines in ecosystem services, create food price spikes, displace people, damage infrastructure, reduce economic activity and contribute to conflicts (The World Bank, 2016). Too much water is not just a result of excess precipitation but is caused by land-use planning that unnecessarily exposes people to flood risks, inadequate or improper infrastructure that transfers, and may magnify, downstream and coastal flooding risks, and the degradation of green infrastructure (e.g., wetlands loss, deforestation, etc.) that would otherwise mitigate flood events (WMO, 2021). Too Little water arises from hydrological droughts, defined as low water availability that can arise from multiple factors including reduced precipitation and excessive water withdrawals (Grafton et al., 2022a; Mukherjee et al., 2018). Hydrological droughts can be particularly devastating, especially if they are multi-year phenomena, and have multiple, and sometimes persistent, negative health and economic impacts, especially on poor and vulnerable communities (Damania et al., 2018). An historical review of global droughts indicates that the severity of hydrological droughts that impose costs on agriculture and ecosystem services is increasing (Vincente-Serrano et al. 2022). Too Dirty water means that globally some 2 billion people are forced to drink unsafe water which has a disproportionate negative impact on both children and women (WHO 2019, 2021; WHO and UNICEF, 2022). Failing to deliver safe water and sanitation causes premature deaths, globally, of about one

[1] "The term Global South functions as more than a metaphor for underdevelopment. It references an entire history of colonialism, neo-imperialism, and differential economic and social change through which large inequalities in living standards, life expectancy, and access to resources are maintained" (Dados and Connell, 2012, p. 13).

million people per year and widespread morbidities associated from water borne diseases and parasites (e.g., cholera, dysentery, schistosomiasis, etc.).

In section 2, we describe the world water crisis in its three critical dimensions (Too Much, Too Little and Too Dirty water) and present some consequences at both a global and regional level. Our regional focus includes seven countries (Australia, China, France, India, Nigeria, South Africa, and the United States of America) across five continents in relation to Too Much and Too Little water. In section 3, and with a water justice lens, we present four framings to better understand the world water crisis: one, water flows and limits; two, water rights and responsibilities; three, water values and prices; and four, green and grey water infrastructure. In section 4, we highlight possible transitional and transformational pathways to mitigate the world water crisis. We offer our conclusions in section 5.

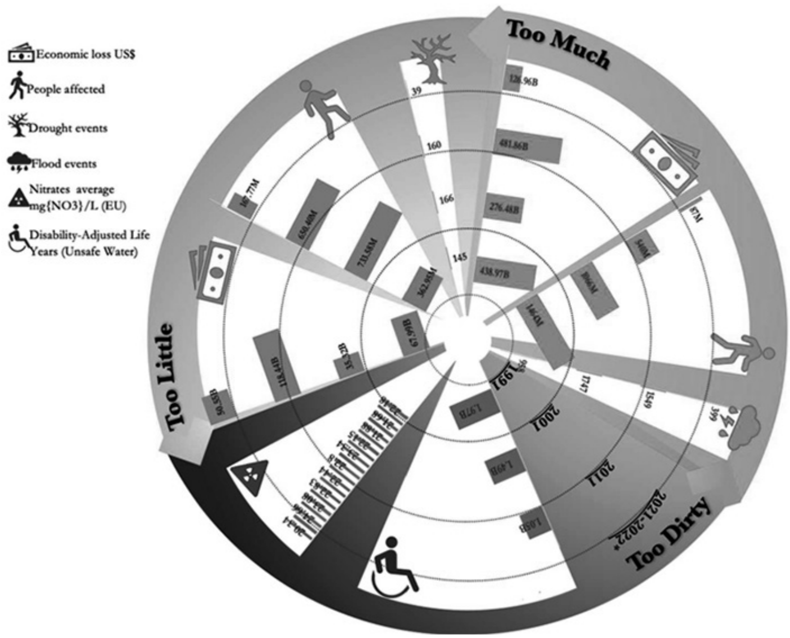
2. **TOO MUCH, TOO LITTLE AND TOO DIRTY WATER**

2.1. Too much water

Figure 1 shows an increasing number of flooding events over time; this is consistent with a growing intensity of rainfall events associated with climate change (IPCC, 2022). For example, for the two years 2021 and 2022 there were more than a quarter of the flood events of the previous decade. The number of floods, however, is not necessarily commensurate with the intensity of the flood events, as measured by economic costs. Globally, between 2001 and 2010, there were some large-scale 1,700 flood events that generated total damages of US$276 Billion (adjusted for inflation). By comparison, between 2011 and 2020 there were some 1,500 flood events with reported damages of US$481 billion.

Despite an increase in flood events over time, human adaptation (Jongman, 2018; Islam et al. 2018) in the form of flood warning systems, flood protection infrastructure, flood risk land-use planning, and nature-based solutions has resulted in a global decline in the reported global number of people impacted by floods in both high and low-income per capita countries (Figure 1). In India and China, the reported number of those affected by flooding in 2010-2020 was less than a third of what it was in 1991-2000 (Figure 2). Africa, however, is not experiencing a downward trend in the numbers affected by floods. Further, in some locations, the consequence of flooding events appears to be increasing. For example, in Australia, flooding events in 2021-22 alone affected more people than in the previous two decades (2000-2020).

Figure 1: The world water crisis: Too Much, Too Little and Too Dirty Water



Source: Authors; for data sources and detailed notes see Appendix.

2.2. Too little water

Due to a changing climate, including increases in atmospheric evaporative demand, extended hydrological droughts are intensifying in the 21st Century (Haile et al., 2020; Vincente-Serrano et al., 2022). Some countries, such as China (Figure 2), have reduced the economic costs and number of people affected by hydrological droughts. In the case of China, adaptation to hydrological droughts has included huge infrastructure investments, especially in large inter-basin water transfers (Sun et al., 2021).

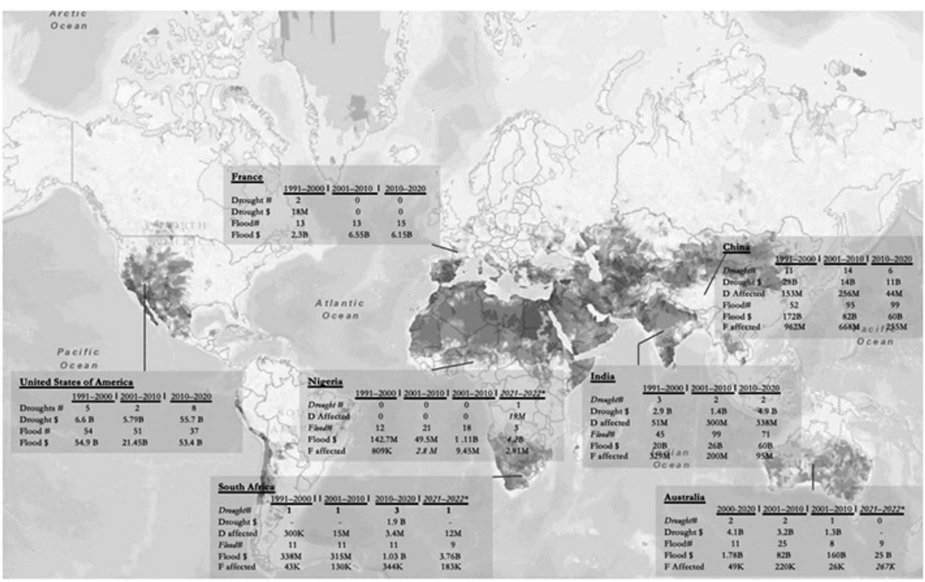
By contrast, the number of people affected by hydrological droughts in India has got worse, not better, increasing by more than two-thirds between the decades 1991-2000 and 2010-2020. In part, this is a result of population growth with some countries, such as Pakistan, experiencing large (80 percent) declines in water availability per capita (World Bank, 2023). Climate change may also mean that countries which have not historically been subject to extended hydrological droughts, such as Nigeria (Shiru, 2020), are particularly vulnerable because of limited experience in adapting to less water.

2.3. Too dirty water

Increasing pollution in rivers, lakes, wetlands, and groundwater has multiple and negative consequences on human and ecosystems health. A global study on the burden of disease (IHME, 2020) shows that unsafe water sources led to as many as 1.7 million deaths in 2017 and caused disabilities (Disability-adjusted life years) for more than 87 million. By comparison, in 2019 the global annual water-related mortality due to unsafe water source was three times larger than the world's deaths due to homicide (IHME, 2020).

The sources of water pollution are diverse and include domestic waste and pollution from agriculture and industry (Mekonnen and Hoekstra, 2018). While there is an extensive network to capture data on water availability, much less water quality data are available (only 37 countries report a broad range of water quality measures to the United Nations) with especially sparse reporting from the Global South (Damania et al., 2019; Grafton et al., 2023a). For one key measure, the reported median level of nitrates in groundwater, the trend is getting worse, not better, in the European Union. Importantly, without regular and widespread water quality reporting, and not just for drinking water, it will be impossible to identify the direct sources of water pollution and/or to measure the progress of mitigating actions.

Figure 2: Global map of water scarcity with Too Much and Too Little Water for Seven Countries (Australia, China, France, India, Nigeria, South Africa, and the United States of America)



Source: The Authors; for data sources and detailed notes see Appendix.

3. FOUR FRAMINGS OF THE WORLD WATER CRISIS

There are multiple ways to describe the world water crisis that include perspectives on; environmental (Gupta et al., 2023; Gupta and Lebel, 2010) and water justice (Grafton et al., 2022; Savelli et al., 2023; Zwarteveen and Boelens, 2014), WASH (WHO and UNICEF, 2022), ecosystem sustainability (Green et al., 2015; Pastor et al., 2022; Vörösmarty et al., 2010), water withdrawals (Rodell et al., 2018; Scanlon et al., 2023; Yao et al., 2023), water scarcity (Dalstein and Naqvi, 2021; Distefano and Kelly, 2017; Kummu et al., 2010; Mekonnen and Hoekstra, 2016), water insecurity (Garrick and Hahn, 2021; Grafton, 2017), food and water insecurity (Rosegrant et al., 2009), water governance (Fanaian and Fanaian, 2023; Grafton et al., 2013; OECD, 2018), planetary tipping points (Lenton and Williams, 2013) and boundaries (Wang-Erlandson et al., 2022), among others (Grafton et al., 2023b).

Connecting all these perspectives on the world water crisis is water justice (Figure 3). At a minimum, water justice requires: one, everyone's basic water needs are met; two, procedural justice such that all those materially affected by water decisions have a respected 'voice' at the table; three, substantive justice such that actions are taken to correct for past and continuing water injustice (Grafton et al., 2022b; Gupta et al., 2023; Syme et al., 1999); four, epistemic justice such that decision-makers value and respect all knowledges and experiences (Mehltretter et al., 2023); and, five, justice for 'living waters' that goes beyond an exclusive anthropogenic and/or utilitarian view of water (Bates et al., 2023; Mcgregor et al., 2020). These five underpinnings of water justice are consistent with the three I's of Earth System Justice; Interspecies, Intergenerational and Intragenerational equity (Gupta et al., 2023).

Figure 3: Towards water justice

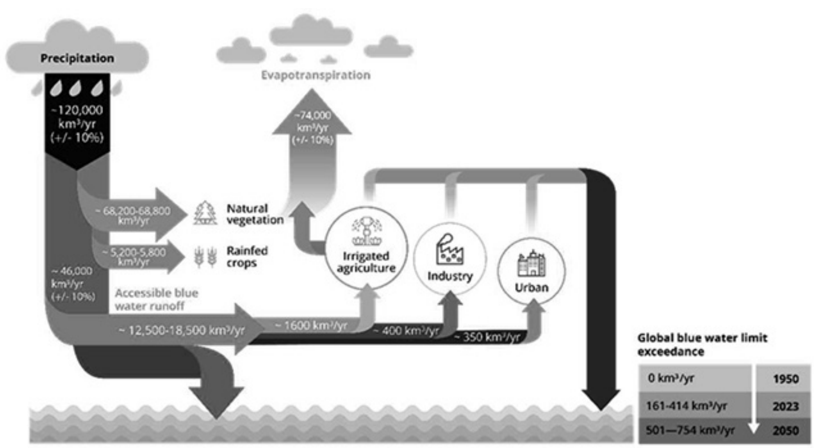
Source: Authors, adapted from or inspired by Bates et al. (2023); Gupta et al. (2023, Figure 2); McGregor, (2018); and Mehltretter et al. (2023).

Including water justice as a connecting theme, we present four framings to better understand the causes, consequences and possible actions required to respond to the world water crisis.

3.1. Water flows and limits

Fresh water availability and accessibility, including both surface and groundwater, have had an enormous impact on human social, cultural, and economic development. People have, over millennia (Hosseiny et al., 2021), developed successful strategies to mitigate against water scarcity and water variability (Hall et al., 2014), such as building or enhancing water storages, water transfers and, more recently, desalination. Nevertheless, local and regional social, and economic development progress remains closely tied to both the quantity and quality of freshwater available for household use, and the production of food and fibre, especially for irrigated agriculture.

Figure 4: The water cycle, global water consumption by sector and blue water consumption exceedance

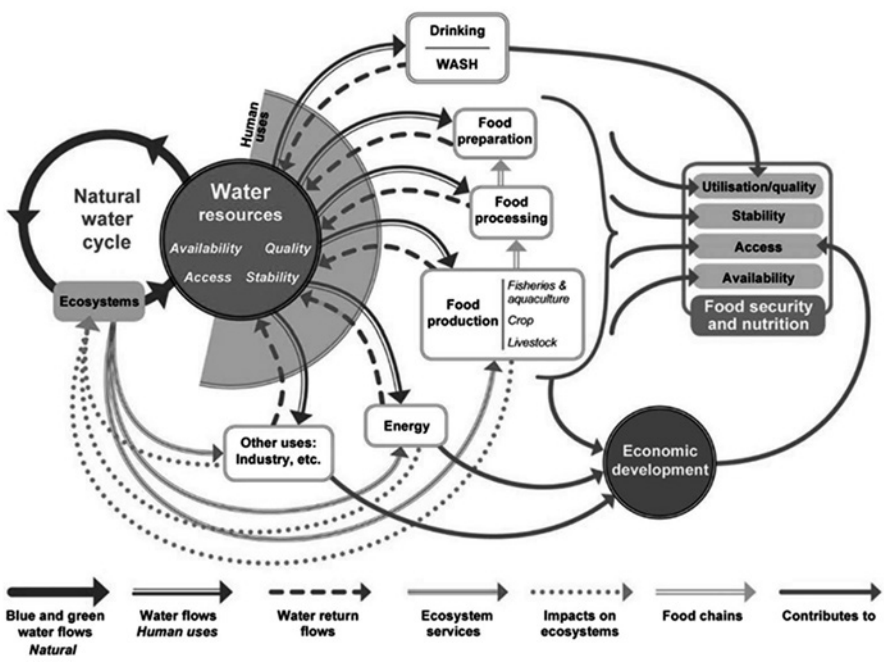


Source: Grafton, Krishnaswamy and Revi (2023).

Much of the global terrestrial freshwater flow is consumed via evapotranspiration from natural vegetation (more than 50% of annual precipitation); rain-fed crops consume about 5% of the total terrestrial precipitation. Accessible runoff, the water available in accessible streams and rivers, represents about 10-15% of the total land precipitation. Of this total runoff, irrigated agriculture accounts for over 80% of human water consumption, via evapotranspiration (see Figure 3), and produces about 30-40% of the world's food (Rosegrant et al., 2009). About one half of the agricultural production from irrigation is associated with unsustainable water consumption (Rosa et al., 2019). Further, about a quarter of the world's food is traded which means that unsustainable water consumption in irrigated agriculture poses systemic risks for global food security (D'Ordorico et al., 2014).

Systemic risks between water and food (Figure 4), and between food and energy because of the intensity of fossil use in intensive agriculture (Rosa et al., 2021), are increasing. This is because: one, the global food trade has increased by more than one half since the mid-1980s, two, the calories from food trade per volume of water withdrawn has declined (D'Ordorico et al., 2014), and three, projected declines in food availability to 2050 and 2100 under multiple climate change scenarios from increased water stress and heat stress (Kompas et al., 2023). Multiple and important connections exist between water resources, water use and water consumption, and food security (Figure 5). Water insecurity in terms of gaps in availability, access, stability, and quality is a key contributor to food insecurity via constraints on food production and of inadequate WASH services.

Figure 5: Food and water interconnections



Source: HLPE (2015, Figure 1).

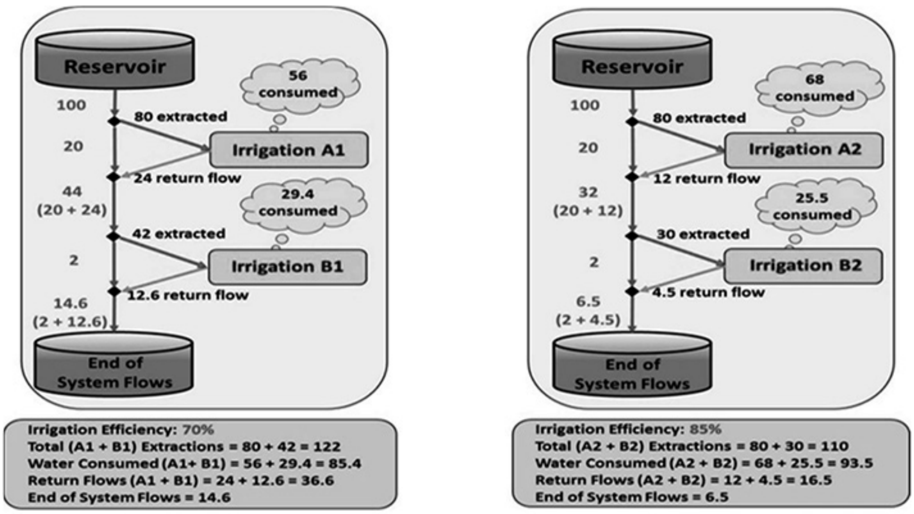
Human blue water withdrawals and consumption (evapotranspiration) account, respectively, for about 35 percent (Postel et al., 1996) and 20 percent (see Figure 4) of the accessible annual water run-off. A key challenge with the world water crisis is that, at a global level, is the annual rate of blue water (water in rivers, lakes, groundwater, and human-made water storages) consumption exceeds the sustainable limit. This exceedance is expected to double by 2050 under business as usual (Grafton, Krishnaswamy and Revi, 2023).

The proximate cause of the exceedance of blue water consumption limits are twofold. First, groundwater depletion, especially in arid and semi-arid locations, that arises from rates of water withdrawal that exceed aquifer recharge (Wada et al., 2012; Yao et al., 2023). Second, excessive surface water withdrawals that have reduced stream flows in streams and rivers below minimum environmental flows (Richter et al., 2012), and this projected to get worse to 2050 (Zhang et al., 2023), degrade ecosystem services (Poff and Zimmerman, 2010). The rates of blue water exceedance are, typically, the greatest in arid and semi-arid areas that have high population densities such as Northern India and Northern China. Overall, the world's current blue water consumption exceeds the sustainable level of blue water consumption, is increasing and, with business as usual, could be twice as large by 2050 (Figure 4).

A common response to blue water exceedance and increasing water scarcity has been to subsidise and/or promote increase in water-use efficiency (HLPW, 2018). In the case of irrigation, water-use efficiency is defined as the ratio of the water consumed in beneficial plant growth to the total water withdrawals measured at either the field, farm, or catchment scale (Figure 6) and is known as irrigation efficiency. While increasing irrigation efficiency benefits irrigators by increasing the returns from any additional volume of water that is withdrawn, this typically reduces the blue water that would otherwise have returned to groundwater and streams and rivers, known as return flows (Willardson et al., 1994). The paradox of irrigation efficiency is that increasing water-use efficiency will, typically, not increase water availability for other purposes, such as for environmental flows (Grafton et al., 2018), and frequently reduces return flows and end-of-system flows (Figure 6), both of which can generate large economic benefits and support water justice (Owens et al., 2022).

Instead of subsidising increases in irrigation efficiency, water accounting complemented by water consumption caps, are much more likely to control anthropogenic blue water consumption (Grafton et al., 2023a). To ensure global food sufficiency from an increased global population and lower growth (or no growth) in yields due to climate change (Grafton et al., 2017; Kompas et al., 2023), there is also a need to substitute unsustainable water withdrawals in irrigated agriculture with green water (soil moisture available from plant growth) for rain-fed agricultural food production (Rosa et al., 2020).

Figure 6: Irrigation efficiency, return flows and end-of-system flows



Source: Perry et al. (2023, Figure 2).

3.2. Water rights and responsibilities

Rights to access, use, consume water and then to dispose of wastewater determine the 'who gets what' of water. Safe drinking water and sanitation are considered a basic human right consistent with Resolution 64/292 of the UN General Assembly. Delivering this right requires much larger than current investments in grey (human built) or green (nature-based) infrastructure and the delivery of affordable (Al-Ghuraiz and Enshassi, 2005) basic water services to the poor (Tortajada and Biswas, 2017).

Both a lack of safe access, especially in rural and urban areas of the Global South, and affordability, explain why some 2 billion people lack access to safely managed drinking water services (WHO, 2021) and some 3.6 billion lack access to improved sanitation services (WHO and UNICEF, 2022). Beyond a right to basic water services and investment in water services, countries need regulatory frameworks to allocate and to reallocate water among sectors (e.g., industry, agriculture, household), and across individual water users to ensure just outcomes. Without proper consideration of 'winners and losers' from water infrastructure investments, such as for large dams, water injustices can, and have, been exacerbated (Blake and Barney, 2021; Duflo and Pande, 2007). Attention must also be given to the scale, distribution and diversity of infrastructure, and their ownership, management, and control (Schwartz et al. 2018; Fanaian and Fanaian, 2023).

Typically, water justice is not prioritised when reallocating water across time and place. Importantly, the responsibility to deliver the basic human right to water and water justice is not only a moral obligation but is closely connected to sustainability of ecosystem services that affects both the rich and poor (Gupta et al., 2023; Rammelt et al., 2023). This means that for those with well-defined water rights and services, there is a responsibility to act to ensure that those who do not have their basic water needs met will, ultimately, achieve this basic human right.

The provision of rights to water must pay special attention to those who have been dispossessed of their rights, including Indigenous peoples' rights (Jackson, 2018) recognised in the United Nations Declaration of the Rights Indigenous Peoples (UN General Assembly 2007), known as UNDRIP. Exercising Indigenous rights as part of UNDRIP should encompass the EAUX principles (Mehltretter et al., 2023) of: Equity (honoring Indigenous Peoples' sovereignty), Access (recognising and affirming Indigenous rights), Usability (benefits Indigenous peoples), and eXchange (on-going flow of information among diverse groups for mutual understanding).

Water rights are increasingly being traded and water markets are expanding in several countries, ostensibly to overcome water insecurity (Wheeler, 2021). Without careful design and regulatory oversight, however, water markets will not deliver efficiency, equity, or sustainability (Grafton, Horne and Wheeler, 2022). That is, there must be, at a minimum, water accounting (Vardon et al., 2023) about 'who gets what and when' and rules about 'how' water is used and consumed to mitigate the external costs imposed on others from any given water use. Where there are water rights and water markets, there must also be: one, responsibilities in relation to fairness in the initial allocation of water rights and, two, complementary regulations and market rules to ensure water withdrawals and consumption are sustainable and do not impose unacceptable costs on those without water rights and the environment.

3.3. Water values and prices

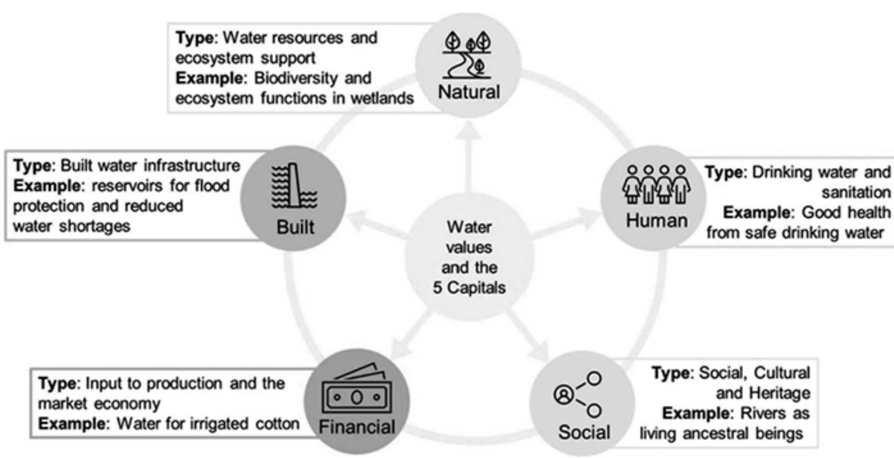
The value of water is the benefit (direct and indirect) to users from access, use and/or consumption of a given volume of water at a particular place and time. By contrast, the price of water is the amount paid (typically in monetary units) by a user (individual, household, community, business, etc.) for a given volume of water of perceived quality at a particular place and time (Grafton et al., 2023c). Thus, while price and value are related (e.g., the higher the value of water the higher price that a user is willing to pay for water) they are not the same.

Water prices that adjust to changes in water availability can provide incentives to conserve water when there is less available (Grafton et al., 2011). The challenge in incentivising water conservation from higher water prices is that, typically, the poor already suffer from inadequate access to safe drinking water and sanitation and frequently pay the highest volumetric price for water (Kariuki and Schwartz, 2005). This is because many poor are not connected to safely managed water supply systems and are forced to rely on private water vendors or collect water themselves. Thus, many of the poor in the Global South are not beneficiaries of water subsidies that primarily go to those with access to centralised water distribution systems. Consequently, when deciding on financial allocations to deliver WASH goals on the basis of water justice, subsidies need to be based on need (Whittington et al., 2015) rather than be determined by those with preferred access to existing water infrastructure (Andrés et al., 2021).

Water pricing also includes pricing 'bads' either directly through pollution charges and fines for non-compliance or indirectly through regulations (Olmstead, 2010). Whatever the pricing approach, active price intervention should include incentives for polluters to reduce pollution, investments to reduce discharges and/or to treat discharges, and appropriate monitoring compliance and enforcement. If fines for pollution are established without complementary public policy interventions and diligent monitoring, there will continue to be large and negative impacts on both people and the environment from poor water quality (Damania et al., 2019).

A comprehensive review of water values (United Nations, 2021) connects water to the major types of human and nature capital. These five capitals include: (1) built infrastructure (e.g., dams); (2) natural infrastructure (e.g., wetlands); (3) human (e.g., public health); (4) cultural (e.g., sacred rivers); and (5) financial (e.g., market benefits from industrial water use). As shown in Figure 7, supporting water values is not simply about investing in built or grey infrastructure. Instead, it requires a comprehensive response to the world water crisis that embraces the values included in human, nature, and cultural capital.

Figure 7: Water values and capital stocks



Source: Grafton et al. (2023c, Figure 2).

A key challenge is that many of the values prioritised in water decision-making are market values, such as the value of water as an input into a production process. This exclusive market and financial focus mean that many uses, including in-situ (e.g., stream flows) uses of freshwater, that may have high non-market values (e.g., wetland's ecosystem services), are frequently treated as having a zero value because they are neither monetised nor easily measured (Manero et al., 2021).

3.4. Green and grey water infrastructure

The natural environment provides, at no charge, huge and multiple benefits (Costanza et al., 1997) for biodiversity, climate change mitigation and adaptation and many non-market values. Green water infrastructure supports groundwater recharge, reduces storm runoff, and promotes higher water quality, among other benefits. These benefits are very large; conserving nature for water is estimated to be worth some USD 3 trillion by 2050 in terms of avoided replacement costs for human-made water infrastructure (Vörösmarty et al., 2021). In the case of New York City, for example, conserving its water source catchments resulted in avoided grey infrastructure capital costs, associated with water filtration plants, of at least USD 6 billion (Chichilnisky and Heal, 1998).

The grey infrastructure investments needed to achieve SDG 6 Targets are very large, in the order of USD1.5 trillion annually. Many of these grey infrastructure investments need to be spent in the Global South (United Nations, 2021) on WASH, flood control and hydropower, among other needs (Figure 8). To some extent, grey infrastructure can be substituted by conserving key aspects of nature such as wetlands and forests. Depending on the context, green infrastructure investments can effectively respond to Too Much (e.g., mangroves protect from storm surges), Too Little (e.g., wetlands can provide natural water storages and increase availability in periods of low inflows) and Too Dirty water (e.g., protected watersheds provide better quality water).

Figure 8: Grey and green infrastructure

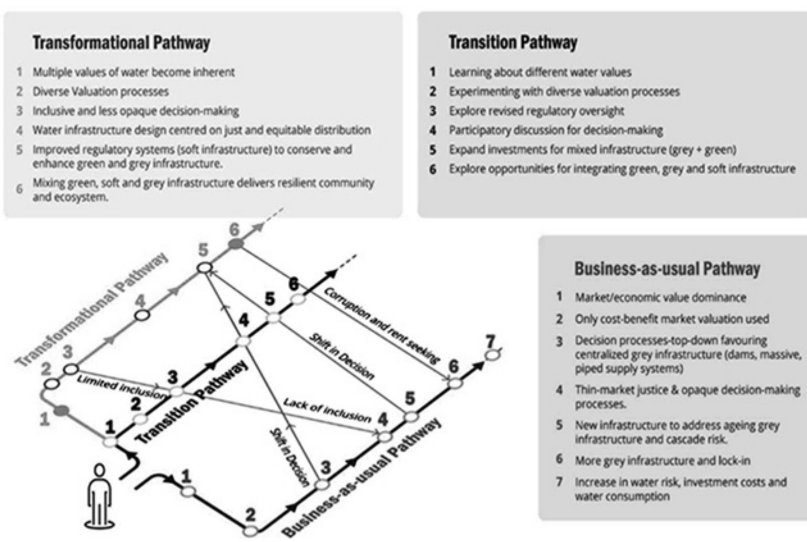
SERVICE	GREY INFRASTRUCTURE COMPONENTS	EXAMPLES OF GREEN INFRASTRUCTURE COMPONENTS AND THEIR FUNCTION
Water supply and sanitation	Reservoirs, treatment plants, pipe network	**Watersheds:** Improve source water quality and thereby reduce treatment requirements
		Wetlands: Filter wastewater effluent and thereby reduce wastewater treatment requirements
Hydropower	Reservoirs and power plants	**Watersheds:** Reduce sediment inflows and extend life of reservoirs and power plants
Coastal flood protection	Embankments, groynes, sluice gates	**Mangrove forests:** Decrease wave energy and storm surges and thereby reduce embankment requirements
Urban flood management	Storm drains, pumps, outfalls	**Urban flood retention areas:** Store stormwater and thereby reduce drain and pump requirements
River flood management	Embankments, sluice gates, pump stations	**River floodplains:** Store flood waters and thereby reduce embankment requirements
Agriculture irrigation and drainage	Barrages/dams, irrigation and drainage canals	**Agricultural soils:** Increase soil water storage capacity and reduce irrigation requirements

Source: Browder et al. (2019, p. 5).

4. Transitional and Transformational Pathways

Multiple actions are required to respond to Too Much, Too Little and Too Dirty water from a local to global scale. The specific actions, especially their prioritisation and sequencing, must be context specific and adapted to local circumstances. Here, we highlight just four, among the many actions, needed to effectively respond to the world water crisis. These actions include: one, valuing water (United Nations 2021), including non-market water values of all peoples, and including these values in decision-making; two, effectively responding to unequal power relationships (Molle et al., 2009; Tetrault and McCuligh, 2018; Wade, 1982) that contribute to rent-seeking behaviour and regulatory capture (Grafton and Williams, 2020) and prevent water being reallocated for sustainability and justice; three, improved water governance in the form of planning and regulation that delivers transformative change, includes water pricing, water accounting, water consumption limits, land-use planning, etc. (OECD, 2010), and avoids attributing much or all the blame for water scarcity on climate change (Grafton et al., 2022a; Muller, 2018); and four, much greater finance for both grey and green infrastructure which prioritises the basic human right to water for all (Tortajada and Biswas, 2017) and the sustainability of key ecosystem services (Green et al., 2015; Vörösmarty et al., 2010).

Figure 9: Pathways towards a safer and more just water future



Source: Grafton et al. (2023b, Figure 3.8).

Sustainable pathways represent a shift from 'business as usual' decision-making that has contributed to the world water crisis and inhibited meaningful transformations (Figure 9). Transitional and transformational pathways towards a safer and more just water future require appropriate and measurable goals that encompass secure food systems, ecosystem health, public health, sustainable cities, innovation, among others (Grafton et al., 2023b).

Transformational pathways require 'positive tipping points' whereby relatively small interventions and actions eventually have large impacts (Lenton et al., 2022). Positive tipping points require enabling conditions that connect socio-economic-ecological systems to create change from the local to the global. We highlight just two key elements to enable improved water governance: one, participatory decision-making that meaningfully includes all affected stakeholders, and draws from and builds upon broad-based inclusive knowledges (Mehltretter et al., 2023); and, two, the inclusion of risk and system-based thinking (Sterman, 2002) into decision-making at all levels, especially the evaluation and mitigation of systemic risks in the food, energy, environment and water nexus (Katic and Grafton, 2023).

5. Conclusions

The world faces critical choices about how to respond to three, global and inter-related crises of biodiversity loss, climate change, and the water crisis. Despite progress towards Sustainable Development Goals (SDGs) by 2030, the world is not on track to deliver on the SDG water targets or to achieve a safer and more just water future.

In terms of the 'glass half full', over the past few decades considerable progress has been made on delivering improved WASH services, including in the Global South. Communities, and some national governments, have substantially reduced the number of their citizens who are subject to severe flooding events and hydrological droughts. In the Global North, and some countries in the Global South, improvements have been made in some measures of water quality. These successes, however, are not universal and have required large infrastructure investments complemented by substantial improvements in how water is governed and how water is (re)allocated.

In terms of the 'glass half empty', billions of people remain without access to the basic human right to water. Much of the economic growth of the past few decades has been at the expense of natural capital that provides key environmental services and on which many poor are reliant for their survival. Despite an increasing recognition of systemic risks, there has been little practical action to mitigate the risks of water insecurity for food security. Nor is mitigation of greenhouse gas emissions currently sufficient to avoid what will likely be catastrophic climate change in the decades to come and that will be manifest through Too Much, Too Little and Too Dirty water.

A much greater and more co-ordinated set of actions, and at all scales, is needed to mitigate the world water crisis. Multiple and context-specific responses are required that include, but are not limited to: one, prioritising and investing in delivering the basic right to water for all; two, financing investments and establishing planning, regulations and incentives to reduce the impacts of flooding and hydrological droughts; three, monitoring and reducing water pollution via vigilant regulation and the pricing of 'bads'; four, water accounting, regulations and incentives to cap blue water consumption where it is unsustainable; and five, pro-active conservation of natural capital (e.g., wetlands), human and social capital that are critical to a sustainable and just water future.

Establishing transitional and transformational pathways for water is a huge global challenge but is not insurmountable. Both local successes and failures can be adapted noting that almost all transformations begin small before they 'take off'. Importantly, actions by those who benefit the most from the status quo must have an effective response or change will be slowed or stopped. To effect the change needed, a convincing narrative of how transformational change can be implemented beyond grey infrastructure, and a greater awareness of the risks to ecosystems and food security of business as usual, are urgently required.

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Appendix

Data sources for Figure 1:

Too much, too little, too dirty- Floods (flood events, economic losses and affected people, droughts (flood events, economic losses and affected people) (Source: EM-DAT: The OFDA/CRED International Disaster Database) and water quality (Nitrates in water in Europe (Source: EIONET Central Data Repository http://discomap.eea.europa.eu/data/wisesoe/deriveddata/T_WISE4_AggregatedDataByWaterBody/0.html), disability due to unsafe water sanitation and hygiene (Source. Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2019 (GBD 2019) Results))

Data sources for Section 2: EM-DAT, CRED / UCLouvain, Brussels, Belgium – *www.emdat.be*

The OFDA/CRED International Disaster Database (EM-DAT, CRED / UCLouvain, Brussels, Belgium).

The database is compiled from various sources including UN, governmental and non-governmental agencies, insurance companies, research institutes and press agencies (see Table 2). As there can be conflicting information and figures, CRED has established a method of ranking these sources according to their ability to provide trustworthy and complete data. In most cases, a disaster will only be entered into EM-DAT if at least two sources report the disaster's occurrence in terms of deaths and/or affected persons.

Disasters: Flood (events, Total Affected, Damages, Adjusted (US$)); Droughts (events, Total Affected, Damages, Adjusted (US$)).

Countries: Australia, China, India, Nigeria, South Africa, France, United States of America.

Timeframe: 1991-2022

Website: www.emdat.be

Version: 2023-06-13

Definitions:

Disaster Events: Count of number of times flood and droughts were listed in the database. "A disaster meeting the EM-DAT criteria and which is recorded in EM-DAT. A disaster event can affect one country or several [see «Country-level disaster»]. In the case of the latter, the disaster event will result in several country-level disasters being entered into the database. A disaster event will always have a unique DISNO identifier."

Disaster criteria: EM-DAT includes all disasters from 1900 until the present, conforming to at least one of the following criteria:

– 10 or more people dead
– 100 or more people affected
– The declaration of a state of emergency
– A call for international assistance

Damages, Adjusted (US$): "A value of all damages and economic losses directly or indirectly related to the disaster. The information may include the breakdown figures by sectors: Social, Infrastructure, Production, Environment and other (when available). Adjusted value indicates that Consumer Price Index was used to convert the damages (which are given at the time the disaster occurred) to the current US$ value."

Total affected: "The total affected is the sum of injured, affected and homeless. Injured: People suffering from physical injuries, trauma, or an illness requiring immediate medical assistance as a direct result of a disaster. The number of injured people is entered when the term "injured" is written in the source. The injured are always part of the "total affected". Any related word like "hospitalized" is considered as injured. If there is no precise number is given, such as "hundreds of injured", 200 injured will be entered (although it is probably underestimated). Affected people: People requiring immediate assistance during an emergency situation. The indicator affected is often reported and is widely used by different actors to convey the extent, impact, or severity of a disaster in non-spatial terms. The ambiguity in the definitions and the different criteria and methods of estimation produce vastly different numbers, which are rarely comparable. Homeless: Number of people whose house is destroyed or heavily damaged and therefore need shelter after an event."

Floods: "A general term for the overflow of water from a stream channel onto normally dry land in the floodplain (riverine flooding), higher-than- normal levels along the coast and in lakes or reservoirs (coastal flooding) as well as ponding of water at or near the point where the rain fell (flash floods)."

Drought: An extended period of unusually low precipitation that produces a shortage of water for people, animals, and plants. Drought is different from most other hazards in that it develops slowly, sometimes even over years, and its onset is generally difficult to detect. Drought is not solely a physical phenomenon because its impacts can be exacerbated by human activities and water supply demands. Drought is therefore often defined both conceptually and operationally. Operational definitions of drought, meaning the degree of precipitation reduction that constitutes a drought, vary by locality, climate, and environmental sector.

Data used in Section 2.3:

Nitrates- figure shows the trends in nitrate in European groundwater in mg No3/l. The timeframe is from 2000-2022. Data from Europe (1258), Albania (7), Austria (41), Belgium (34), Cyprus (14), Czechia (22), Denmark* (38), Estonia (36), Finland** (70), France** (241), Germany (122), Iceland (1), Ireland** (17), Italy (25), Latvia (16), Lithuania (22), North Macedonia (18), Poland (16), Romania (89), Serbia (34), Slovakia (8), Slovenia (8), Spain** (250), Sweden* (113), Switzerland (16).

Data from: European Environmental Agency https://www.eea.europa.eu/data-and-maps/daviz/nitrate-in-groundwater-and-rivers-1#tab-chart_2

Disability-adjusted life year: due to unsafe water: GBD Results tool: Use the following to cite data included in this download: Global Burden of Disease Collaborative Network.

Global Burden of Disease Study 2019 (GBD 2019) Results. Seattle, United States: Institute for Health Metrics and Evaluation (IHME), 2020. Available from https://vizhub.healthdata.org/gbd-results/.

DALY is an abbreviation for disability-adjusted life year. It is a universal metric that allows researchers and policymakers to compare very different populations and health conditions across time. DALYs equal the sum of years of life lost (YLLs) and years lived with disability (YLDs). One DALY equals one lost year of healthy life. DALYs allow for the estimation of the total number of years lost due to specific causes and risk factors at the country, regional, and global levels.

Data sources for Figure 2:

Through a base global map of water scarcity, regional insights into too much and too little (Source: Base map- WWF Risk Filter Suite: riskfilter.org; regional data- EM-DAT: The OFDA/CRED International Disaster Database); and WWF Risk Filter Suite: riskfilter.org).

Water scarcity definition:

"Water scarcity refers to the physical abundance or lack of freshwater resources, which can significantly impact business such as production/supply chain disruption, higher operating costs, and growth constraints. Water scarcity is human-driven and can be aggravated by natural conditions (e.g., aridity, drought periods), and it is generally calculated as a function of the volume of water use/demand relative to the volume of water available in a given area.

The Water Risk Filter risk category water scarcity is a comprehensive and robust metric as it integrates a total of 7 best available and peer-reviewed datasets covering different aspects of scarcity as well as different modelling approaches: aridity index, water depletion, baseline water stress, blue water scarcity, available water remaining, drought frequency probability, and projected change in drought occurrence." (WWF 2021, p.9)

Citation: WWF 2021 *WWF Water Risk Filter Methodology Documentation, January 2023* Online: https://cdn.kettufy.io/prod-fra-1.kettufy.io/documents/riskfilter.org/WaterRiskFilter_Methodology.pdf

Regional data information:

Source: EM-DAT, CRED / UCLouvain, Brussels, Belgium

Database: EM-DAT: The OFDA/CRED International Disaster Database

Disasters: Flood (events, Total Affected, Damages, Adjusted (US$)); Droughts (events, Total Affected, Damages, Adjusted (US$)).

Countries: Australia, China, India, Nigeria, South Africa, France, United States of America.

Timeframe: 1991-2022

Website: www.emdat.be

Version: 2023-06-13

Definitions of indicators as listed above.