Chapter 5

Food and agriculture

FAO

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5.1 Introduction

Food security has long been a challenge for human societies and will become an increasingly pressing global issue over the coming decades (Fischer, 2018). Although global food production has kept pace with population growth, close to 750 million people (or 10% of the global population) were exposed to severe levels of food insecurity in 2019 (FAO/IFAD/UNICEF/WFP/WHO, 2020). Unfortunately, this number has increased even further over the course of 2020 due to the COVID-19 pandemic and its economic impacts worldwide. In the 2030 Agenda for Sustainable Development, Sustainable Development Goal (SDG) 2 aims to "*end hunger, achieve food security and improved nutrition and promote sustainable agriculture*" (UNGA, 2015). The food system is almost entirely supported by water, and agriculture uses the major share of global freshwater resources. However, water use for food production is being questioned continually as intersectoral competition for water intensifies and water scarcity increases. Additionally, in many regions of the world, water for food production is used inefficiently (D'Odorico et al., 2020). This is a major driver of environmental degradation, including depletion of aquifers, reduction of river flows, degradation of wildlife habitats, and pollution (Willett et al., 2019). A fundamental transformation of how water is being managed in the food system is therefore necessary if most of the SDG 2 targets are to be achieved by 2030, without further degradation of water resources to concurrently achieve SDG 6 to "*ensure availability and sustainable management of water and sanitation for all*" (IFPRI, 2019).

5.2 The multiple benefits of water for food production

Water is used for food production in various ways, including for agriculture, livestock and inland fishery production. Water use in agriculture ranges from essentially rainfed, relying on soil moisture from rainfall, to entirely irrigated. The global water footprint related to crop production in the period 1996–2005 was 7,404 km^3 per year, representing 92% of humanity's water footprint (Hoekstra and Mekonnen, 2012). Rainfed agriculture covers 80% of the world's cropland and accounts for the major part (60%) of food production (Rockström et al., 2007). Rainfed agriculture has a global water footprint of 5,173 km^3 per year (Mekonnen and Hoekstra, 2011a). Irrigated agriculture covers about 20% of cultivated lands, yet it accounts for 40% of food production (Molden et al., 2010) (Table 5.1), and has a global water footprint of 2,230 km^3 per year (Mekonnen and Hoekstra, 2011a). Water withdrawals from surface and groundwater resources for irrigation currently amount to 2,797 km^3 per year, which represents 70% of all water withdrawals in the world (Table 5.1). In many drier countries, it is not unusual for irrigation water use to account for more than 90% of total water withdrawals (FAO, 2012a). Water for livestock production is used for growing and producing livestock feed (which is included in rainfed and irrigation water demand), direct consumption by livestock, and livestock processing. While direct water consumption by livestock is very small in most countries, representing less than 1–2% of total water use, water availability and its quality are of utmost importance for livestock production (FAO, 2019c). Finally, inland fishery production relies fully on natural and modified water bodies (FAO, 2014a).

Efforts to value water for food production have advanced over the past 30 years (Young and Loomis, 2014). Existing water valuation studies often indicate that the value assigned to water in food production is low compared to its value in alternative water uses, such as domestic and industrial uses. They also indicate that the value of water could be very low (typically less than US$0.05/m^3) where water is used for irrigating food grains and fodder, while it could be high (of the same order of magnitude as values in domestic and industrial uses) where reliable supplies are needed for high-value crops such as vegetables, fruits and flowers (FAO, 2004). D'Odorico et al. (2020) indicate that the global mean values assigned to water in the production of the four major staple crops (wheat, maize, rice and soybean), representing about 60% of global food production, range between US$0.05 and 0.16 per m^3. Those values vary considerably within and among regions.

As exemplified in Box 1.3, there are multiple ways of expressing and calculating values of water used for food production. Variation also exists in terms of what is included in accounting, providing a wide range of results. However, estimates of values of water for food

Table 5.1 Land cultivated and equipped for irrigation, and total and agricultural water withdrawals, 2010

	Total cultivated land (million ha)	Land equipped for irrigation (million ha)	Land equipped for irrigation as % of total cultivated land	Total water withdrawal (km^3/yr)	Agricultural water withdrawal (km^3/yr)	Agricultural water withdrawal as % of total water withdrawal
Africa	259	15	6	226	183	81
Americas	365	52	14	854	412	48
Asia	562	227	40	2 584	2 103	81
Europe	291	25	9	322	88	27
Oceania	28	3	6	19	11	58
World	**1 505**	**322**	**21**	**4 005**	**2 797**	**70**

Note: Total cultivated land includes arable land and areas used for permanent crops, both rainfed and irrigated. Total water withdrawal includes water withdrawn for agricultural, industrial and municipal purposes. Agricultural water withdrawal consists of water withdrawn for irrigation.

Source: Based on data from FAOSTAT (land area) and AQUASTAT (water withdrawal).

production normally only consider the direct economically beneficial use of water (i.e. value to users of water), while many of the other direct and indirect benefits associated with water, which may be economic, sociocultural or environmental, remain unaccounted for or only partially quantified (Comprehensive Assessment of Water Management in Agriculture, 2007). Some of those benefits include achieving food security and improving nutrition, accommodating shifts in consumption patterns, generating employment and providing livelihood resilience especially for smallholder farmers, contributing to alleviating poverty and revitalizing rural economies, supporting climate change mitigation and adaptation, and providing multiple-use water services.

The food security value of water is high but rarely quantified – and it is often a political imperative irrespective of other values

5.2.1 Food security

Water is central to food security and nutrition. Making water available to agriculture helps boost crop yields, enables the expansion of the area under cultivation – as it allows for planting during the dry season and using areas where production was formerly unfeasible – and supports the production of more nutrient-dense fruits and vegetables (Hanjra and Qureshi, 2010; Domènech, 2015). The food security value of water is high but rarely quantified – and it is often a political imperative irrespective of other values. In two case studies in India, Rogers et al. (1998) estimated the food security value of water based on the avoided impact on consumers of increasing foodgrain prices – which could have resulted from water shortages and the subsequent reduction of food supply – and found that it is at least two times higher than the net value of crop output. Moreover, it has been shown that people who have better access to water tend to have lower levels of undernourishment, while lack of it can be a major cause of famine and undernourishment, especially in areas where people depend on local agriculture for food and income (FAO/WWC, 2015). Recently, disruptions of food supply and trading systems due to the COVID-19 pandemic had a negative impact on food security and nutrition in many countries that depend largely on food trade. This clearly adds to the often hidden value of water for local agriculture (FAO, 2020a).

In the coming decades, water for food production will be even more critical for food security. Global demand for food and other agricultural products is projected to increase by 50% between 2012 and 2050, driven by population growth (FAO, 2017b). Furthermore, rapidly rising incomes and urbanization in much of the developing world will encourage dietary changes towards increased consumption of livestock-based products, sugar and horticultural products, which all rely on crops with higher water requirements than traditional staple food diets (Ringler and Zhu, 2015). Food production is thus required to sustainably intensify and expand to keep up with food demand.

5.2.2 Poverty alleviation

Despite striking economic growth in the past, there are still 2.1 billion poor people, of whom 767 million people live in extreme poverty. Of all people living in poverty, 80% live in rural areas, where agriculture continues to be the mainstay of their livelihoods (World Bank, 2016b). In many of those areas, such as in Sub-Saharan Africa, insufficient and erratic water supplies constrain agricultural productivity and compromise income stability, with dramatic effects for the poorest households, who have limited assets and safety nets to cope with risks (WWAP, 2016). This limits rural inhabitants' capacities to accumulate the human capital and assets needed to sustainably lift themselves out of poverty (FAO, 2014b). In India, for example, a 30-year analysis shows that wages are highly sensitive to rainfall shocks (World Bank, 2007). Prolonged drought causes persistent unemployment, which often leads to migration from rural to urban areas, notably when off-farm employment is limited (WWAP, 2016). The impacts could be extremely large for women, who comprise about 43% of the agricultural labour force globally and half or more of the agricultural labour force in many African and Asian countries (FAO, n.d.a). Therefore, improving water security for food production in both rainfed and irrigated systems can contribute to reducing poverty and closing the gender gap directly and indirectly. Direct effects include higher yields, reduced risk of crop failure and increased diversity of cropping; higher wages from enhanced employment opportunities; and stabilized local food production and prices. Indirect effects include income and employment multipliers beyond the farm, and reduction of migration (Faurès and Santini, 2008). Enhanced and more stable incomes could help improve education and the skillsets of women, and thus foster their active participation in decision-making. Although increasing water productivity can have substantial positive impacts, care should be taken to account for possible perverse effects and implications for poverty alleviation (i.e. land grabbing and increasing inequality).

Water for food production can serve as a conduit of broader rural access to water resources

5.2.3 Multiple uses of water

Water for food production can serve as a conduit of broader rural access to water resources. Multiple uses of water involve the practice of using water from the same source or infrastructure for multiples uses and functions (FAO, 2013b). It may be used for different domestic purposes such as drinking, washing, bathing or hygiene, and for other productive purposes such as livestock rearing, aquaculture or supporting small businesses (Domènech, 2015). Water for food production could also indirectly support natural vegetation and simultaneously provide various cultural (e.g. recreation, tourism) and environmental services (e.g. groundwater recharge, water purification) (FAO, 2013b). Exploiting these opportunities is of paramount importance in order to make water use consistent with productivity, livelihoods, efficiency and environmental objectives, thus enabling direct contribution to various SDG targets.

The additional services that can be provided by water for food production result in improved environmental and human health, hygiene, and livelihood opportunities for the rural poor. The potential of multiple water uses is particularly high in irrigation, where the scheme irrigation efficiency (the proportion of water pumped or diverted through the scheme inlet that is used effectively by the crops) has been estimated at roughly 40–50% globally. This figure varies widely among regions and drops to 28% in Sub-Saharan Africa and 26% in Central America and the Caribbean (AQUASTAT, 2014). By allowing water to be used for different purposes, the value of water can be significantly amplified (FAO, n.d.b).

For example, in areas of northwest India where groundwater is saline, irrigation canals not only provide water for domestic and livestock uses, but seepage from these canals also recharges the groundwater table, thus enabling the pumping of high-quality water from handpumps and shallow tubewells. In the absence of this freshwater, use of saline groundwater by animals is reported to result in about 50% reduction of milk production. In this region, income from livestock accounts for a significant proportion of the income of poor households, particularly in the dry season. In addition to livestock, irrigation canals provide water for the environment. In some canals in southern India, canal drops are used for installation of small and mini hydropower plants (Rogers et al., 1998).

Promotion of multiple water use is particularly timely in the light of the spreading COVID-19. In response to the crisis, the Food and Agriculture Organization of the United Nations (FAO) highlights that inherent effects of the pandemic have grown beyond the well-defined spear of health risks and have shocked livelihoods and food security in several countries. Irrigation plays an important role in improving crop productivity and ensuring food security. However, expanding irrigation could impact the availability of water for sanitation and hygiene, which has a central role in slowing down the spread of the disease. Developing multiple water uses would certainly allow to fight the pandemic while ensuring the basic needs of food security in rural communities. A new initiative of the FAO's Land and Water Division, called SMART Irrigation – SMART WASH, offers corporate solutions to enhance irrigation and provide water, sanitation and hygiene (WASH) facilities to vulnerable communities, thus responding to their critical needs during the pandemic (FAO, 2020b).

5.3 Impacts and costs of inefficient use of water for food production

Despite the multiple benefits that water used for food production provides, its inefficient use has resulted in serious economic, social and environmental impacts (or negative values), such as the depletion of freshwater resources, deterioration of water quality, land degradation, increased vulnerability to climate shocks, and declines of biodiversity and ecosystem services (Willett et al., 2019).

5.3.1 Water scarcity

Water scarcity occurs when water supply is insufficient to meet water demand (FAO, 2012b). Continued increase in water use for food production over the last decades has exacerbated water scarcity conditions in many regions around the world (e.g. northeastern China, India, Pakistan, the Middle East and North Africa), where available surface water is limited due to lower precipitation and higher evaporation rates (Wada, 2016). In these regions, when the available surface water resources are insufficient for productive farming, groundwater resources serve as a main source for irrigation. Estimates based on comprehensive national and subnational data indicate that 40% of actually irrigated area in the world is serviced by groundwater sources (Siebert et al., 2010). In India, privately developed groundwater infrastructure now supports a larger area of irrigation than the area serviced by all surface irrigation investment (FAO, 2020c). However, excessive groundwater pumping often leads to overexploitation, causing groundwater depletion, which constrains sustainable food production (Giordano et al., 2017) and has devastating effects on groundwater-dependent ecosystems sustaining the livelihood of millions of people (Wada, 2016).

In the coming decades, many regions around the world are expected to face either absolute or seasonal water scarcity conditions, driven by increasing competition for water between agriculture and other sectors and a more variable water availability because of climate change (Greve et al., 2018). The World Bank (2016a) estimated that regions affected by water scarcity could see their growth rates decline by as much as 6% of Gross Domestic Product (GDP) by 2050 as a result of losses in agriculture, health, income and property – sending them into sustained negative growth.

5.3.2 Water quality degradation

Water scarcity is caused not only by the physical scarcity of the resource and lack of access to it, but also by the progressive deterioration of water quality in many countries, reducing the quantity of water that is safe to use (Van Vliet et al., 2017). Water use for food production is both the source and the receptor of water quality problems. During recent decades, food production became highly intensive in many developed and rapidly growing economies striving for food security. This intensification included high levels of agrochemicals use to maximize crop yields, as well as a significant increase in livestock production (Lu and Tian, 2017). This has resulted in high nutrient loads (mainly phosphorus and nitrogen), which are the main causes of the degradation of downstream water quality and the eutrophication of water bodies (Vilmin et al., 2018). There are numerous socio-economic costs associated with the deterioration of water quality, including costs related to water treatment and health; impacts on economic activities such as agriculture, fisheries, industrial manufacturing and tourism; degradation of ecosystem services; reduced property values; and opportunity costs of further development (WWAP, 2012). For example, the estimated total of annual cost of water pollution from diffuse sources (mainly agriculture) exceeds billions of American dollars in just the Member States of the Organisation for Economic Co-operation and Development (OECD). Algal blooms associated with excessive nutrients in freshwater systems cost Australia US$116–155 million annually, including through major disruptions of water supplies for livestock and urban areas, as well as fish kills (OECD, 2017a).

Water use for food production is both the source and the receptor of water quality problems

5.3.3 Increased vulnerability and ecosystem degradation

Over the past decades, intense irrigation has substantially affected local and downstream water flow in various regions of the world, including in Asia, southern Europe, and the western and central parts of the USA, which subsequently increased the magnitude and frequency of hydrological droughts in those regions (Wada et al., 2013). Additionally, irrigation was found to accentuate vulnerability to droughts. If farmers grow water-intensive crops, crop productivity suffers disproportionately during droughts as a result of their higher water needs (Damania et al., 2017). Irrigation has also caused environmental degradation of aquatic ecosystems that exceeds by far that of terrestrial and marine ecosystems (Arthington, 2012). Aquatic ecosystems, such as wetlands, provide a wide range of goods and services of significant value to society, including habitat for valuable species, flood control, carbon sequestration, pollution attenuation and recreational opportunities. The global economic value of the ecosystem services provided by wetlands only was estimated at US$26 trillion per year in 2011 (Costanza et al., 2014). However, much of the irrigation development worldwide that occurred in the last decades was considered a priority over environmental flows. If environmental flow requirements are being satisfied without improving irrigation efficiency, half of the globally irrigated cropland would face production losses of more than 10%, with losses reaching 20–30% of total production in some regions such as Central and South Asia (Jägermeyr et al., 2017).

5.4 Scalable solutions for valuing water for food production

Lack of valuation of water for food production has resulted in its inefficient use, which has hindered the progress towards global food security and poverty alleviation, and resulted in various negative socio-economic and environmental externalities. Therefore, valuing water in food production can play a key role in making the trade-offs explicit that are intrinsic to decision-making and priority-setting, especially when it concerns social needs such as food security, which is not revealed in the marketplace (Hellegers and Van Halsema, 2019). It also enables a better understanding of the causes of inefficient use of water in the food system and provides incentives to increase investments in the modernization of water infrastructure. This can in turn increase the efficiency and productivity of water use for food production, while avoiding the cascading negative impacts of inefficient water use (such as water scarcity and pollution) and ensuring that sufficient water remains for aquatic ecosystems to sustain their health, productivity and resilience to climate change.

Several management strategies that could maximize the multiple values of water for food production could be implemented, including improving water management in rainfed areas; transitioning to sustainable intensification; sourcing water for irrigated agriculture, especially from nature-based and non-conventional sources; improving water use efficiency; reducing demand for food and its consequent water use; and improving knowledge and understanding of water use for food production (FAO, 2011a; 2017b; 2018a; FAO/IFAD/UNICEF/WFP/WHO, 2020).

5.4.1 Improving water management in rainfed lands

Increasing water scarcity in many regions around the world leaves little room for further expansion of large-scale irrigation. Moreover, the large gaps between actual and attainable yields in rainfed agriculture in many regions suggest a large untapped potential for yield increases without irrigation (Rockström et al., 2010). For example, several African countries have yields that are at around 20% of their potential (FAO, 2011a). Closing this yield gap could substantially increase food production and reduce the need for irrigation. Some experts therefore indicate that rainfed agriculture will remain the major source of food production in the coming decades and argue that more investment should be directed toward improving water management in rainfed lands (Rockström et al., 2007). There are two broad water management strategies to improve yields and water productivities in rainfed agriculture: (i) capturing more water and allowing it to infiltrate into the root zone with water harvesting techniques such as surface microdams, subsurface tanks or some tree species, and with soil and water conservation practices such as runoff strips and terracing; and (ii) using the available water more efficiently by increasing the plants' water-uptake capacity and reducing non-productive soil evaporation with integrated soil, crop and water management strategies, such as conservation agriculture and improved crop varieties (Rockström et al., 2010). These management options are key to reducing yield losses in rainfed lands during dry spells, and play an important role in climate change adaptation. They allow farmers additional guarantees that may encourage them to invest in other inputs, such as fertilizers and high-yielding varieties, providing them with the opportunity to grow higher-value market crops, such as vegetables or fruits (Oweis, 2014). However, it is important to mention that water harvesting and other management practices to improve the infiltration and storage of rainwater in soils may result in water trade-offs with downstream users and ecosystems (Zhu et al., 2019).

Increasing water supply to irrigation must be coupled with options to improve water use efficiency (better management practices, technologies and regulatory measures)

5.4.2 Sustainable agricultural intensification

The transition of agricultural development towards sustainable intensification is a strategic avenue to use resources, including water, more efficiently (FAO, 2018a). Sustainable intensification refers to producing more from the same area of land while conserving resources, reducing negative impacts on the environment, and enhancing natural capital and the flow of ecosystem services (FAO, 2011b). Sustainable intensification includes production systems and practices such as agroforestry, conservation agriculture, integrated crop–livestock and aquaculture–crop systems, nutrition-sensitive agriculture, sustainable forest and fisheries management, and water-smart agriculture. Water-smart agricultural practices, for instance, aim at improving agricultural productivity while reducing vulnerability to increasing water scarcity (Lipper et al., 2014) (Box 5.1). Water-smart agricultural practices range from planting crops suited to higher temperatures and longer droughts, to adopting practices (such as alternate wetting and drying) that minimize energy and water use while improving crop yields. However, the adoption of these solutions tends to be slow in the absence of adequate incentives. For instance, a large share of the gains of approaches such as water-smart agriculture accrue to beneficiaries other than farmers, while the costs of technology adoption fall mainly on farmers. A wider uptake of such practices requires introducing incentives, including changes in subsidy regimes, public investments in infrastructure or extension services, selective forms of crop insurance, and increased access to credit (World Bank, 2016a). Moreover, "*achieving sustainable agricultural intensification requires a substantial paradigm shift to reconcile growing human needs with the need to strengthen the resilience and sustainability of landscapes and the biosphere. This calls for bold changes in the technological aspects of production systems to improve their ecological efficiency*." (FAO, 2018a, p. 148).

5.4.3 Increasing water use efficiency in irrigation

Increasing water supply to irrigation must be coupled with options to improve water use efficiency (better management practices, technologies and regulatory measures) (Scheierling and Tréguer, 2018). Jägermeyr et al. (2015) showed that with proper water accounting and

Box 5.1 Systems of Rice Intensification (more productivity with less water)

Rice is a staple for nearly half the world's population. Irrigated, lowland rice cultivation, which covers about 56% of the total rice-cropped area, produces about 76% of the total amount of rice produced globally (Uphoff and Dazzo, 2016). The System of Rice Intensification (SRI) provides an example of a successful water-smart agricultural practice. SRI is a practice developed to increase the productivity of land, water and other resources in rice production systems, and is promoted in many rice-producing countries. It is based on the principle of developing healthy, large and deep root systems that can better resist drought, waterlogging and rainfall variability – all of which are potential impacts of climate change. SRI has proved particularly beneficial as it requires only intermittent water application, rather than continuous flood irrigation. The average increase in income from SRI compared to conventional practices in eight countries (Bangladesh, Cambodia, China, India, Indonesia, Nepal, Sri Lanka and Viet Nam) amounted to around 68%. Crop yields increased between 17 and 105%, while water requirements decreased between 24 and 50%. Additionally, SRI can possibly reduce methane emissions, as it reduces the amount of flooding required for irrigated rice cultivation (FAO, 2013c).

the enforcement of strict withdrawal regulations, the adoption of highly efficient irrigation systems could reduce non-beneficial water consumption at the river basin level with more than 70% while maintaining the current level of crop yields, enabling the reallocation of water to other uses, including environmental restoration. While irrigation losses may appear high, as globally on average only 40–50% of the water supplied to agriculture reaches the crops, it is now widely accepted that a large part of these losses return to the river basin in the form of return flow or aquifer recharge, and can be tapped by other users further downstream or serve important environmental functions (FAO, 2012b).

Efficiency measures to reduce irrigation losses upstream, such as the adoption of efficient on-farm-irrigation techniques (sprinkler and drip systems) or canal lining, while maintaining existing levels of withdrawal, often lead to intensification of water usage and even a net increase in water consumption (Box 5.2): the so-called rebound effect or irrigation efficiency paradox (Grafton et al., 2018). To avoid this rebound effect, some attempts have been made to introduce water consumption quotas or water extractions caps (Xie, 2009). Thus, measures to reduce irrigation water losses must be assessed at the basin level, and not only at individual farm level (Hsiao et al., 2007).

5.4.4 Sourcing water for irrigated agriculture

In order to have secure access to water for irrigation, people have always tried to control and store seasonal and irregular water flows (FAO, 2012b). Augmenting the supply of freshwater resources can be done by investing in built water supply infrastructure, such as water storage facilities, water transfer canals and groundwater wells, or through aquifer recharging and rainwater harvesting. Alternatively, nature-based solutions and improved land management offer promising possibilities to enhance the availability and quality of water for agriculture, while simultaneously preserving the integrity and intrinsic value of ecosystems and minimizing negative impacts for society (WWAP/UN-Water, 2018).

Water resources of lesser quality (e.g. domestic wastewater, drainage water, saline water) are now being valued, both for the resources they contain and for their associated benefits. Significant synergies for the wide adoption of non-conventional water supplies could be created through a transition to a circular economy, fostering sustainable agricultural water management with enhanced resource recovery (Voulvoulis, 2018). Drainage water can be reused either through loops in systems or by farmers pumping directly from drains. Use of these relatively saline waters poses agricultural and environmental risks, as it can cause soil salinization and affect water quality downstream. Therefore, salinity risk assessments and monitoring are required, as are actions to prevent the further salinization of land and water and to remediate saline or sodic soils. A successful example can be found in Egypt, which reuses over 10% of its annual freshwater withdrawals without deterioration of the salt balance (FAO, 2011a).

Box 5.2 Improved irrigation water use efficiency does not always lead to increased availability downstream

With the advent of pressurized irrigation, particularly from groundwater sources, governments worldwide have created subsidies for farmers who wish to transfer from flood irrigation to sprinkler and drip technologies, in the hope that improvements in irrigation efficiency at scheme level would reduce water withdrawals – whether from surface or groundwater sources. Documented examples have included China (Kendy et al., 2003), the United States of America (Ward and Pulido-Velazquez, 2008), Spain (Lopez-Gunn, 2012), Mexico (Carrillo-Guerrero et al., 2013), Chile (Scott et al., 2014), India (Birkenholtz, 2017), Morocco (Molle and Tanouti, 2017) and Australia (Grafton and Wheeler, 2018). Evidence from these countries indicates that any efficiency gains made through agricultural water use programmes, including the adoption of irrigation technology (subsidized or not), are internalized by farming units who tend to intensify crop production, expand areas under irrigation and thereby increase their evaporative consumption of water.

In the case of Australia, farmers were subsidized for adopting irrigation technology as an inducement to give up long-held water use rights in the Murray-Darling River basin and return the right to the Commonwealth in order to increase in-stream flows. After more than a decade of implementation, this recovery or 'buy-back' of water rights and the accompanying subsidy of irrigation technology has not resulted in any measurable impact on in-stream flows (Wheeler et al., 2020). This example highlights the relevance of implementing accompanying socio-economic and environmental policies, and of carefully selecting compliance instruments, including the operation of water markets (Seidl et al., 2020b). At the very least, technical 'fixes' to water scarcity problems need accurate measurement of the resulting surface and groundwater flows and a stronger approach to regulatory compliance and water accounting. What might be apparent on paper (the return of water entitlements) does not necessarily translate to reductions in agricultural water withdrawals.

The conclusion reached is that water productivity can be increased through efficiency programmes in agriculture, but that there is little or no evidence for water being 'freed up' for other uses, including environmental flows. Compliance at the point of withdrawal is essential, but has to go hand-in-hand with the capacity to measure and account for return flows and the environmental outcomes downstream of irrigated areas.

The use of treated wastewater is becoming particularly appealing for agriculture in peri-urban and urban settings

The use of treated wastewater (see Section 2.6.1) is becoming particularly appealing for agriculture in peri-urban and urban settings (Box 5.3). It is estimated that 380 km^3 of wastewater is produced annually across the world, which equals about 15% of agricultural water withdrawals. The irrigation potential of this volume of wastewater stands at 42 million ha (Qadir et al., 2020). With urbanization, more and more wastewater will be available in the coming years, revealing an opportunity to address water scarcity in dry areas through the collection, treatment and fit-for-purpose use of wastewater in agriculture and other sectors. Wastewater is also a source of nutrients for agricultural production systems. The full nutrient recovery from wastewater would offset more than 13% of the global demand for these nutrients in agriculture. The recovery of these nutrients could result in a revenue generation of US$13.6 billion globally (Qadir et al., 2020). Beyond the economic gains of reusing wastewater to maintain or improve agricultural productivity, there are critical human health and environmental benefits (FAO, 2010a).

Desalination (see Section 2.6.2 and Box 3.5) is one of the technological options that can provide an additional source of freshwater for irrigation, especially in water-stressed coastal areas. One challenge with its large-scale implementation is that most desalination technologies entail considerable upfront investment costs and energy requirements. However, investment costs for the main commercial desalination technologies, along with energy requirements, have been decreasing since the first projects were implemented (Mayor, 2020). The supply of desalinated water for agriculture is most likely to be cost-effective in a tightly controlled environment, using agricultural practices with the most efficient water use, crops with high productivity, and renewable energies (Barron et al., 2015). Such conditions are often associated with greenhouses, vertical farming and the production of high-value crops in urban and peri-urban areas, where the cost of water is small compared to the infrastructure investment. In recent years, the use of desalination powered by renewable energies for irrigating high-value crops in remote areas became a more viable option (Burn et al., 2015).

Box 5.3 The use of treated wastewater to address agricultural water scarcity

Treated municipal wastewater is increasingly recognized as an important source of water for agriculture. Despite such recognition, the potential of wastewater irrigation remains underexploited. The *Real Acequia de Moncada* is a centuries-old irrigation system in Valencia (Spain) that successfully uses treated wastewater for irrigation. The *Real Acequia de Moncada* uses treated wastewater obtained from the closest wastewater treatment plant (WWTP) and shows clear benefits for both farmers and WWTP managers. Benefits for agriculture include additional regularity in the water supply for farmers, especially during the dry summers when the crop water requirements are higher and water is scarce. At the same time, using treated wastewater in agriculture avoids its pumping into the sea, providing wastewater treatment with an additional value proposition while protecting aquatic environments. Several factors fostered the use of treated wastewater in the traditional irrigation systems of Valencia. First, the high level of water scarcity and recurring droughts reduced freshwater availability for irrigation. Second, traditional irrigation systems in Valencia have always used wastewater (even untreated) for irrigation. Lastly, the treated wastewater was supplied to farmers at no additional cost, as all the costs involved in treating the wastewater were financed by the sanitation fees.

Source: Hagenvoort et al. (2019).

Although water pricing to reduce the demand from the domestic and industrial water sectors has been met with varying levels of success, for agriculture, zero or very low water prices are common, and in some areas even the energy for pumping is subsidized

5.4.5 Water pricing and incentives for efficiency gains

Water pricing can be used to improve water use efficiency in agriculture and to make users aware of the value of water. Different pricing instruments (e.g. volumetric pricing, non-volumetric pricing, tradeable permits) can be implemented to achieve different objectives (e.g. cost recovery, efficient use, reallocating water use) (Davidson et al., 2019). Although water pricing to reduce the demand from the domestic and industrial water sectors has been met with varying levels of success, for agriculture, zero or very low water prices are common, and in some areas even the energy for pumping is subsidized. This situation may persist because of vested interests, political problems associated with price reform, practical difficulties in measuring and monitoring water use, and social norms (e.g. the perception of water as a free good and access to water as a basic right) (FAO, 2004). These low prices can have an adverse bearing on the effectiveness of irrigation systems and water use. They result in poor maintenance and consequent inefficient operation of existing irrigation systems, limited capacity for improvements or investment in new infrastructure, and waste of water at the farm level. It is, however, well documented that irrigation demand is highly inelastic when prices are in a low range. The price levels that can induce substantial conservation or recover the costs of providing sustainable irrigation services would have to be very high to be feasible (Zhu et al., 2019). Such high prices would impose disproportionate costs for farmers, leading to land fallowing while hindering food security and poverty alleviation (Cornish et al., 2004). Two-tiered water pricing, setting a low price for subsistence needs while charging a price equal to marginal cost, including environmental cost, for discretionary uses, has been alternatively suggested (Ward and Pulido-Velazquez, 2009). This pricing arrangement can promote efficient and sustainable water use patterns, while meeting subsistence needs of poor households and supporting the provision of ecosystem services. An alternative instrument to implement water pricing would be to pay farmers to save water and improve its quality (e.g. subsidies for investing in efficient irrigation systems) (Ringler and Zhu, 2015). However, it is claimed that those payments tend to favour the wealthy and thereby exacerbate inequalities in resource access and wealth distribution in rural areas (FAO, 2004).

5.4.6 Reducing food loss and waste and adopting sustainable diets

Lifestyle changes, such as reducing food loss and waste (FLW) and adopting sustainable diets, when aggregated at a larger scale, could have a considerable impact on water use for food production (Jalava et al., 2016). Reduction of FLW could increase food availability without the need for extra food production and the associated resource needs. Updated estimates of food losses, prepared by FAO, indicate that globally around 14%, in terms of economic value, of the food produced is lost from post-harvest up to, but not including, the retail level (FAO, 2019c).

Kummu et al. (2012) found that the global production of lost and wasted food crops accounts for 24% of total freshwater resources used in food crop production. However, efforts to reduce FLW must overcome the challenge posed by the fact that losses occur mostly in small percentages at different stages of the food chain. Reducing these losses requires shared commitments, strong quantitative goals, careful measurement and persistent action. Additionally, public interventions (i.e. policies and infrastructure investments) should create an enabling environment that allows private actors to invest in the reduction of FLW (FAO, 2019a).

Shifts towards sustainable diets could also reduce the use of water for food production by about 20% compared to current diets

Shifts towards sustainable diets could also reduce the use of water for food production by about 20% compared to current diets (Springmann et al., 2018). Sustainable diets are defined as those that are healthy, have a low environmental impact, are affordable and culturally acceptable (FAO, 2010b). Such diets involve a limited consumption of meat, added sugars and highly processed foods, and eating a diversity of plant-based foods (Tilman and Clark, 2014). Several measures could be implemented to encourage shifts towards sustainable diets. One of the biggest challenges for these shifts is the current cost and affordability of sustainable diets. To address this challenge, agricultural priorities must be reoriented towards sustainable food and agricultural production. This requires an increase in public expenditure to raise productivity, encourage diversification in food production and ensure that sustainable healthy foods are made abundantly available. Policies that penalize food and agricultural production (through direct and indirect taxation) should be avoided, as they tend to have adverse effects on the production of sustainable healthy foods (FAO/IFAD/UNICEF/WFP/WHO, 2020). At the consumption level, it is necessary to raise the awareness of the general public on the importance of sustainable consumption through education, public information and promotional campaigns (e.g. meat-free days), and food labelling (Capacci et al., 2012).

5.4.7 Improving knowledge on water use for food production

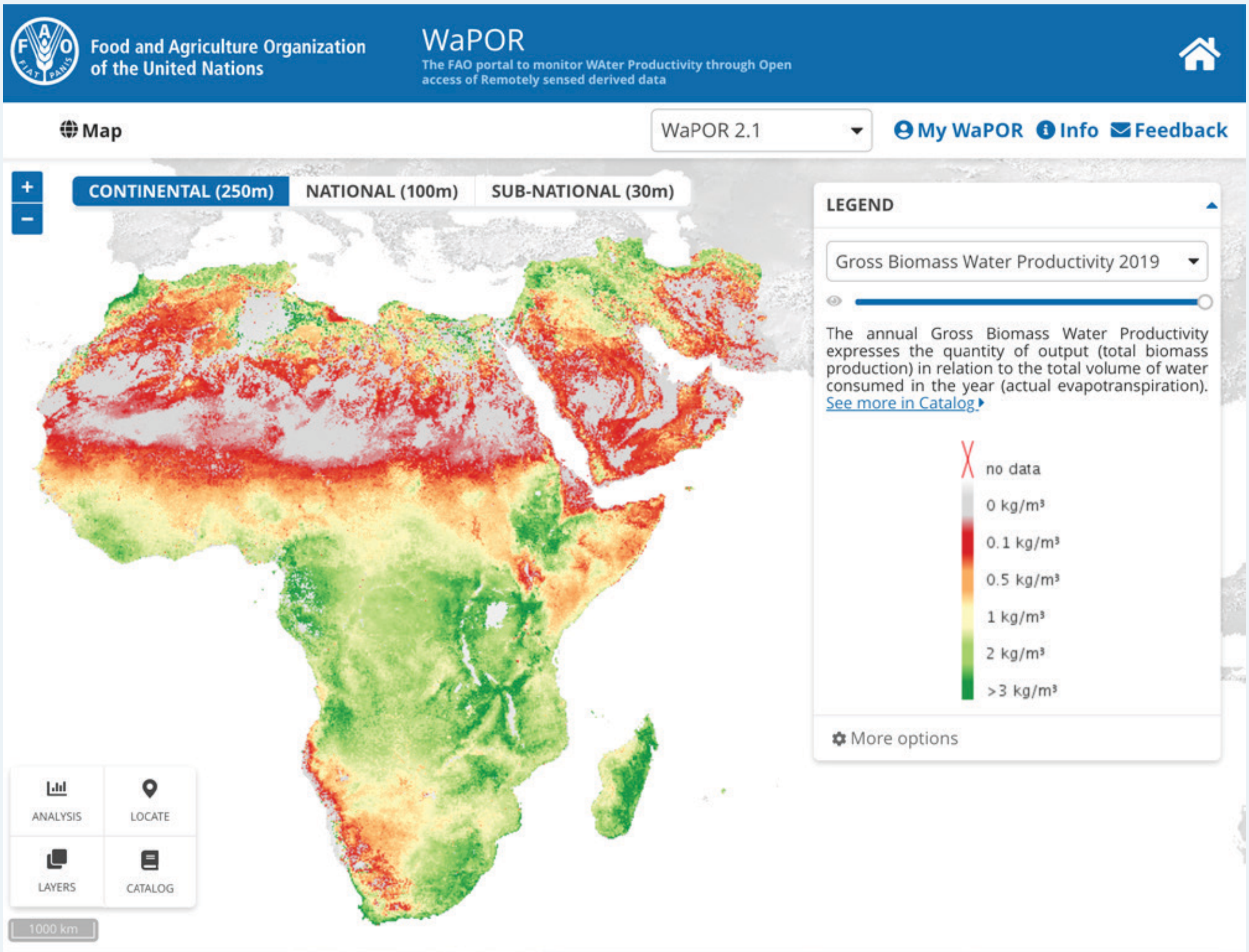
Lastly, robust water monitoring, modelling and accounting collectively constitute the foundation for water valuation, and a necessary step towards sustainable management of water resources (Garrick et al., 2017). However, only limited knowledge and data are available about freshwater resources and how they are being used for food production at the global scale. The FAOSTAT and AQUASTAT databases are unique sources on agriculture and water, containing data for over 200 countries and grouped by region, from 1961 to the most recent year available.[7] New digital technologies are creating unprecedented opportunities to leverage data and analytics in order to improve the assessment and management of water use (IWA, 2019). As an example, the FAO Water Productivity Open Access Portal (WAPOR) (Box 5.4) can be used to interactively map, monitor and report on agricultural water productivity in near-real time, using data generated with remote sensing technologies.

[7] See www.fao.org/faostat/en/; www.fao.org/aquastat/en/.

Box 5.4 Water Productivity Open Access Portal (WaPOR)

Water productivity, which is expressed as the quantity of biomass produced in relation to the total volume of water consumed in that year (actual evapotranspiration) can be retrieved from the FAO Water Productivity Open Access Portal (WaPOR). These data can be assessed at the continental, national, river basin and sub-basin/irrigation scheme scales (FAO, n.d.c). Water productivity gaps can be identified this way, facilitating proposed solutions to reduce them, and contributing to a sustainable increase of agricultural production, while taking valued ecosystems and equitable use of water resources into account (FAO, 2020d). Eventually these steps should lead to reduced overall water stress. Many of the new digital technology interventions are already in use on large-scale commercial farms (e.g. in Europe), but knowledge transfer to small-scale farms using simple agricultural methods (e.g. in Africa or Asia) is limited and needs to be further enhanced.

Illustration of mapping with the WaPOR system



Source: FAO WaPOR.