Water for Food Systems and Nutrition

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1 Introduction

Water is essential for all life and is integral to the function and productivity of the Earth's ecosystems, which depend on a complex cycle of continuous movement of water between the Earth and the atmosphere. Water is also fundamental for food systems, and a food systems transformation will be essential to meeting SDG 6 on water and sanitation. As described by the High-Level Panel of Experts on Food

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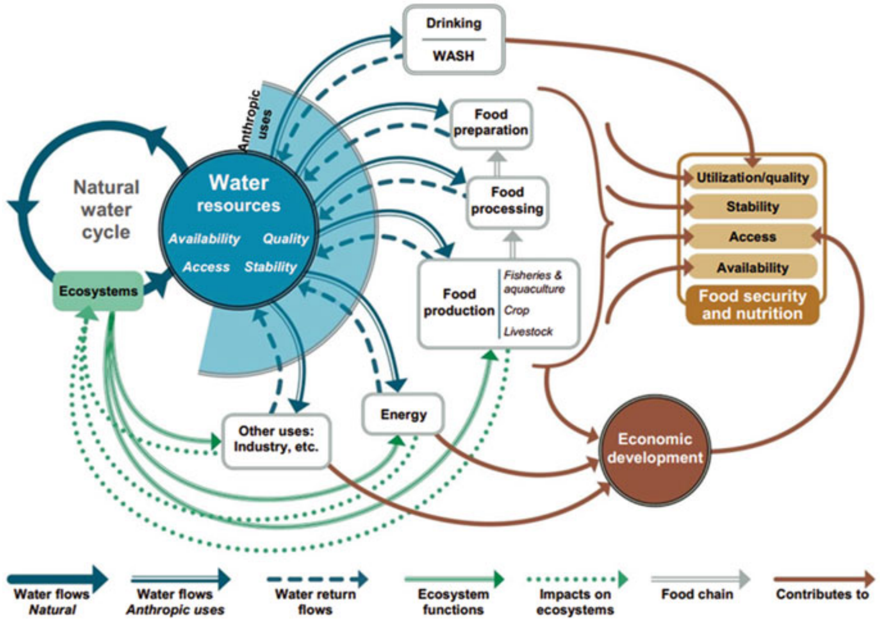

Fig. 1 The linkages between water and food systems (Source: HLPE 2015)

Security and Nutrition (HLPE) (HLPE 2015) and illustrated in Fig. 1, the key dimensions of water that are of importance for humanity are its availability, access, stability, and quality. These have multiple, close linkages and feedback loops with food systems, which can be defined as the activities involved in the production, processing, distribution, preparation, and consumption of food within wider socio-economic, political, and environmental contexts (HLPE 2017). For example, waste streams from food processing often re-enter water bodies, affecting other components of food systems, such as drinking water supplies (water is itself essential for all bodily functions and processes, and is an important source of nutrients) (UNSCN 2020), as well as water-based and water-related ecosystems.

More than 70% of all freshwater withdrawals are currently used for agriculture, and about 85% of withdrawn resources are consumed in irrigated agricultural production. With these resources, irrigated crop areas generate 40% of global food production on less than one-third of the globally harvested area (Ringler 2017). Another key water-food system linkage is water supply for WASH (water, sanitation

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and hygiene), which is important for human health, can support nutrition outcomes, particularly if combined with other interventions (Cumming et al. 2019), and is a basic human right, as is the right to food. Water is also essential for agricultural processing and food preparation.

Climate change and other environmental and societal changes (e.g., land use changes, biodiversity loss, urbanisation, and changing lifestyles and diets) are impacting the dynamics of natural water cycles and water resource availability, with further, subsequent impacts on food systems. More than half of all natural wetland areas have been lost due to human activity since 1900 and forest degradation affects streamflow regulation (Sun et al. 2017). At the same time, the growing frequency and severity of floods and droughts in many regions of the world (IPCC 2021) increase competition over water resources. This calls for changes in water management, including increased water productivity, integrated storage solutions, accelerated land restoration and smarter water distribution to support food systems, as well as a reduction in impacts on domestic, industrial, energy-related, and environmental water uses.

2 SDG 2 and SDG 6 Can Only Be Achieved If the Water and Food System Communities Work Together

2.1 Water Scarcity and Pollution Are Growing, Affecting Poorer Populations, Particularly Food Producers

Freshwater-related ecosystems include wetlands, rivers, aquifers, and lakes that sustain biodiversity and life (UN Environment 2018). Although they cover less than 1% of the Earth's surface, these habitats host approximately one-third of vertebrate species and 10% of all species (Stayer and Dudgeon 2010), including mammals, birds (IUCN 2019), and fish (Fricke et al. 2020). Water-related ecosystems are also vital for the function of all terrestrial ecosystems, providing regulating, provisioning, and cultural services (Martin-Ortega et al. 2015). Furthermore, hydropower is an essential energy source, accounting for 85% of global renewable electricity generation in 2015, but has since declined to around 60% (IEA 2016, 2020), and is also key for commerce and industry (Willet et al. 2019). Notably, de-carbonising the energy system can also adversely impact the water system, particularly in the case of increasing hydropower and biofuel production.

Progress on achieving the water and sanitation targets of SDG 6 has been unsatisfactory and uneven. More than 2 billion people live in places with high water stress (FAO SOFA 2020; UN 2018): by 2050, every second person, half of the world's grain production, and close to half of the globe's Gross Domestic Product might well be at risk from water insecurity (Ringler et al. 2016). In 2020, approximately 2.0 billion people lacked access to safely managed drinking water, and 3.6 billion people lacked access to safely managed sanitation services.

One in ten people lacked basic services, including the 122 million people who depend on untreated surface water, mostly in sub-Saharan Africa (UNICEF, WHO 2021). Poor women and girls, who are responsible for more than 70% of all water collection, spend about 200 million hours a day on this task, undermining their health and livelihood opportunities (UNICEF n.d.; Geere and Cortobius 2017).

In terms of agricultural water use, farmers across the world, but particularly in sub-Saharan Africa, continue to rely heavily on rainfall for food production. More than 62 million hectares of crop and pastureland experience high to very high water stress and drought, affecting about 300 million farm households (FAO 2020). With climate change, temperatures and crop evaporation levels are increasing, and there is growing uncertainty about the timing, duration and quantity of rainfall, increasing the risks related to producing food and undermining the livelihood security of the majority of rural people (AUC 2020). Fertiliser use on crop land and livestock excreta are key sources of agricultural water pollution, affecting aquatic life and threatening human health. Projections suggest that nitrogen and phosphorous deposition in water bodies will grow rapidly, particularly in low- and middle-income countries (Xie and Ringler 2017).

With respect to the other SDG 6 targets, such as water use efficiency, water-dependent ecosystems, and integrated water management, progress has been slow and is often not well understood, due to the lack of effective monitoring mechanisms and insufficient data. New, integrated approaches and reinforced efforts to measure and manage water are urgently needed (Sadoff et al. 2020).

While water availability differs dramatically around the globe, differences in access are most often due to politics, public policy, lack of capacity and investment, and flawed water management strategies, as well as exclusions due to geography (i.e., remote rural areas), gender, ethnicity, caste, race, and class. In many cases, water does 'flow uphill' to power and money (Mehta et al. 2019). Furthermore, increasing urbanisation and changing diets are affecting the demand and supply of water resources for food systems and aggravating water stress in many parts of the world, particularly in water-scarce areas of low/middle-income countries where coping capacity is often insufficient.

2.2 Malnutrition Levels Are on the Rise and Are Closely Linked to Water Scarcity

An estimated 690 million people, or 8.9% of the global population, were undernourished in 2019, prior to the COVID-19 pandemic (Headey et al. 2020). The number has since grown to between 720 and 811 million people (2020 values). Moreover, 149 million children below the age of five were stunted, 45 million were wasted, and another 39 million were overweight (FAO, IFAD, UNICEF, WFP and WHO 2021). Climate change, associated conflict, and a lack of sufficient water for food production, including irrigation for fruit and vegetable production, are key contributors to unaffordable diets and overall levels of undernutrition. At the same time, overweight continues to dramatically increase around the globe, including in children. Latin America, in particular, suffers from the associated public health burden. Overall, rural areas are currently experiencing the most rapid rate of increase in overweight (NCD Risk Factor Collaboration et al. 2019). Given these trends, neither the 2025 World Health Assembly nutrition targets nor the 2030 SDG nutrition targets will be met. As with inequities in access to water, inequities in access to food and nutrition are highest in rural areas (Perez-Escamilla et al. 2018).

2.3 SDG 2 and SDG 6 Targets Are Co-Dependent

Ending hunger and malnutrition requires access to safe drinking water (SDG 6.1), as well as equitable sanitation and hygiene (SDG 6.2). The underlying productivity (SDG 2.3) and sustainability (SDG 2.4) of agricultural systems are also dependent on adequate availability (SDG 6.4 and 6.6) of good quality (SDG 6.3) water. Moreover, water and related ecosystems (e.g., wetlands, river or lakes in SDG 6.6), which are embedded in sustainable landscapes, are important contributors to sustainable agriculture through regulating and providing water for food production (SDG 2.4) (Ringler et al. 2018).

A key contributor to poor nutritional outcomes in subsistence farming households in low-income countries is the seasonality of production, leading to a seasonality in diets, which can affect pregnancy outcomes and child growth (Baye and Hirvonen 2020; Madan et al. 2018). Well-managed irrigation systems can buffer seasonal gaps in diets, contributing to improved food security and nutritional outcomes, for example, through homestead gardening (Baye et al. n.d.; Hirvonen and Headey 2018).

It is equally important to stress the need for changes in food systems in meeting SDG 6 targets: reducing food loss and waste in food value chains (SDG 12.3), lowering pollution from slaughterhouses, food processing, and food preparation, and considering environmental sustainability in food-based dietary guidelines. All of these actions will be essential to meet the SDG 6 targets (UNSCN 2020).

3 Solutions for Improving Food System Outcomes and Water Security

Based on the above assessment, as well as recent water-food system reviews (Ringler et al. 2018; UNSCN 2020; Mehta et al. 2019; Young et al. 2021), the following actions are proposed for uptake by governments, the private sector, and civil society.

3.1 Strengthen Efforts to Retain Water-Based Ecosystems and Their Functions

The ecological processes underlying the movement, storage, and transformation of water are under severe threat from deforestation, erosion, and pollution, with impacts on local, regional, and global water cycles (WWAP 2018). In addition to a direct halt of deforestation and the destruction of water-based ecosystems, nature-based solutions that use or mimic natural processes to enhance water availability (e.g., groundwater recharge), improve water quality (e.g., riparian buffer strips, wetlands), and reduce risks associated with water-related disasters and climate change (e.g., floodplain restoration, wetlands) should be strengthened (WWAP 2018). Limiting overconsumption of water, particularly in water-stressed regions, will be necessary to stay within sustainable water use limits (Yu et al. 2021).

3.2 Improve Agricultural Water Management for Better Diets for All

Around 3 billion people on this planet cannot afford a healthy diet, particularly dairy, fruits, vegetables, and protein-rich foods (FAO, IFAD, UNICEF, WFP, WHO 2021). Both rainfed and irrigated systems play essential roles in lowering the prices of nutrient-dense foods, growing incomes to be able to afford these foods, and strengthening the diversity of foods available in local markets (Hirvonen et al. 2017).

3.2.1 Strengthen the Climate Resilience of Rainfed Food Systems

Rainfed systems produce the bulk of food, fodder, and fibre, and most animal feed is produced under rainfed conditions (Heinke et al. 2020). These systems are under severe and growing stress from climate change, including extreme weather (FAO 2020). This can be addressed, to some extent, through structural measures (e.g., terracing, soil bunds, drainage), investment in breeding, improved agronomic practices, effective incentives (e.g., payments for watershed conservation), and strong institutions for water, soil and land management (e.g., watershed committees) (Jägermeyr et al. 2016; World Bank 2010).

3.2.2 Strengthen the Nutrient Density of Irrigated Agriculture

As irrigation accounts for the largest share of freshwater withdrawals by humans (more than 90% in some agrarian economies), the potential for water conservation is also largest in this sector. Irrigation development needs keep environmental limits – which are increasingly affected by climate change – in mind. This includes addressing groundwater depletion. The potential for increasing water and nutrition productivity in irrigation remains large. It includes crop breeding for transpiration efficiency, salinity tolerance, climate resilience and increased micronutrients, integrated storage solutions – such as joint use of grey and green infrastructure – advanced irrigation technology, and soil moisture monitoring (Rosegrant et al. 2009). There are clear trade-offs between the nutrient density of foods and irrigation water use. Fruit and vegetable yields depend on frequent water applications in many parts of the world (although the water content of the end product also tends to be high) and need precision applications of agrochemicals to maximise water inputs and avoid water pollution (Meenakshi and Webb 2019). Many livestock products are highly water-intensive due to animal feeds, although the majority of the feed comes from rainfed agriculture. Awareness-raising and social learning interventions can help internalise the water externality of water-intensive diets. Improved coordination of water with other agricultural inputs can also enhance yield per drop of water. This requires access to technology packages, as well as to better agricultural information (Lundqvist et al. 2021), which is increasingly supported by ICTs (Asenso-Okyere and Mekonnen 2012). Moreover, subsidies for water-intensive crops, such as rice, milk and sugar, should be revisited and eventually removed. For water-scarce countries, importing virtual water via food and other commodities will remain essential (Allan 1997).

3.2.3 Address Water Pollution to Improve Food Production, Food Safety, and Water-Based Ecosystems

Globally, 80% of municipal sewage and industrial wastewater with heavy metals, solvents, toxic sludge, pharmaceuticals, and other waste are directly discharged into water bodies, affecting the safety of food, particularly vegetable production, and also, directly, human health (WWAP 2018). Agriculture also directly pollutes aquatic ecosystems and risks food production with pesticides, organic matter, fertilisers, sediments, pathogens, and saline drainage (UNEP 2016). Key measures to address agricultural and overall water pollution include the breeding of crops with higher crop nutrient use efficiency, better agronomic practices, the expansion of nature-based solutions for pollution management, low-cost pollution monitoring systems, improved incentive structures for pollution abatement, and continued investment and innovation in wastewater treatment, including approaches such as implementing the 3Rs (reduce, reuse, and recycle) of the circular economy across the entire food system (Mateo-Sagasta et al. 2018).

3.3 Reduce Water and Food Losses Beyond the Farmgate

Irrigated agriculture is often focused on high-value crops with a higher share of marketed surplus, compared to rainfed agriculture (Nkonya et al. 2011). At the same time, many irrigated crops, such as fruits and vegetables, are time-sensitive, perishable products that require efficient market linkages to consumption centres. Strengthening market linkages includes investment in physical infrastructure that supports on-farm production (irrigation, energy, transportation, pre- and post-harvest storage), efficient trading and exchange (telecommunications, covered markets), value addition (agro-processing and packaging facilities), and improved transportation and bulk storage (Warner et al. 2008). Investments are also needed in ICTs that facilitate farmers' access to localised and tailored information about weather, water consumption, diseases, yield, and input and output prices (Elsabber 2020).

3.4 Coordinate Water with Nutrition and Health Interventions

3.4.1 Strengthen Institutional Coordination and Develop Joint Programmes

Governance and management of water for various uses and functions, as shown in Fig. 1, follow different institutional arrangements. Similarly, professionals engaged in various roles within water-related institutions have different kinds of training and experiences. Few irrigation engineers have a professional background or skills related to WASH, and few WASH professionals have the technical skills needed to design water infrastructure for multiple uses, for example. The notion of integrated water resource management (SDG 6.5) has been promoted as a principle to overcome problems due to sectoral division. Coordination at the lowest appropriate levels is urgently needed between WASH and irrigation for improved food security, nutrition, and health outcomes, as well as to strengthen women's agency over water decisions. Multiple-use water systems can increase food security and WASH outcomes (van Koppen et al. 2014). An example is the MiAgua programme in Bolivia supported by CAF, the development bank of Latin America, which included rural water supply, climate change adaptation measures such as watershed protection, and micro-irrigation projects for small-scale agriculture. MiAgua benefited 2.25 million people with improved or new access to water and contributed to increasing rural water coverage from 59 percent in 2011 to 69% in 2020. At a larger scale, improved coordination across riparian countries is essential for improving water securities linked to competing uses. A key example is the Aral Sea Basin, where lack of coordination between upstream and downstream countries affect both energy and food security (Bekchanov et al. 2015).

3.4.2 Implement Nutrition-Sensitive Agricultural Water Management

Nutrition and health experts need to join forces with water managers at the farm household level, at the community level, and at the government level to strengthen positive transmission pathways between both rainfed and irrigated agriculture and food and nutrition security. A recent guidance (Bryan et al. 2019) describes eight actions for increasing the nutrition sensitivity of water resource management and irrigation, as well as indicators for monitoring progress.

3.5 Increase the Environmental Sustainability of Food Systems

The water footprint of diets varies dramatically between rich and poor countries, but also by socioeconomic group within countries (Lundqvist et al. 2021). More work is urgently needed on the impact of current dietary trends on environmental resources, including water. Food-based dietary guidelines should consider the environmental footprint of proposed diets, whereby government regulations and consumer awareness should be strengthened to reduce the over-consumption of food, and further efforts are needed to reduce post-harvest waste and losses (UNSCN 2020).

3.6 Explicitly Address Social Inequities in Water-Nutrition Linkages

Vulnerable groups need to be proactively included in the development of water services, including incorporating their needs and constraints into initial infrastructure design. For rural smallholders who most lack water and food security, irrigation design should consider multiple uses of water, such as drinking, irrigation, and livestock watering, to meet women's and men's needs. While women make up a large part of the agricultural workforce, they often lack recognition and formal rights, and farmers are often considered to be 'male' in many parts of the world. Women's productive roles should be promoted, and they should be trained in irrigation and water management. Their involvement has important implications for water and food security (Meinzen-Dick et al. 2021; Balasubramanya 2019). It is also important to ensure that women and disadvantaged social groups (e.g., lower castes, stigmatised social groups) have equal access to credit, irrigable land, labour, and markets to be able to buy agricultural inputs and sell their produce (Mehta et al. 2019; UNSCN 2020).

3.7 Improve Data Quality and Monitoring for Water-Food System Linkages, Drawing on Innovations in ICT

Better data are needed if we are to truly understand the water footprint of diets and devise policies that co-maximise water and food security and nutrition goals. Challenges include poor water and poor food intake data and a lack of indicators connecting the two, but improvements are emerging (Bryan et al. 2019; HWISE network (https://hwise-rcn.org/); Lundqvist et al. 2021). More and better data will support better water management and food systems and increase transparency in decision-making. This requires sustained investments in the monitoring of a wide range of hydrological and food-related parameters worldwide. Modern Earth observation methods can support larger-scale assessment, but need to be complemented by dedicated field measurements.

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References

Allan JA (1997) 'Virtual water': a long term solution for water short middle eastern economies? Paper presented at the 1997 British association festival of science, Roger Stevens lecture theatre, University of Leeds, Water and Development Session, TUE.51, 14.45. https://www.soas.ac.uk/water/publications/papers/file38347.pdf

Asenso-Okyere K, Mekonnen DA (2012) The importance of ICTs in the provision of information for improving agricultural productivity and rural incomes in Africa, UNDP working papers 2012–015. United Nations Development Programme, Regional Bureau for Africa

AUC (2020) Framework for irrigation development and agricultural water Management in Africa. https://au.int/en/documents/20200601/framework-irrigation-development-and-agricultural-water-management-africa

Balasubramanya S (2019) Effects of training duration and the role of gender on farm participation in water user associations in southern Tajikistan: implications for irrigation management. Agric Water Manag 216:1–11. https://doi.org/10.1016/j.agwat.2019.01.019

Baye K, Hirvonen K (2020) Seasonality: a missing link in preventing undernutrition. Lancet Child Adolesc Health 4(1):e3

Baye K, Mekonnen D, Choufani J, Yimam S, Bryan E, Griffith JK, Ringler C (n.d.) Seasonal variation in maternal dietary diversity is reduced by small-scale irrigation practices: a longitudinal study. Matern Child Nutr. https://onlinelibrary.wiley.com/doi/10.1111/mcn.13297

Bekchanov M, Ringler C, Bhaduri A, Jeuland M (2015) How does the Rogun dam affect water and energy scarcity in Central Asia? Water Int 40(5–6):856–876. https://www.tandfonline.com/doi/full/10.1080/02508060.2015.1051788

Bryan E, Chase C, Schulte M (2019) Nutrition-sensitive irrigation and water management. World Bank, Washington, DC. http://hdl.handle.net/10986/32309

Cumming O, Arnold BF, Ban R, Clasen T, Esteves Mills J, Freeman MC, Gordon B et al (2019) The implications of three major new trials for the effect of water, sanitation and hygiene on childhood diarrhea and stunting: a consensus statement. BMC Med 17(1):173. https://doi.org/10.1186/s12916-019-1410-x

Elsabber R (2020) ICT for small-scale irrigation: a market study. GIZ GmbH, Bonn/Eschborn

FAO, IFAD, UNICEF, WFP and WHO (2021) The state of food security and nutrition in the world. 2021. Transforming food systems for food security, improved nutrition and affordable healthy diets for all. FAO, Rome. https://www.fao.org/documents/card/en/c/cb4474en

FAO SOFA (2020) Overcoming water challenges in agriculture. http://www.fao.org/state-of-food-agriculture/en

Fricke R, Eschmeyer W, van der Laan R (2020) Catalog of fishes: genera, species, references. California Academy of Sciences. https://researcharchive.calacademy.org/research/ichthyology/catalog/SpeciesByFamily.asp

Geere JA, Cortobius M (2017) Who carries the weight of water? Fetching water in rural and urban areas and the implications for water security. Water Altern 10(2):513–540

Headey D, Heidkamp R, Osendarp S, Ruel M, Scott N, Black R, Bouis H (2020) Impacts of COVID-19 on childhood malnutrition and nutrition-related mortality. Lancet 396(10250):519–521. https://doi.org/10.1016/S0140-6736(20)31647-0

Heinke J, Lannerstad M, Gerten D, Havlík P, Herrero M, Notenbaert AMO, Hoff H (2020) Water use in global livestock production –opportunities and constraints for increasing water productivity. Water Resour Res. https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2019WR026995

Hirvonen K, Headey D (2018) Can governments promote homestead gardening at scale? Evidence from Ethiopia. Glob Food Sec 19:40–47

Hirvonen K, Hoddinott J, Minten B, Stifel D (2017) Children's diets, nutrition knowledge, and access to markets. World Dev 95:303–315

HLPE (2015) Water for food security and nutrition. A report by the high level panel of experts on food security and nutrition of the committee on world food security, Rome. http://www.fao.org/3/av045e/av045e.pdf

HLPE (2017) Nutrition and food systems. A report by the high level panel of experts on food security and nutrition of the committee on world food security, Rome. http://www.fao.org/3/i7846e/i7846e.pdf

IEA (2016). www.eia.gov/electricity/data/browser

IEA (2020) Global energy review 2020. IEA, Paris. https://www.iea.org/reports/global-energy-review-2020

IPCC (2021) Climate change 2021: the physical science basis. In: Masson-Delmotte V, Zhai P, Pirani a, Connors SL, Péan C, Berger S, Chaud N, Chen Y, Goldfarb L, Gomis MI, Huang M, Leitzell K, Lonnoy E, Matthews JBR, Maycock TK, Waterfield T, Yelekçi O, Yu R, Zhou B (eds) Contribution of Working Group I to the sixth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press. (in press)

IUCN (2019) The IUCN red list of threatened species, version 2019–1. http://iucnredlist.org

Jägermeyr J et al (2016) Integrated crop water management might sustainably halve the global food gap. Environ Res Lett 11:025002. https://iopscience.iop.org/article/10.1088/1748-9326/11/2/025002

Lundqvist J, Malmquist L, Dias P, Barron J, Wakeyo MB (2021) Water productivity, the yield gap, and nutrition. The case of Ethiopia. FAO land and water discussion paper No. 17. FAO, Rome. http://www.fao.org/documents/card/en/c/CB3866EN

Madan EM, Haas JD, Menon P, Gillespie S (2018) Seasonal variation in the proximal determinants of undernutrition during the first 1000 days of life in rural South Asia: a comprehensive review. Glob Food Sec 19:11–23

Martin-Ortega J, Ferrier R, Gordon I, Khan S (eds) (2015) Water ecosystem services: a global perspective (international hydrology series). Cambridge University Press, Cambridge

Mateo-Sagasta J, Zadeh SM, Turral H (eds) (2018) More people, more food, worse water? A global review of water pollution from agriculture. FAO/IWMI. CGIAR Research Program on Water, Land and Ecosystems (WLE), Rome/Colombo. http://hdl.handle.net/10568/93452

Meenakshi JV, Webb P (2019) Food systems, diets, and nutrition: global trends, challenges and opportunities. Agric Food Syst 2050:215–242. https://doi.org/10.1142/9789813278356_0007

Mehta L, Oweis T, Ringler C, Schreiner B, Varghese S (2019) Water for food security, nutrition and social justice. Routledge, London

Meinzen-Dick RS, Pradhan P, Zhang W (2021) Migration and gender dynamics of irrigation governance in Nepal. IFPRI discussion paper 2061. IFPRI, Washington, DC. https://doi.org/10.2499/p15738coll2.134815

NCD Risk Factor Collaboration, Bixby H, Bentham J et al (2019) Rising rural body-mass index is the main driver of the global obesity epidemic in adults. Nature 569:260–264. https://doi.org/10.1038/s41586-019-1171-x

Nkonya E, Iannotti L, Sakwa B, Wielgosz B (2011) Baseline study of KickStart treadle pumps in East Africa. IFPRI, Washington, DC

Perez-Escamilla R, Bermudez O, Buccini GS, Kumanyika S, Lutter CK, Monsivais P, Victora C (2018) Nutrition disparities and the global burden of malnutrition. BMJ 13:361:k2252. https://doi.org/10.1136/bmj.k2252

Ringler C (2017) Investment in irrigation for global food security. IFPRI policy note. IFPRI, Washington DC. http://ebrary.ifpri.org/utils/getfile/collection/p15738coll2/id/131045/filename/131256.pdf

Ringler C, Zhu T, Gruber S, Treguer R, Auguste L, Addams L, Cenacchi N et al (2016) Role of water security for agricultural and economic development – concepts and global scenarios. In: Pahl-Wostl C, Bhaduri A, Gupta J (eds) Handbook on water security. Edward Elgar Publishing Ltd, Aldershot

Ringler C, Choufani J, Chase C, McCartney M, Mateo-Sagasta J, Mekonnen D, Dickens C (2018) Meeting the nutrition and water targets of the sustainable development goals: achieving progress through linked interventions. IWM. CGIAR WLE, World Bank, Colombo. https://doi.org/10.5337/2018.221

Rosegrant MW, Ringler C, Zhu T (2009) Water for agriculture: maintaining food security under growing scarcity. Annu Rev Environ Resour 34:205–223. https://doi.org/10.1146/annurev.environ.030308.090351

Sadoff CW, Borgomeo E, Uhlenbrook S (2020) Rethinking water for SDG 6. Nat Sustain 3(5):346–347

Stayer DL, Dudgeon D (2010) Freshwater biodiversity conservation: recent progress and future challenges. J N Am Benthol Soc 29(1):344–358. https://bioone.org/journals/journal-of-the-north-american-benthological-society/volume-29/issue-1/08-171.1/Freshwater-biodiversity-conservation-recent-progress-and-future-challenges/10.1899/08-171.1.full

Sun G, Hallema D, Asbjornsen H (2017) Ecohydrological processes and ecosystem services in the Anthropocene: a review. Ecol Process 6(35). https://doi.org/10.1186/s13717-017-0104-6

UN (2018) Sustainable development goal 6 synthesis report 2018 on water and sanitation, New York

UN Environment (2018) Progress on water-related ecosystems. Piloting the monitoring methodology and initial findings for SDG indicator 6.6.1. https://reliefweb.int/sites/reliefweb.int/files/resources/661-progress-on-water-related-ecosystems-2018.pdf

UNICEF (n.d.) Collecting water is often a colossal waste of time for women and girls. Press release. https://www.unicef.org/press-releases/unicef-collecting-water-often-colossal-waste-time-women-and-girls

UNICEF, WHO (2021) Progress on household drinking water, sanitation and hygiene, 2000–2020: five years into the SDGs. UNICEF, WHO, New York. https://washdata.org/sites/default/files/2022-01/jmp-2021-wash-households_3.pdf

UNSCN (2020) Water and nutrition. Harmonizing actions for the United Nations decade of action on nutrition and the United Nations water action decade. UNSCN, Rome. https://www.unscn.org/uploads/web/news/document/Water-Paper-EN-WEB-2mar.pdf

van Koppen B, Smits S, del Rio CR, Thomas J (2014) Scaling up multiple use water services: accountability in the water sector. IWMI Books, Reports H046385

Warner M, Kahan D, Lehel S (2008) Market-oriented agricultural infrastructure: appraisal of public-private partnerships. FAO, Rome

Willet J, Wetser K, Vreeburg J, Rijnaarts HHM (2019) Review of methods to assess sustainability of industrial water use. Water Resour Ind 21:2212–3717. https://doi.org/10.1016/j.wri.2019.100110

World Bank (2010) Improving water Management in Rainfed Agriculture: issues and options in water-constrained production systems. World Bank other operational studies 13028. The World Bank. https://openknowledge.worldbank.org/bitstream/handle/10986/13028/696130ESW0P1100gement0Rainfed0Final.pdf
WWAP (2018) The United Nations world water development report 2018: nature-based solutions. UNESCO, Paris
Xie H, Ringler C (2017) Agricultural nutrient loadings to the freshwater environment: the role of climate change and socioeconomic change. Environ Res Lett 12:104008
Young SE, Frongillo E, Melgar-Quinoñez H, Perez-Escamilla R, Rosinger R, Ringler C, Jamaluddine Z (2021) Perspective: the importance of water security for ensuring food security, good nutrition, and well-being. Adv Nutr. nmab00. https://academic.oup.com/advances/advance-article/doi/10.1093/advances/nmab003/6144691
Yu W, Uhlenbrook S, Von Gnechten R, Van der Bliek J (2021) Can water productivity improvements save us from global water scarcity? A white paper. FAO, Rome