Engineering 16 (2022) 13–15

Contents lists available at ScienceDirect

Engineering

journal homepage: www.elsevier.com/locate/eng

Views & Comments

Water Security: Why We Need Global Solutions

Roger A. Falconer

[a] *Hydro-environmental Research Centre, School of Engineering, Cardiff University, Cardiff CF24 3AA, UK*
[b] *Yangtze Institute for Conservation and Development, Hohai University, Nanjing 210024, China*

1. Introduction to the challenges of water security

Over the past two to three decades, international concern about global water security has been increasing, along with a need for a more holistic approach to deliver sustainable solutions that address the growing challenges of water management. Although a series of high-profile reports have been published on global water security during this period (e.g., Ref. [1]), the challenges remain and—if anything—are becoming more extreme. Our planet has limited freshwater resources: The total global volume of water is 1.4 billion km^3, but only 35 million km^3 of this resource is freshwater, and much of it is locked in the form of ice. Thus, only 105 000 km^3 of fresh water is accessible for use as water supply, and 70% of all withdrawals of freshwater are currently used for agriculture, primarily for food production [2].

Some examples of the challenges relating to water security, particularly in developing countries, are summarized below:

- Today, 1.2 billion people live with no access to safe drinking water. Slightly more than 0.5 million children under the age of five die annually of diarrhea [3], mainly due to poor water quality and inadequate sanitation.
- About 2 billion people still have no basic sanitation facilities, such as toilets or latrines. Of these, 673 million people still defecate in the open, such as in street gutters or into open bodies of water [4].
- On average, women and children in developing countries walk 5 km and carry more than 20 L every day to bring clean water to their families [5].
- Floods often cause significant loss of life and destroy homes and businesses; for example, the 2004 Indian Ocean tsunami led to an estimated 227 898 fatalities in 14 countries [6]. Moreover, the aftereffects of floods often lead to high faecal bacteria levels in water, resulting in even greater loss of life in communities and countries than was caused by the floods themselves [7].
- Other interesting examples relating to water security include these facts: A greater number of people across the globe have access to mobile phones than to a toilet [8]; and it was estimated in 2010 that more than half of the world's hospital beds at any one time were occupied by people with water-related diseases [9].

If water and environmental engineers are to provide sustainable water solutions to address the challenges listed above, among others, for the protection of their fellow citizens, flora and fauna, ecosystem services, and so forth, then we will need to deliver global solutions to address challenges such as floods, droughts, pollution, and sanitation. To add to these challenges, there are growing international concerns relating to ① climate change, where the global temperature rise is now expected to be between 1.5 and 5 °C by the end of the century [10]; and ② population growth, which currently exceeds 7.5 billion and is predicted to stabilize at about 11.5 billion by the end of the century [11]. If the average global temperature increases by 2–5 °C, then there will be major water resource problems globally, including more extreme droughts and floods, as well as significant sea level rise causing catastrophic coastal flooding worldwide [12]. Also, the predicted population growth by the end of the century is expected to lead to increases in the demand for water, food, and energy of 30%, 50%, and 50%, respectively. The water–food–energy nexus is crucial to humanity's survival on this planet, with water being essential to almost everything, including energy supply, food, health, industry, and trade.

2. The water cycle and virtual water

The first priority is to consider the water cycle, through which fresh water is provided in the form of rainfall and run-off. In developing a "cloud-to-coast" approach to solving water security in river basins [13], it is notable that only 36% of the rainfall that falls on the land typically reaches the coast directly (referred to as "blue water"), as shown in Fig. 1 [1]. The remainder of this rainfall is held in soil and vegetation (referred to as "green water") and is utilized across the landscape. The blue water entering rivers, lakes, and aquifers provides much of the water that is withdrawn for domestic consumption and thus receives the most public attention. Finally, "grey water" is the wastewater that is returned to rivers after consumption and is generally polluted to some degree.

The blue and green water withdrawn from rivers, groundwater, and the soil can be used to produce food and other commodities (through crops and/or manufacturing processes), as shown in Fig. 1. These crops and products can be provided to the domestic market or exported to other countries, depending on the local economy. The water that is used to produce crops and products is referred to as "virtual water" and leads to the water footprint, which is analogous to the carbon footprint. Typical values for the

https://doi.org/10.1016/j.eng.2021.10.009
2095-8099/© 2021 THE AUTHOR. Published by Elsevier LTD on behalf of Chinese Academy of Engineering and Higher Education Press Limited Company.
This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

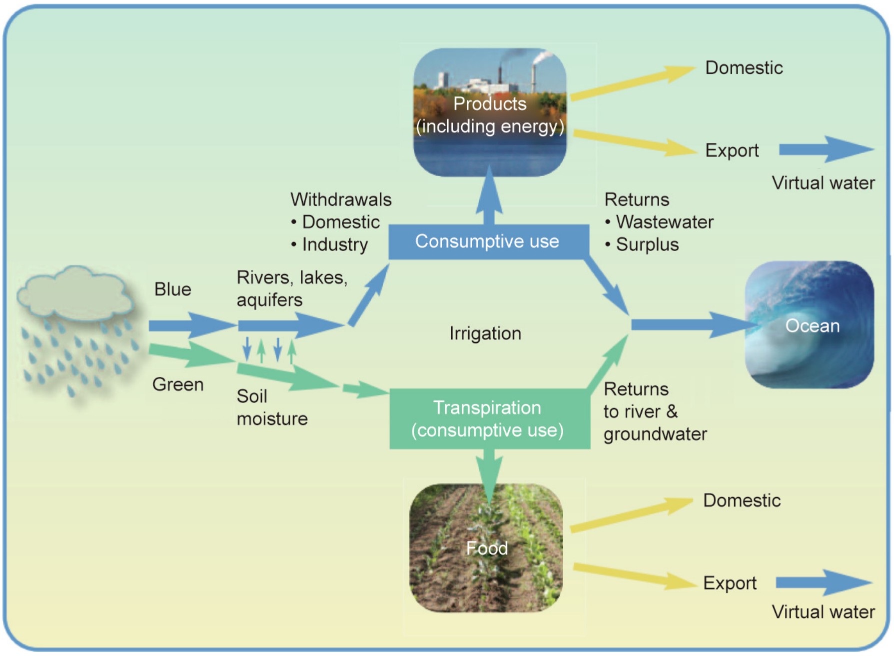

Fig. 1. The water cycle, showing green and blue water [1].

total amount of water consumed in producing food and other commodities are given in Ref. [14]. For example, 1 kg of wheat requires 1300 L of water, while 1 kg of beef requires 15 000 L of water—that is, over 10 times as much water is needed to produce the same weight of beef. Looking at other commodities, it takes 140 L of virtual water to produce one cup of coffee; this water is mainly used in one country (e.g., Brazil or Kenya), but the coffee may be drunk in another country, such as the United Kingdom. Similarly, one pair of cotton jeans typically requires 73 baths of water, each containing 150 L, to produce the cotton and dyes; this water resource is mainly used in countries such as India, Uzbekistan, Pakistan, Turkey, and Egypt, for the supply of cotton products to European countries [15].

One of the key reasons why water security must be considered at the global scale for sustainable water management is best typified by considering cotton as an example of a commodity. The annual water footprint of the United Kingdom, as an example of a Western country, typically consists of 38.6 $\mathrm{Gm^3{\cdot}a^{-1}}$ of internal water use (for household consumption, agriculture, and industry), in addition to a typical external water footprint of 63.6 $\mathrm{Gm^3{\cdot}a^{-1}}$. Thus, the United Kingdom is one of the biggest importers of virtual water worldwide. The United Kingdom produces no cotton crops internally, so virtually almost all of its cotton water footprint is external. This is further exacerbated by the traditional Western culture in which a man can wear the same color suit (e.g., grey) and shirt (e.g., white) to work every day of the week, whereas a woman with the same job is culturally expected to wear a different colored dress or blouse and trousers most days of the week. Assuming that a proportion of these outfits are made of cotton, a typical working woman thus has a much larger virtual water footprint in terms of cotton consumption than her male counterpart. The cotton used in their clothing mainly comes from the large cotton-exporting countries listed above, and many such cotton producers either do not treat contaminated water or apply minimal treatment before discharging the effluent back into the river basin. In turn, this polluted wastewater can lead to potentially serious health risks downstream, particularly to vulnerable infants and young children. Cotton production leads to some of the most serious harmful pollutants in the aquatic ecosystem; the World Bank estimates that 17%–20% of industrial water pollution comes from textile dyeing and the finishing treatment given to fabric [16], with wastewater from crop production often being discharged untreated directly into river basin systems, as illustrated in Fig. 2 [17].

One of the key challenges in addressing virtual water issues, in relation to the acquisition of crops or products in one country having an impact on water pollution in another country, is related to pricing. For example, in the United Kingdom, a domestic consumer uses about 150 L of water per day and is then typically charged about 6 $\mathrm{USD{\cdot}m^{-3}}$ by the local water company. However, while this charge includes the delivery and collection of treated water and wastewater respectively to and from the home, it does not include the cost of virtual water treatment (e.g., in crop production) that would be needed to maintain good ecological status in river basins in other countries. For example, the cost of cotton clothes produced in lower gross domestic product (GDP) countries often does not include the cost of treating the polluted effluent before it is discharged back into the river basin, thereby leading to increased health risks for citizens living downstream of the polluted water source inputs. This begs the question: Should the consumers of products (e.g., cotton clothing) in higher GDP countries pay more for their products to ensure that the water used for crop

Fig. 2. Highly polluted agricultural wastewater discharged into a river basin [17].

production and clothing manufacturing in lower GDP countries is first treated before being discharged back into the river basin? This would not only result in a fairer price when trading crops and products from one country to another, but would also be fairer as a way of ensuring that importing virtual water from another country does not lead to increased water pollution and health risks in the country of production. This fairer pricing would go a long way in delivering United Nations (UN) Sustainable Development Goal (SDG) 6: "Ensure availability and sustainable management of water and sanitation for all."

While virtual water is one aspect of global water security, many other non-technical aspects deserve similar consideration. These additional considerations were highlighted at the 2018 Global Water Security Conference, as championed by Margaret Catley-Carlson, especially for scientists and engineers, who tend to focus on discussing and addressing technical solutions. Catley-Carlson presented a reality that scientists and engineers forget far too often: Focusing only on technical aspects rarely in itself results in effective solutions. Thus, the conference perspective paper [18] emphasizes several non-technical aspects such as virtual water, and includes the following statements: ① Social sciences must be appreciated and incorporated into all phases of water resource engineering design, research, decision-making, and policy formulation; ② interdisciplinary teams are crucial for effectively moving technical solutions forward; ③ all relevant players (e.g., community leaders, industry, agriculture, and elected officials) must be involved in discussing problems and effective solutions; and ④ political dimensions and constraints related to the formulation of coherent public policy are vital to the effective application of technological solutions. Because these non-technical aspects are rarely fully integrated into water resource science and engineering, they are highlighted and discussed within each of the seven key priorities presented in Ref. [18]: Reduce food waste, increase wastewater reuse, increase agricultural resiliency and efficiency, optimize irrigation efficiency and increase crop water productivity (thereby delivering "more crop per drop"), improve water supply management, improve water resource infrastructure, and enhance water resource decision-making and policy formulation.

3. Engineering global water security solutions

In addressing the challenges of achieving global water security and ensuring the delivery of SDG 6, water engineers and scientists have a key role to play in achieving these deliverables and engaging in some, or all, of the following tasks:

- Promoting the need to address water security at the global scale, particularly in terms of the increasing global water stress that is primarily associated with climate change.
- Promoting education on the water–food–energy nexus and on the concept of virtual water, where citizens of a high-GDP nation can have a severe adverse impact on water pollution and health risks in a much lower GDP nation by importing virtual water (e.g., by purchasing cotton products).
- Promoting appropriate pricing of the water used in crop production and product manufacturing to ensure that water is treated at the source before being discharged back into aquatic systems and polluting rivers downstream.
- Promoting the development of low-cost solutions for farmers and industries to treat grey water before discharging the wastewater back into the natural water course;
- Promoting the widespread use of nature-based solutions (NBS) to help cool the planet and restore degraded ecosystems [19].
- Promoting state-of-the-art solutions (e.g., hydroponic and vertical farming) that allow food production to produce "more crop per drop" of water, thereby requiring less water and fertilizers.
- Promoting the need for multidisciplinary teams to provide cost-effective solutions to address the challenges of global water security.
- Promoting the need for more global investment in the research and development of water security, particularly in comparison with the much higher levels of investment in other industries, such as car manufacturing, information technology, and so forth.

The global community and key international agencies must appreciate that water is ultimately one of the most precious resources on the planet today; people have suvived on our planet without commodities such as the motor car, but water is essential for life on earth. We need to value water accordingly and ensure that water security lies at the heart of global decision-making and investment.

References

[1] The Royal Academy of Engineering. Global Water Security—an engineering perspective. Report. London: The Royal Academy of Engineering; 2010 Apr.
[2] Khokhar, T. Charts: globally, 70% of freshwater is used for agriculture [Internet]. Washington, DC: The World Bank Group; 2017 Mar 22 [cited 2021 Aug 20]. Available from: https://blogs.worldbank.org/opendata/chart-globally-70-freshwater-used-agriculture.
[3] UNICEF data diarrhoea [Internet]. New York City: United Nations International Children's Emergency Fund (UNICEF); 2021 Apr [cited 2021 Aug 20]. Available from: https://data.unicef.org/topic/child-health/diarrhoeal-disease/.
[4] Sanitation Key Facts [Internet]. Geneva: World Health Organisation [cited 2019 Jun 14]. Available from: https://www.who.int/news-room/fact-sheets/detail/sanitation.
[5] World Water Day: how far would you walk for water? [Internet]. Boston: OXFAM; 2019 Mar 21 [cited 2021 Aug 20]. Available from: https://www.oxfamamerica.org/explore/stories/world-water-day-how-far-would-you-walk-water/.
[6] What was the Indian Ocean Tsunami of 2004? [Internet]. St. Laurent: WorldAtlas [cited 2021 Aug 20]. Available from: https://www.worldatlas.com/articles/what-was-the-indian-ocean-tsunami-of-2004.html.
[7] Kay D, Falconer R. Hydro-epidemiology: the emergence of a research agenda. Environ Fluid Mech 2008;8(5–6):451–9.
[8] More people have mobile phones than toilets [Internet]. Jersey City: Forbes; 2013 Mar 23 [cited 2021 Aug 20]. Available from: https://www.forbes.com/sites/timworstall/2013/03/23/more-people-have-mobile-phones-than-toilets/?sh=619d611d6569.
[9] Falconer RA, Norton MR. Global water security: engineering the future. In: Fernando H, Klaić Z, McCulley J, editors. National security and human health implications of climate change. NATO science for peace and security series C: environmental security. Dordrecht: Springer. p. 261–70.
[10] Tollefson J. How hot will Earth get by 2100? Nature 2020;580:443–5.
[11] The 2019 revision of the world population prospects [Internet]. New York City: United Nations; 2019 [cited 2021 Aug 20]. Available from: https://population.un.org/wpp/.
[12] Herring D. Climate change: global temperature projections [Internet]. Silver Spring Maryland: NOAA Climate.gov; 2012 Mar 6 [cited 2021 Aug 20]. Available from: https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature-projections.
[13] Huang G, Falconer RA, Boye BA, Lin B. Cloud to coast: integrated assessment of environmental exposure, health impacts and risk perceptions of faecal organisms in coastal waters. Int J River Basin Manage 2015;13(1):73–86.
[14] Hoekstra AY, Chapagain AK, Aldaya MM, Mekonnen MM. The water footprint assessment manual: setting the global standard. London: Earthscan Publishing; 2011. p. 224.
[15] Hoekstra AY, Chapagain AK. Globalization of water: sharing the planet's freshwater resources. Oxford: Blackwell Publishing; 2008. p. 208.
[16] Kant R. Textile dyeing industry an environmental hazard. Nat Sci 2012;4(1):22–6.
[17] Water's promise: making every drop count [Internet]. Washington, DC: World Bank Group; 2018 Mar 14 [cited 2021 Aug 20]. Available from: https://www.youtube.com/watch?v=X9H1Z37lmzs.
[18] Harmel RD, Chaubey I, Ale S, Nejadhashemi AP, Irmak S, DeJonge K, et al. Perspectives on global water security. Trans ASABE 2020;63(1):69–80.
[19] Girardin CAJ, Jenkins S, Seddon N, Allen M, Lewis SL, Wheeler CE, et al. Nature-based solutions can help cool the planet-if we act now. Nature 2021;593:191–4.