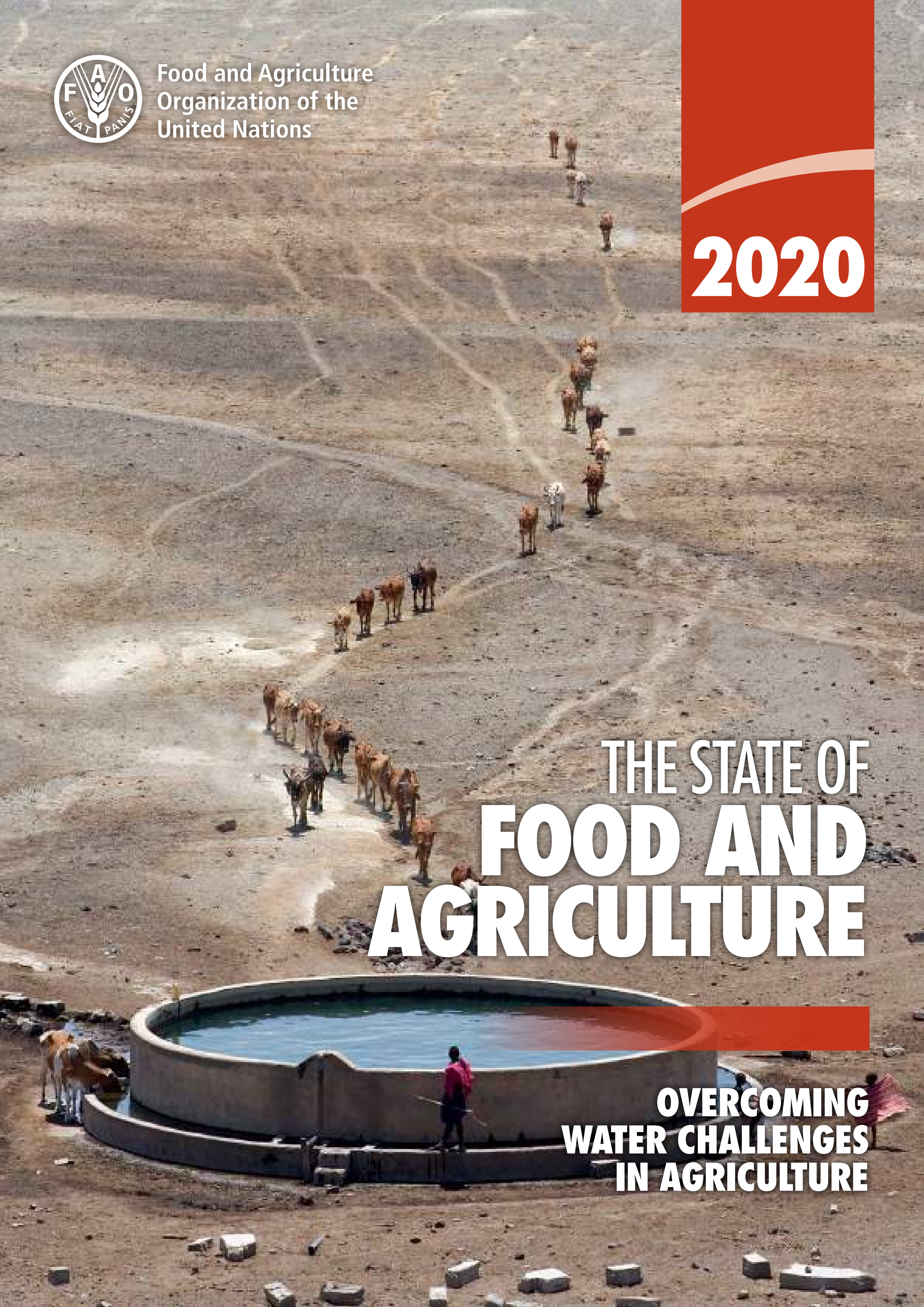
Food and Agriculture Organization of the United Nations



2020

THE STATE OF FOOD AND AGRICULTURE

OVERCOMING WATER CHALLENGES IN AGRICULTURE

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COVER PHOTOGRAPH ©FAO/Giulio Napolitano

KENYA. Pastoralists and herds of livestock gather at a water well in a dry area of Lake Magadi.

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THE STATE OF FOOD AND AGRICULTURE

OVERCOMING WATER CHALLENGES IN AGRICULTURE

Food and Agriculture Organization of the United Nations
Rome, 2020

CONTENTS

TABLES, FIGURES AND BOXES

TABLES

FIGURES

BOXES

TABLES, FIGURES AND BOXES

FOREWORD

Our very existence depends on water – water to drink and water to grow food. Agriculture relies on freshwater from rivers, lakes and aquifers. Rainfed agriculture and much of livestock production depend on the water from limited rainfall. Moreover, water-related ecosystems also sustain livelihoods, food security and nutrition by, *inter alia*, supporting inland fisheries and aquaculture. Supplies of uncontaminated freshwater are needed for safe drinking water, and to ensure hygiene and food safety standards to guarantee human health. In addition, water has numerous other uses and supports other human activities.

Against this backdrop, no doubt, water underpins many of the Sustainable Development Goals (SDGs). SDG 6, in particular, seeks to ensure availability and sustainable management of water and sanitation for all. Unfortunately, this report shows that achieving this objective by 2030 will be a challenge. The need to "produce more with less" is underscored by the fact that, with growing population, the freshwater resources available per person have declined by more than 20 percent in the last two decades. As demand rises, freshwater becomes increasingly scarce, competition for it intensifies, and excessive water withdrawals threaten water-related ecosystems and the ecosystem services they provide. Agriculture has an important role to play on the path to sustainability, as irrigated agriculture accounts for more than 70 percent of global water withdrawals, and, globally, 41 percent of withdrawals are not compatible with sustaining ecosystem services. Rainfed agriculture is called on to complement irrigation from scarce freshwater resources, yet rainwater also arrives in finite amounts. In addition, climate change is already seriously disrupting rainfall patterns. Increased drought frequency and consequent water shortages in rainfed agriculture represent significant risks to livelihoods and food security, particularly of the most vulnerable populations in the least developed parts of the world.

We must take very seriously both water scarcity (the imbalance between supply and demand for freshwater resources) and water shortages (reflected in inadequate rainfall patterns), for they are now the reality we all live with. Thanks to work by the Food and Agriculture Organization of the United Nations (FAO), we can assess how many people and how much land are experiencing water scarcity and water shortages. This report estimates that 1.2 billion people live in agricultural areas experiencing very high levels of water stress (affecting irrigated areas) or very high drought frequency (affecting rainfed cropland and pastureland). Of these, 520 million live in rural areas, while 660 million live in small urban centres surrounded by agricultural land. If we also include areas that experience high (in addition to very high) levels of water stress and drought frequency, the overall number increases to 3.2 billion, of whom 1.4 billion live in rural areas. In relative terms, about 11 percent of total cropland and 14 percent of pastureland experience recurring droughts, while more than 60 percent of irrigated cropland is highly water-stressed. These first estimates for SDG Indicator 6.4.2 on water stress, and the evidence of persistent water shortages in rainfed agriculture, underscore the need for urgent action to ensure that water is managed sustainably. In the absence of such action, the rising demand for water and the increasing effects of climate change risk worsening the situation.

Beyond SDG 6, addressing water shortages and scarcity is essential for many other goals of the 2030 Agenda for Sustainable Development (2030 Agenda), not least that of achieving Zero Hunger. The world still has ten years to achieve these objectives, but we can only succeed if we make better and more productive use of our limited water resources, both freshwater and rainwater. Agriculture is central to this challenge, not only because it is seriously affected by water constraints, but because it is the world's largest water user. This means that the way agriculture uses freshwater is crucial to ensuring availability

FOREWORD

for other activities and preserving water-related ecosystems. As the world aims to shift to healthy diets – often composed of relatively water-intensive foods, such as legumes, nuts, poultry and dairy products – the sustainable use of water resources will be ever more crucial. Rainfed agriculture provides the largest share of global food production. However, for it to continue to do so, we must improve how we manage water resources from limited rainfall.

With this report, FAO is sending a strong message: water shortages and scarcity in agriculture must be addressed immediately and boldly if our pledge to commit to achieve the SDGs is to be taken seriously. Global food security and nutrition are at stake. Water shortages and scarcity jeopardize the environment that is necessary to enable and ensure access to food for millions of people who are hungry in many parts of the world and to reduce the cost of nutritious food so as to ensure billions of people will be able to afford a healthy diet. Growing competition for water – including among sectors, among users and, sometimes, among countries – also leads to serious challenges. In the absence of appropriate governance, the increased competition can exacerbate already severe inequalities in access to water. Again, those most at risk are the poorest and most vulnerable groups, such as small-scale farmers and women. Communities and individuals reliant on water-related ecosystems, such as inland fisherfolk, also risk losing out as they are frequently neglected. In the worst case, increased competition can lead to conflicts at all levels – from local to international – and among different groups.

For this reason, a key emphasis of this report is on improved water governance, which aims at ensuring the most productive use of limited water resources, while safeguarding water-related ecosystem services and ensuring equitable access for all. While water governance in agriculture has focused on irrigation, this report broadens the scope to cover the challenges in rainfed agriculture, including pastoral systems. It further recognizes the importance of restoring and maintaining environmental flows and ensuring environmental services. It places water accounting and auditing at the centre of any programme to overcome water constraints. The report takes the view that water accounting and auditing are best designed and implemented as mutually supportive processes. By connecting people and their relationship with water resources to the broader water balance, this report also highlights the potential of water tenure in addressing water constraints and complementing auditing and accounting. With the importance of governance as the underlying theme, the report lays out suggested courses of action at three different levels: (i) technical and management; (ii) institutional and legal; and (iii) broader policy.

At the technical and management level, a key challenge is to unlock the potential of rainfed agriculture through improved water management. This involves either better conservation of water in soils or the adoption of rainwater harvesting techniques. The productivity of irrigated systems can be significantly enhanced through investments in new irrigation systems or the rehabilitation and modernization of existing ones. In all instances, improved water management practices are most effective when combined with improved agricultural practices, such as the use of drought-tolerant varieties. Options also exist in livestock production to improve water productivity, such as through improved grazing and animal health. However, actions at the farm level must be part of a broader landscape-level approach to account for effects on water balances in catchments and river basins.

This calls for effective institutional and legal frameworks that, once adapted to each specific context, will enable improved water governance and, consequently, innovative management strategies. The starting point for any effective water management and governance strategy should be water accounting and auditing. Subsequently, effective institutions and regulations that promote coordination among actors are required to manage competing demands for water, ensure equitable access and safeguard ecosystems. A cornerstone of this approach is secure water and land tenure, which – also in combination with water trading and pricing mechanisms – can establish incentives for efficient water use. Often, community-based water users associations can contribute to improved water management. However, solutions must be adapted to local conditions and developed by or with the stakeholders concerned.

Finally, at the level of the broader policy environment, policy coherence and coordination are crucial. This applies across and within sectors and locations. Coherent strategies are needed across rainfed and irrigated cropland, livestock production systems, forestry, and inland fisheries and aquaculture. Incentives represent a key element of policy coherence and should promote water productivity and ecosystem protection. However, subsidies on inputs, energy and production may promote inefficiencies and unsustainable use of water; for example, in the form of excessive groundwater abstraction.

There is no "one-size-fits-all" approach to addressing water shortages and scarcity. Different countries – and even different regions within countries – have different characteristics and face different challenges. Therefore, the solutions proposed by the report are consistent with the territorial approaches adopted by FAO's Hand-in-Hand Initiative to target problems and challenges at the territorial subnational level. The report proposes potential policy priorities in different types of production that can be tailored, for both irrigated and rainfed agriculture, using geospatial data available through FAO.

To paraphrase Benjamin Franklin, who was also a distinguished scientist, let us not wait until the well is dry to understand the worth of water. This report highlights the urgency of the problem at hand, and the important role that the agriculture sector must play to address growing water shortages and scarcity. I invite all stakeholders to read the report and, from their perspective, take from it appropriate options for addressing water-related challenges and, more importantly, implement them so as to improve food security and nutrition, and environmental sustainability, in the spirit of the 2030 Agenda.

Qu Dongyu
FAO Director-General

PAKISTAN
A child drinking water from a communal pump.
©FAO/Asim Hafeez

METHODOLOGY

The preparation of *The State of Food and Agriculture 2020* began with a meeting held at FAO headquarters in Rome on 19 November 2019 and attended by FAO specialists from relevant units to discuss the outline of the report. Following the meeting, an advisory group representing all relevant FAO technical units and chaired by the Deputy Director of FAO's Agrifood Economics Division was formed to assist in the drafting process. First drafts of the chapters were presented to the advisory group and panel of external experts between 17–21 February 2020. The full draft was then discussed at a workshop held on 26–27 February. With inputs from that workshop, the report was revised and presented to the management team of FAO's Economic and Social Development stream. The revised draft was sent for comment to other FAO streams and to the FAO regional offices for Africa, Asia and the Pacific, Europe and Central Asia, Latin America and the Caribbean, and the Near East and North Africa, as well as to external reviewers. Comments were incorporated in the final draft, which was reviewed by the Assistant Director-General of the Economic and Social Development stream, and then submitted to the Office of the FAO Director-General on 3 November 2020. In drafting the report, the research and writing team drew on background papers prepared by FAO and external experts.

ACKNOWLEDGEMENTS

The State of Food and Agriculture 2020 was prepared by a multidisciplinary team from FAO, under the direction of Marco V. Sánchez Cantillo, Deputy Director of FAO's Agrifood Economics Division, and Andrea Cattaneo, Senior Economist and Editor of the publication. Overall guidance was provided by Máximo Torero Cullen, Chief Economist of the Economic and Social Development stream. Guidance was also provided by the Economic and Social Development stream's management team.

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The annex was prepared by Laura D'Aietti, Giovanni Federighi and Sara Vaz.

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ACRONYMS AND ABBREVIATIONS

2030 Agenda	2030 Agenda for Sustainable Development
COVID-19	novel coronavirus disease
FAO	Food and Agriculture Organization of the United Nations
GAEZ	Global Agro-Ecological Zones
GDP	gross domestic product
GHG	greenhouse gas
GLAAS	UN-Water Global Analysis and Assessment of Sanitation and Drinking Water
GMIA	Global Map of Irrigated Areas
GPS	Global Positioning System
HWTS	household water treatment and safe storage
ICT	information and communication technology
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
IIASA	International Institute for Applied Systems Analysis
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IWMI	International Water Management Institute
LEAP	Livestock Environmental Assessment and Performance
LEGS	Livestock Emergency Guidelines and Standards
LSMS-ISA	Living Standards Measurement Study – Integrated Surveys on Agriculture
m^3	cubic metre
NENA	Near East and North Africa
R&D	research and development
SDG	Sustainable Development Goal
SIDS	Small Island Developing States
SPAM	Spatial Production Allocation Model
UN	United Nations
UN DESA	UN Department of Economic and Social Affairs
UNICEF	United Nations Children's Fund
USD	United States dollar
WaPOR	Water Productivity Open-access Portal
WASH	water for sanitation and hygiene
WHO	World Health Organization

GLOSSARY

Blue water refers to the water in lakes, rivers and aquifers. It occurs in two different forms: surface runoff in surface waterbodies; and renewable groundwater runoff in aquifers.[1]

Consumptive water use refers to the part of water withdrawn from its source for use in a specific sector (e.g. for agricultural, industrial or municipal purposes) that will not become available for reuse because of evaporation, transpiration, incorporation into products, drainage directly to the sea or evaporation areas, or removal in other ways from freshwater resources. See also non-consumptive water use (below).[1]

Environmental flow requirements refer to the quantity and timing of freshwater flows required to sustain ecosystems, and the human livelihoods and well-being that depend on them.[1]

External renewable water resources are defined as the part of a country's long-term average annual renewable water resources that are not generated in that country. They include inflows from upstream countries (groundwater and surface water), and part of the water of border lakes and/or rivers. They take into account the quantity of flow reserved by upstream (incoming flow) and/or downstream (outflow) countries through formal or informal agreements or treaties.[1]

Freshwater refers to the water occurring on the earth's surface in glaciers, lakes and rivers (i.e. surface water), and underground in aquifers (i.e. groundwater). Its key characteristic is a low concentration of dissolved salts. The term excludes rainwater, water stored in the soil (soil moisture), untreated wastewater, seawater and brackish water.[1]

Green water refers to that fraction of rainfall that is stored in the soil and available for the growth of plants.[1]

Internal renewable water resources for a country are defined as the long-term average annual flow of rivers and recharge of aquifers generated from endogenous precipitation.[1]

Land tenure is the relationship, whether legally or customarily defined, between people, as individuals or groups, with respect to land.[2]

Non-consumptive water use refers to water use that does not consume water. If ever withdrawn, almost all of the water returns to the system. Example of non-consumptive water uses are navigation, capture fisheries and recreational or cultural uses. Most in-stream water uses are non-consumptive. Hydropower is also considered as having a very low consumptive water use, except in cases where an artificial reservoir has been built upstream, because this substantially increases the surface area of the waterbody and, in doing so, increases evaporation.[1]

Non-conventional water refers to water that can be available for use without increasing the load on primary renewable freshwater resources. It includes (i) desalinated seawater or brackish water; (ii) direct use of (treated) wastewater; and (iii) direct use of agricultural drainage water.[1]

Return flow is the part of the water withdrawn from its source which is not consumed and returns to its source or to another body of surface water or groundwater. Return flow can be divided into non-recoverable flow (flow to salt sinks, uneconomic groundwater or flow of insufficient quality) and recoverable flow (flow to rivers or infiltration into groundwater aquifers).[1]

Sustainable Development Goal (SDG) Indicator 6.4.1 – Change in water-use efficiency over time – is defined as the value added per unit of water used, expressed in USD/m^3 of a given sector of the economy (showing over time the trend in water-use efficiency).[3] This indicator has been designed for the purpose of monitoring progress against SDG Target 6.4 – specifically, the target component "substantially increase water-use efficiency across all sectors," by comparing the value added produced by the economy with the volumes of water used by the same economy, including losses in the distribution networks. In other words, this indicator provides an estimation of the reliance of economic growth on the use of water resources, indicating the decoupling of economic growth from water use. The indicator differs from the concept of water productivity as it does not consider the productivity of the water used in a given activity as an input to production. Moreover, water productivity is calculated as the ratio of economic output to the amount of water consumed, not water used.[3] Finally, the monitoring concept of the SDG indicator has forcibly led to a distinct definition of "water-use efficiency" (mentioned below).

Sustainable Development Goal (SDG) Indicator 6.4.2 – Level of stress: freshwater withdrawal as a proportion of available freshwater resources – is defined as the proportion of total freshwater withdrawal by all major sectors (agricultural, industrial and municipal) in relation to the total renewable freshwater resources after taking into account environmental flow requirements. Water stress is human-driven; it is a function of the volume of human freshwater withdrawals relative to the volume of available water resources in a given area once water ecosystems are sustained. As such, an arid region with very little water, but no human water competition, would not be considered "stressed," but rather "arid." Water stress is a physical objective reality that can be measured consistently across regions and over time. This indicator has been designed for the purpose of monitoring progress against SDG Target 6.4 – specifically, the environmental target component to "ensure sustainable withdrawals and supply of freshwater to address water scarcity." This indicator evolved from the previous Millennium Development Goal Indicator 7.5 "Proportion of total water resources used."[4] Water stress reflects the physical availability of freshwater rather than whether the water is suitable for use.

Total renewable water resources refer to the sum of internal renewable freshwater resources and external renewable freshwater resources. They correspond to the maximum theoretical yearly amount of water available for a country at a given moment.[1]

Water accounting is the systematic study of the current status and trends in water supply, demand, accessibility and use within specified spatial and temporal domains.[5]

Water auditing goes one step further than water accounting by placing trends in water supply, demand, accessibility and use in the broader context of governance, institutions, public and private expenditure, legislation and the wider political economy of water of specified domains.[5]

Water governance refers to the processes, actors and institutions involved in decision-making for the development and management of water resources and for the delivery of water services, encompassing the political, administrative, social and economic domains along with the formal and informal systems and mechanisms involved.[6]

GLOSSARY

Water pricing refers to the action of establishing a price for a water service. The price can be calculated to cover all or part of the costs of the water service, or to induce a change in behaviour in water use through less wasteful water use. In irrigation, it can be calculated per area of land, per type of crop, or on a volumetric basis.[7]

Water productivity is the ratio of the net benefits from crops, forestry, fisheries, livestock and mixed agricultural systems to the volume of water used as actual evapotranspiration to produce those benefits.[1] These benefits can be expressed in various forms: as yield (kilograms), nutritional content (calories, protein, calcium, etc.), income (US dollars), or any other agreed measure of well-being derived from the goods and services coming from the agricultural system (e.g. jobs). In its broadest sense, water productivity reflects the objectives of producing more food, income, livelihood and ecological benefits at less social and environmental cost per unit of water consumed. In the agricultural context, physical water productivity is defined as the ratio of agricultural output to the volume of water consumed – ''more crop per drop'' (kilograms of product per cubic metre of water), and economic water productivity is defined as the monetary value generated from each unit of water consumed (US dollars per cubic metre of water). Economic water productivity has been used to relate water use in agriculture to nutrition, jobs, welfare and the environment.

Water risk is defined in this report as the possibility of an area experiencing any water-related challenge.[8] Challenges include water scarcity or water shortages – in this report measured through indicators such as water stress and drought frequency – but also natural hazards, such as flooding, where the problem is an excess of water.

Water scarcity refers to an imbalance between the supply of and demand for water in a specified domain (country, region, catchment, river basin, etc.) as a result of a high rate of demand compared with available supply, under prevailing institutional arrangements (including price) and infrastructural conditions. Symptoms of water scarcity are unsatisfied demand; tensions between users; competition for water; over-extraction of groundwater; and insufficient flows to the natural environment. Artificial or constructed water scarcity refers to the situation resulting from over-developments of hydraulic infrastructure relative to available supply, leading to a situation of increasing water shortage.[1] In this report, water stress – expressed by the SDG Indicator 6.4.2 (see above) is used as a proxy for the severity of water scarcity affecting irrigated agriculture.

Water services can be defined as the activity of providing users (households, industries and municipalities) with the abstraction, storage, treatment and distribution of water resources, including wastewater. Examples of water services include the supply of drinking water; the supply of irrigation for agricultural production; the collection, treatment and disposal of wastewater; drainage operations, including the management of stormwater, groundwater, surface water or soil salinity; and desalination of seawater or brackish water.

Water shortage refers to a shortage of water supply of an acceptable quality; low levels of water supply, at a given place and a given time, relative to design supply levels. The shortage may arise from climatic factors, or other causes of insufficient water resources, such as a lack of, or poorly maintained, infrastructure, or a range of other hydrological or hydrogeological factors.[1] In this report, an indicator of drought frequency is used as a proxy for water shortage affecting rainfed agriculture.

Water tenure is the relationship, whether legally or customarily defined, between people, as individuals or groups, with respect to water resources.[2]

Water use refers to any deliberate application or utilization of water for a specific purpose. There is an important distinction between consumptive use and non-consumptive use of water (see above).[1]

Water-use efficiency is the ratio between the effective water use for a specific purpose and actual water withdrawal. In irrigation, water-use efficiency presents the ratio between estimated irrigation water requirements (through evapotranspiration) and actual water withdrawal. It is dimensionless and can be applied at any scale (plant, field, irrigation schemes, basin, country, etc.). Efficient use of water in agriculture can be pursued by reducing water losses in transmission and distribution or by increasing crop yields, changing planting dates, and using different crop varieties, among others. However, just because an agricultural use of water becomes more efficient, it does not mean that water is actually saved.[1] In the quest for greater efficiency, it is important to take a broader view (e.g. at the basin level), recognizing the contribution that so-called "losses" can make to the productivity of other users and in other parts of the water cycle.

Water-use right is, in its legal sense, a legal right: to abstract or divert and use water from a given natural source; to impound or store a specified quantity of water in a natural source behind a dam or other hydraulic structure; or, to use or maintain water in a natural state (ecological flow in a river, and water for recreation, religious or spiritual practices, drinking, washing and bathing, and the watering of animals).[1]

Water withdrawal is the gross volume of water withdrawn for any purpose (agricultural, industrial and municipal).[1] It can include water from renewable freshwater resources, as well as water from over-abstraction of renewable groundwater or withdrawal from fossil groundwater, direct use of (treated) wastewater, desalinated water and direct use of agricultural drainage water.

CORE MESSAGES

➔ Achieving sustainable development faces a key challenge: 3.2 billion people live in agricultural areas with high to very high water shortages or scarcity, of whom 1.2 billion people – roughly one-sixth of the world's population – live in severely water-constrained agricultural areas.

➔ Population growth is a key driver of water scarcity as it implies rising demand for this precious natural resource. Consequently, the annual amount of available freshwater resources per person has declined by more than 20 percent in the past two decades.

➔ Socio-economic development is another important driver of increasing demand for water, as it contributes to shifting diets towards more water-intensive foods (e.g. meat and dairy products). Healthy diets that include sustainability considerations at the food systems level can reduce the associated water consumption.

➔ Rising competition for water and the effects of climate change are leading to tensions and conflicts among stakeholders, thereby exacerbating inequalities in access to water, especially for vulnerable populations, including the rural poor, women and indigenous populations.

➔ With ten years to go until 2030, first estimates for Sustainable Development Goal (SDG) Indicator 6.4.2 on water stress, together with persistent water shortages in rainfed agriculture, suggest that ensuring sustainable management of water for all remains a challenge. As water is closely linked to several other SDGs, not least that of achieving Zero Hunger, managing scarce water resources well will be a critical determinant for fully achieving them.

➔ Success is still achievable, but only by ensuring more productive and sustainable use of freshwater and rainwater in agriculture, the world's largest water user, accounting for more than 70 percent of global withdrawals.

➔ Improving sustainability of water use in agriculture will mean guaranteeing environmental flow requirements to sustain ecosystem functions, which are often overlooked – it has been estimated that 41 percent of current global irrigation water use occurs at the expense of environmental flow requirements. This will entail reducing withdrawals and improving water-use efficiency in those watersheds where environmental flow requirements are not guaranteed.

➔ Water accounting and auditing, which are rarely done, should therefore be the starting point of any effective strategy for addressing water shortages and scarcity. FAO's recent sourcebook provides a good starting point for all those wishing to implement water accounting and auditing.

➔ Producers – many of them small-scale farmers – working on 128 million hectares (or 11 percent) of rainfed cropland affected by recurring drought can greatly benefit from water-harvesting and water-conservation techniques. By one estimate, these practices could boost rainfed kilocalorie production by up to 24 percent and, if combined with irrigation expansion, by more than 40 percent.

➔ For herders working on 656 million hectares (or 14 percent) of drought-affected pastureland, a variety of farming measures can buffer the impact of drought and improve water productivity. Many of these measures are indirectly related to water, including disease control and animal health, livestock feeding and drinking management, mobility and stratification of production to reduce grazing pressure in arid areas.

➔ For the 171 million hectares (or 62 percent) of the world's irrigated cropland under high or very high water stress, priority should be given to incentivizing practices that increase water productivity – including rehabilitation and modernization of existing irrigation infrastructure and adoption of innovative technologies. These should be combined with improved water governance to guarantee equitable allocation and access to water, as well as environmental flow requirements. In sub-Saharan Africa, irrigated areas are expected to more than double by 2050, benefiting millions of small-scale farmers.

➔ Investing in non-consumptive uses of water – as can be done in aquaculture – and in non-conventional sources of water, such as water reuse and desalination, is an increasingly important strategy to offset scarcity; however, examples in this report show that innovations must be economically efficient, socially acceptable, environmentally sustainable and appropriate to the context.

➔ Policies and regulations play a central role in boosting the implementation of technologies and innovations, for example, through financing, capacity-development programmes and enforcing environmental flow requirements. However, they require appropriate allocation of water rights and secure water tenure to enable secure, equitable and sustainable access to water, especially for the most vulnerable, while ensuring environmental flow requirements.

➔ Policy coherence and governance mechanisms across administrative scales and sectors are essential for efficient, sustainable and equitable water resources management. In agriculture, specifically, coherent and inclusive strategies are needed across rainfed and irrigated cropland, livestock production systems, inland fisheries, aquaculture and forestry.

EXECUTIVE SUMMARY

WATER SHORTAGES AND SCARCITY AROUND THE WORLD – WHAT DO WE KNOW?

Critical water resources are under increasing pressure worldwide

Sustainable and equitable management of water resources is a key element of sustainable food systems and essential for achieving Zero Hunger. However, water scarcity (the imbalance between supply and demand of freshwater) and water quality issues are increasingly threatening food security and nutrition through their impacts on food systems – from agricultural production, through food processing to households and consumers. At the same time, persistent and severe droughts, exacerbated by climate change, are causing increasingly serious water shortages in rainfed agriculture, posing a higher risk to the livelihoods of rural people by reducing crop and livestock yields. The situation will only grow worse if immediate action is not taken – the reason why *The State of Food and Agriculture 2020* report addresses the two main water challenges affecting agriculture and food production: water shortages and scarcity.

For the challenges it presents not only to achieving Zero Hunger but also to meeting a myriad of other Sustainable Development Goals (SDGs), the urgent need of ensuring sustainable management of water for all features prominently in the 2030 Agenda for Sustainable Development (2030 Agenda). In particular, SDG 6 – Ensure availability and sustainable management of water and sanitation for all – covers many key dimensions relating to the availability and management of water. Growing concern over water scarcity and misuse is reflected more specifically in SDG Target 6.4, which calls for increasing water-use efficiency and ensuring sustainable withdrawals and supply of freshwater to address water scarcity.

Thanks also to efforts by FAO, it is now possible to monitor progress towards SDG Target 6.4 and assess how many people and how much agricultural land are experiencing water scarcity (through SDG Indicator 6.4.2 on water stress) and water shortages (through the historical drought frequency indicator). By these measures, this report finds that 3.2 billion people live in agricultural areas with high to very high levels of water shortages (affecting rainfed agriculture) or scarcity (affecting irrigated agriculture), of whom 1.2 billion people – about one-sixth of the world's population – live in severely water-constrained areas.

Population growth and socio-economic development drive water scarcity

Population growth is a key driver of water scarcity, as rising populations drive increased demand for water. Consequently, the annual amount of available freshwater per person has declined by more than 20 percent in the last two decades. This is a particularly serious issue in Northern Africa and Western Asia, where per capita freshwater has declined by more than 30 percent and where the average annual volume of water per person barely reaches 1 000 m^3, which is conventionally considered the threshold for severe water scarcity.

Other important drivers are rising incomes and urbanization, leading to increased water demand from industry, energy and services, and to dietary changes. As incomes, urbanization and nutrition standards rise, people are expected to move towards more land- and water-intensive diets, in particular through the consumption of more meat and dairy products, although such products can have vastly different water footprints depending on how they are produced. A study in Brazil, China and India has shown a transition in diets towards more livestock products and cereals and, consequently, an increase in daily water consumption of more than 1 000 litres per person. The world must also move towards healthy diets – varied with water-intensive nutritious foods, such as fruits and vegetables, legumes, nuts, and moderate amounts of dairy, eggs and poultry – making the sustainable use of water resources ever more crucial.

Climate change will exacerbate water-related challenges

The challenges of water shortages and scarcity must be addressed together with the anticipated impacts of climate change, which are expected to increase the risk of extreme weather events, such as floods and climate variability. This, in turn, will increase pressure on agricultural production, as crop growth and yields are highly sensitive to climate conditions. Although there is uncertainty as to their location and magnitude, climate change impacts are expected to exacerbate water shortages and scarcity, and negatively affect agricultural production, especially in low-latitude and tropical regions. Climate change also affects freshwater ecosystems, fish and other aquatic populations that have low buffering capacity and are sensitive to climate-related shocks and variability.

Climate change will thus put additional stress on agricultural production systems as they seek to meet the food requirements of a growing population. This can jeopardize the food security and nutrition of both rural and urban populations; but the rural poor, who are most vulnerable, are likely to be disproportionally affected. For this reason, despite the uncertainty associated with climate, immediate action is a prudent and necessary form of insurance, which calls for strategies to be formed and prioritized in a flexible way depending on the context.

How many people and how much agricultural land are experiencing water constraints, and where?

As mentioned at the beginning of this summary, about 1.2 billion people live in areas where severe water shortages and scarcity challenge agriculture, with very high drought frequency in rainfed cropland and pastureland areas or very high water stress in irrigated areas. This means that about one out of six people on the planet face severe water shortages or scarcity in agriculture, with about 15 percent of the rural population being at risk. Around 520 million of such people live in Southern Asia, and about 460 million live in Eastern and South-eastern Asia. In Central Asia and in Northern Africa and Western Asia, about one-fifth of the population live in agricultural areas with very high water shortages or scarcity. In Europe, Latin America and the Caribbean, Northern America and Oceania, only 1–4 percent live in extremely water-constrained areas. In sub-Saharan Africa, only about 5 percent of the population live in affected areas. There, most areas are rainfed, suggesting that water constraints are driven by severe drought or lack of irrigation. While 5 percent might seem negligible, it implies that about 50 million people live in areas where severe drought has catastrophic impacts on cropland and pastureland.

In terms of agricultural land affected, 128 million hectares of rainfed cropland and 656 million hectares of pastureland face frequent droughts, while 171 million hectares of irrigated cropland are subject to high or very high water stress. This means that about 11 percent of rainfed cropland and 14 percent of pastureland experience severe recurring droughts, while more than 60 percent of irrigated cropland is highly water stressed. More than 62 million hectares of cropland and pastureland experience both severe water stress and drought frequency, affecting about 300 million people.

In these areas, unless demand and user practices change or alternate water resources are found, people may be driven to migrate. While orderly and regular migration can contribute to economic development and improve livelihoods, it can be disruptive during a crisis. Furthermore, male outmigration may increase the domestic burden for women, shifting responsibilities in the home, with women taking on additional burdens such as caring for livestock.

Spatial analysis of water constraints is important because levels of water stress and drought frequency can vary substantially even within countries, and the same areas can experience different levels of water stress and drought. A certain number of countries face the dual challenge of severe drought frequency and water stress, all of them in Northern Africa and Asia, including Afghanistan, Egypt, Iran (Islamic Republic of), Kazakhstan, Saudi Arabia, Uzbekistan and Yemen. National-level assessments may hide such information, so it is essential to generate it through spatial analysis to identify hotspots and the most appropriate interventions.

Agricultural production systems cope with, and are affected by, water constraints in different ways

Within rainfed and irrigated agriculture, there are different production systems, which may differ both in terms of how they are affected by lack of access to water and in their capacity to address it. In reality, there is a continuum of technologies from fully irrigated to fully rainfed production. This report distinguishes between three broad types of crop production systems: (i) irrigated; (ii) high-input rainfed production; and (iii) low-input rainfed production. Their prevalence within countries provides an indication of a country's level of agricultural development and ability to address water-related risks.

High-income countries in Europe and Northern America – which have a capital-intensive and efficient agriculture sector as well as a high rate of public expenditure on agricultural research and development (R&D) – have a considerable share of cropland under high-input rainfed production. Consequently, they have a greater capacity to address the challenges associated with severe drought frequency. By contrast, in sub-Saharan Africa, where countries have lower levels of agricultural capital intensity and of R&D, more than 80 percent of cropland is low-input rainfed production, while only 3 percent of land is irrigated. In these countries, farmers have difficulty in accessing irrigation equipment, modern inputs and technologies, including technologies to optimize the efficiency of water use in rainfed agriculture. On a more positive note, only a relatively small share of rainfed cropland is subject to severe drought frequency. Conversely, countries in Southern Asia irrigate and employ modern inputs on about half of the region's cropland – despite the low level of development of many – while most irrigated areas are highly water stressed.

Beyond agricultural production, water affects food security and nutrition in multiple ways

Beyond agricultural production, challenges in terms of access to water and water pollution are found along the food supply chain, affecting food security and nutrition, and health. For example, the food industry is a water-intensive activity that uses potable-quality water and generates a significant amount of wastewater per unit of product. Without proper treatment, the disposal of contaminants into waterbodies may expose humans to harmful substances and limit access to safe drinking water.

Downstream in the food supply chain are consumers, for whom safe and reliable water for drinking, sanitation and hygiene is a basic human necessity and a major determinant of food security. A lack of access to clean water is a key underlying cause of malnutrition. Water-related diseases undermine productivity, reinforcing deep inequalities and trapping vulnerable households in cycles of poverty. Insufficient access to basic drinking water on the premises (e.g. in the home) is more pronounced in rural than in urban areas, and entails considerable use of time in terms of accessing drinking water off the premises, often time spent by women.

WHAT INNOVATION AND INVESTMENTS ARE NEEDED FOR SUSTAINABLE AND PRODUCTIVE WATER USE?

Improved water management strategies – where combined with agronomic practices, such as improved varieties – will be a crucial component to reduce water risks and attain potential yields in agriculture for improved food security and nutrition. These strategies are expected to help deal with climate change, although considerable uncertainty about the impacts and the effectiveness of adaptations remains. Farmers' incentives to adopt water management strategies and to change their water use and management behaviour will depend on the level of water accessibility, the magnitude of water shortages and scarcity, and the level of uncertainty under a changing climate, as well as on the availability and cost of other inputs, including labour and energy.

Water management includes a range of options – from entirely rainfed to fully irrigated conditions, to supporting livestock, forestry and fisheries, to interacting with important ecosystems – and not all water risks can be addressed by farmers alone. Some may require public-sector intervention, for example, in the form of investments, information and support to farmers to overcome constraints to adoption.

Unlocking the potential of rainfed agriculture calls for improved water management

Rainfed production dominates agriculture, covering about 80 percent of total cropland. Farmers, particularly small-scale farmers, have limited influence on the amount and timing of water made available to plants. The inherent challenges are to manage and adapt to weather variability, and to use water from rainfall more productively. Farmers engaging in high-input rainfed production are more likely to have the capacity to invest in improved water management than are farmers in low-input rainfed settings.

There are two broad strategies for increasing yields in rainfed agriculture: (i) collecting or harvesting more water, and infiltrating it into the root-zone; and (ii) conserving water by increasing plant uptake capacity and/or reducing root-zone evaporation and drainage losses. Combining both strategies can be highly effective. According to one study, these practices could boost rainfed kilocalorie production by up to 24 percent and, if combined with irrigation expansion, by more than 40 percent. Almost 20 percent of global cropland is suitable for water harvesting and conservation strategies, with hotspots in large parts of Eastern Africa and South-eastern Asia.

Investing in irrigation for improved water productivity will be key to addressing scarcities

Making more productive use of irrigation water can help produce more crops with less water. This can be achieved through increasing crop yields and/or reducing evapotranspiration. Significant differences in water productivity (output per unit of water consumed) across countries are explained by farmers' access to modern agricultural inputs, efficient irrigation systems, and better soil and water management. Despite improvements in water productivity in recent years, yield gaps remain. Closing or reducing these gaps can significantly contribute to improved food security and nutrition, and livelihoods, and reduce vulnerability to climate variability.

However, doing so will require investment in new irrigation systems or the rehabilitation and modernization of existing ones. The most appropriate system will depend on a range of factors, including climatic conditions, sources and prices of energy, labour availability, depth of groundwater sources and infrastructure costs. In sub-Saharan Africa, for example, many small-scale farmers are developing their own small-scale irrigated equipment – including buckets, watering cans and treadle pumps – which tend to have lower unit costs and better performance relative to those managed by government agencies. There is considerable potential to expand profitable small-scale irrigation in the region, with area expansion potential of up to 30 million hectares for motor pumps, benefiting millions of rural people. One study has projected a doubling of irrigated areas between 2010 and 2050 in sub-Saharan Africa. However, to actually save water, irrigation modernization must be preceded by policy instruments such as water allocation to maintain or reduce basin-wide water use after the introduction of new technologies.

Improving water productivity in animal production can ease pressure on water resources

The water productivity – in physical and nutritional terms – of animal products is commonly lower than that of crop products, and highly dependent on the type of animal product and production systems. For example, livestock may rely on rainfed pastureland for feed – often with no alternative productive use of water – or on irrigated cropland. In mixed production systems, livestock may even consume crop residues. Given the above conditions, various options exist for improving the sector's water productivity. They include proper control of grazing, improved animal health, and changes to diets and drinking systems.

Another area for improvement in productivity is that of integrated fish–irrigation systems, whose potential has yet to be fully realized. Irrigation and fisheries are interlinked. Irrigation can change physical aquatic habitats and nutrient contents, with effects on fisheries resources. In most cases, the intensification of crop production through irrigation has coincided with the decline of fisheries production. However, irrigation can also create new opportunities for fish production. For example, in an irrigated area in Bangladesh, rice farmers replaced one of three annual cycles of rice production with the production of fingerling fish, with benefits in terms of reduced pest problems and increased profits. However, the extent to which fish production can be integrated into irrigation systems will depend to a large extent on national and regional policies and governance structures.

Agricultural water management goes beyond the farm level and requires innovative approaches

Agricultural production systems are major drivers of a range of environmental impacts, both desirable and undesirable. For example, decentralized water management approaches, such as some water harvesting schemes, can negatively affect water balances in catchments and river basins and, consequently, riverine fisheries. However, agricultural water management strategies can bring beneficial environmental impacts. For example, reducing or interrupting periods of flooding can substantially reduce rice-related emissions, as shorter flooding intervals and more frequent interruptions lower bacterial methane production and, thus, methane emissions. Nature-based solutions – which use natural processes to improve water management and conserve or rehabilitate natural ecosystems and processes – are another case in point. However, their adoption requires a landscape approach and paradigm shift where forests, peatlands and other ecosystems are viewed and managed as regulators of freshwater at different scales. Water management practices, such as vegetation strips and aquaculture–crop integrated systems, can further help retain excess nutrients and reduce pollution. The benefits of nature-based solutions can offset the opportunity costs of setting aside land for conservation that might otherwise be used to produce crops or be developed.

In situations where water supply is severely constrained, innovation in non-conventional sources of water – such as treated wastewater and desalinated water – is gaining momentum in some countries and regions. The generation of wastewater is predicted to increase considerably. Definitive numbers are not available, but it has been estimated that 10 percent of global irrigated area receives untreated or partially treated wastewater. When treated according to the needs of end users, wastewater has proved to be a realistic option for non-conventional sources of water. However, the feasibility of water reuse in agriculture will depend on local circumstances. Desalination represents another attractive option for increasing water supplies. Globally, there are about 16 000 desalination plants, producing about 100 million m^3/day. The cost of desalination has always been the main obstacle limiting its application in agriculture. However, thanks to rising demand and technological advances, costs have fallen dramatically and will continue to do so, making this technique more feasible for agricultural activities, particularly for the production of high-value crops. On average, it is estimated that large-scale desalination plants can produce water at a cost in the range of USD 0.5–2.0/m^3, depending on plant size. Benefit–costs estimate of desalination plants are very context-dependent; however, several countries, such as Australia, China, Mexico, Morocco and Spain, are already profitably using desalinated water for agriculture.

IF EFFECTIVE SOLUTIONS ARE WITHIN REACH, WHY ARE THEY NOT BEING ADOPTED?

Innovations in water management are widely influenced by the overall institutional and legal framework – encompassing water rights, licensing, regulations, incentive measures and the institutional set-up. They are also driven by the overall policy environment, which includes societal choices, priorities, sectoral policies and trade-offs. The different roles, attitudes and responsibilities of stakeholders involved in water policy and management are dispersed across sectors, locations and jurisdictions, but they all need to be clearly understood. One concern is that of affordability and ensuring the human right of access to water. Another is that of ensuring environmental flows, ecosystems services and non-consumptive use of freshwater resources, e.g. for inland fisheries.

Hence, good water governance is critical and calls for adaptive management at the catchment level to address the needs of all water users. In turn, this requires complex collaboration across several stakeholders, locations and entities. Improved coordination is needed both vertically from sectoral, river-basin and irrigation systems down to households, and horizontally across sectors, including agriculture, industries, municipalities and households. In this respect, water users associations that bring farmers together (particularly small-scale farmers) for the purpose of managing a shared irrigation system, can play a role in both planning and implementation. They can pool resources for operating and maintaining irrigation systems and river and water basins. A key challenge is to safeguard the interests of groups with less power and influence but reliant on ecosystems services (e.g. fisherfolk) and to ensure that they are included.

Transparent water accounting and auditing, and clear water tenure are key building blocks

Effective water management strategies must be based on a better understanding of how much water there is, how it is used and whether current patterns are sustainable. Water accounting – the systematic study of the current status and trends in water supply, demand, accessibility and use – will be key to achieving this. However, water accounting will only make a difference if it forms part of a broader process of improving governance. Combining water accounting with water auditing – the process that places the findings of water accounting into the broader societal context of water resources – can provide the basis for more realistic, sustainable, effective and equitable water management.

The overall cost of water accounting and auditing programmes varies enormously with, for example, the scale and ambition of the programme, the cost of contracting an implementation team, and the need to collect primary and secondary information. Advances in remote sensing and metering technologies, as well as a number of open-access global and regional databases, reduce costs and make it easier to share information. A recent FAO sourcebook provides a good starting point for all those wishing to implement water accounting and auditing.

Water tenure – the relationship, whether legally or customarily defined, between people, as individuals or groups, with respect to water resources – can be a strong building block for efficient water use and equitable and sustainable access to water when based on sound water accounting and an equitable allocation system. The development of community organizations to manage water allocations can also contribute to the effective establishment of water rights. Well-defined water rights can empower users and increase the economic value of water, while providing farmers with the incentive to invest in water-use-efficient or income-enhancing technologies and to reduce resource degradation. Despite the importance of water tenure systems, and although they can be found in virtually any setting where water is scarce, in most cases these systems are not formally recognized and enforced, and water tenure may not be respected. Improving irrigation technology for conveyance, diversion and metering can improve compliance through better monitoring.

Water markets and water pricing can ensure productive use of water, but equitable implementation is challenging

In areas where freshwater allocations are already in place, it may be possible to introduce market instruments that allow producers to transfer their current entitlements among themselves. Water market mechanisms can be an effective way of allocating water because they are economically efficient, transactions are voluntary and the system is responsive in that it encourages water users to direct water to its most productive use. For example, groundwater markets are an attractive option for improving farmers' access to groundwater irrigation if implemented with caps on overall water withdrawal in an aquifer. Negative aspects include the possibility of monopoly power by water sellers in some locations. In this respect, from the standpoint of equity, water markets are only as good as the initial allocation system on which they are based. Of particular relevance is the incentive that markets can create for some stakeholders to disenfranchise more vulnerable water rights holders to appropriate the rent from water as a resource, creating a conflict with the concept of water as a basic necessity and as a human right. To this day, there are very few actual functioning water markets with sufficiently long experience.

Independently of whether water rights are traded, when water prices reflect its true economic value, there is an incentive to put water to its best economic use. Water pricing can also help avoid excessive use, depletion and quality degradation of water resources. Indeed, water pricing is increasingly seen as not just a cost recovery mechanism and a means for ensuring economic efficiency, but also as a tool to address social and environmental dimensions. Social dimensions that need to be considered for an equitable implementation of a pricing scheme include the impact of water pricing on lower-income groups.

Raising water prices should occur over several years in order to give farmers time to adapt, with integrated management involving communities to make sure no one is left behind. Encouraging payment for water management and services also requires consistent quality of water services and a clear explanation of how revenue is used to benefit users, in addition to regulations and sanctions.

Lack of focus on governance issues in rainfed areas has led to missed opportunities

To date, policy and governance on water resources management for agriculture has remained focused on irrigation. This has resulted in limited investment and innovation in governance, policy, institutions, practices and technologies to support small-scale farmers in rainfed areas – including pasturelands – and non-consumptive uses of water, such as inland fisheries. Water-resource planning needs to promote investment options across the continuum from rainfed to irrigated agriculture and include water management in rainfed areas with impacts at the catchment and river-basin scale. As in irrigation systems, attention to land tenure, water ownership and market access is also needed, together with community-based watershed management approaches for addressing water shortages and land degradation, which cannot be tackled at the farm level alone. These approaches need to extend to forest conservation and restoration at the watershed level. Finally, improved water management in rainfed agriculture also requires public support by investing in infrastructure and access to roads to link farmers to markets, and by subsidizing water capturing and conserving technologies to help attenuate the effects of drought while at the same time contributing to overall agricultural development.

A range of other institutional and governance strategies can improve water management of livestock, which are an essential asset to pastoralists and other communities. Involvement of community representatives and local institutions can help ensure effective design of interventions. Similarly, customary or indigenous institutions can play a key role in emergency interventions and in the management of natural resources, including of grazing land and water resources. In some countries, national guidelines for livestock-based interventions in emergencies, such as drought events, already exist and can provide rapid assistance to protect and rebuild the livestock assets of crisis-affected communities. Finally, the identifying and mapping of water sources and the use of early warning systems in drought-prone areas are an important step forward. In Kenya, for example, the extreme drought in 2000 led to the loss of up to 50 percent of the cattle in certain districts, and relief agencies remained helpless owing to a lack of information to guide them at short notice.

Strengthening policy coherence is a must, both across sectors and within agriculture

The behaviour of different actors is affected by policy choices in different sectors that often remain disconnected. Ensuring policy coherence across sectors and policy domains is the first condition for improving the management of water resources. This calls for coordination across the various policies, items of legislation, and fiscal measures that affect water management and water supply and demand, including energy prices, trade agreements, agricultural subsidy regimes and poverty reduction strategies. There is also a need to integrate decision-making by different entities on water resources and related policies – including on irrigation, and on industrial and municipal use of water.

Providing proper incentives is a crucial component of policy coherence. Subsidies are a case in point, as governments often provide large subsidies for private goods, such as energy, fertilizer and credit, which can incentivize excessive and unproductive use of water resources and lead to water pollution.

Greater policy coherence across agricultural subsectors is a further necessity. Often, the impact of policies is uneven across agricultural subsectors, with a tendency to favour irrigated farming to the detriment of rainfed farming or inland fisheries. While the expansion of irrigation has improved food security and nutrition in low-income countries, it has also contributed to the loss of inland fisheries, excessive groundwater withdrawals, and changes in surface water flows and ecosystems. However, there are opportunities to obtain greater synergies for improved productivity and nutritional benefits from irrigated agriculture, while ensuring water connectivity, flows and habitat preservation. Examples include aquaculture–irrigation integrated systems, forest conservation and upstream management. Innovations that improve rainfed agriculture productivity may also reduce the need for irrigation.

Reform is needed for greater policy coherence

Strengthening policy coherence and improving water management will require, first and foremost, the aligning of incentives. In this regard, general subsidies should be replaced by targeted ones to spur adoption of new irrigation technology and the provision of environmental services, such as fish-friendly irrigation structures that mitigate the impacts of irrigation development and dam construction. Payments for environmental services – payments to farmers or landowners who agree to manage their land or watersheds for environmental protection – can also help ensure the proper valuation of well-functioning ecosystems.

A more integrated approach based on water accounting and auditing that takes into consideration all the different water users is also needed. Examples include irrigation scheme management that maintains food production levels while providing other environmental and ecosystem services.

Finally, policy coherence calls for strong mechanisms and processes to manage and coordinate policy, budgeting and regulatory development. Specific steps include capacity strengthening for public institutions; coordination across ministries (water, agriculture and energy); improved planning and monitoring tools; and upgraded and integrated databases. Improving the design of irrigation investments to include gender, health and nutrition outcomes could also transform irrigation programmes to make them an integral part of strategies to reduce poverty, hunger and malnutrition. ■

VIET NAM
A worker watering seedlings at an acacia tree nursery.
©FAO/Joan Manuel Baliellas

CHAPTER 1 SETTING THE SCENE: PEOPLE, WATER AND AGRICULTURE

Key messages

➔ Increasing water scarcity and water quality issues threaten food systems worldwide, with the annual amount of available freshwater per person declining by more than 20 percent in the last two decades – a serious constraint for Northern Africa, and Western and Southern Asia that requires urgent attention.

➔ Agriculture must adapt to the complex challenges of rising populations, economic growth, changing consumer preferences and competition for water. Healthy diets that include sustainability considerations at the food systems level can reduce the associated water consumption.

➔ Challenges in access to water and increasing pollution are evident all along the food supply chain – including food processing – affecting food security, nutrition, health and ecosystem services, and posing major risks to vulnerable populations.

➔ Around 41 percent of current global irrigation occurs at the expense of environmental flow requirements. Reconciling irrigation with environmental flows – essential to sustain ecosystems that provide life-supporting functions – will be pivotal for attaining the 2030 Agenda.

➔ Insufficient and unreliable access to water impedes the livelihoods of many millions of small-scale farmers, fishers and herders, requiring countries to adopt equitable and inclusive sustainable water management.

➔ In least developed countries, 74 percent of rural people do not have access to safe drinking water, adversely affecting women who spend a great part of each day drawing water and exposing the rural poor to waterborne diseases and malnutrition.

CHAPTER 1

SETTING THE SCENE: PEOPLE, WATER AND AGRICULTURE

THE WATER CHALLENGES FOR SUSTAINABILITY – A GROWING SENSE OF URGENCY

Water resources and the way they are managed are central to improving livelihoods and to sustainable development. The challenge of meeting greater human needs for water from finite freshwater is a growing concern, along with threats from climate change, such as uncertain rainfall and water availability, affecting rainfed and irrigated agriculture. The implications for food security and nutrition are severe, through the impact on food systems, from agricultural production – including rainfed and irrigated crop production, livestock, inland fisheries and aquaculture – through food processing to households and consumers.

This report addresses two main water challenges affecting agriculture and food production: scarcity and shortages. Water scarcity refers to a physical lack of freshwater, which can seriously affect production and productivity in irrigated agriculture. Water scarcity is not just about inadequate freshwater but also inadequate infrastructure and institutional capacity to ensure equitable access to water services, such as drinking water and irrigation. Shortages through inadequate rainfall – in volume and timing – limit crop production in rainfed agriculture and livestock production on pastureland. Other water risks include natural hazards, such as flooding, where the problem is excess water (see Glossary for definitions of terms related to water).

While freshwater resources are finite, demand for water to meet basic human needs for food, drinking water and sanitation continues to grow. This includes water for irrigated agriculture, but also for broader food systems, including food processing. These needs cover domestic drinking water, and water for sanitation and hygiene (WASH). Sustainable management of water resources must reconcile these with the need to maintain aquatic ecosystem goods and services, which in turn depend on groundwater and river flow. Preserving water resources and using them sustainably is not just a question of volume; water quality is also a major and growing problem.

Rainfed agriculture is facing greater challenges from inadequate rainfall. The impacts can take several forms, including droughts, floods, and extreme rainfall and weather events. Precipitation anomalies on grazing lands are also a threat to livestock production.

The dual challenge of growing freshwater demand leading to increasing water scarcity, and the risk of drought or inadequate rainfall on rainfed areas leading to water shortages, is the focus of this report. The last time *The State of Food and Agriculture* addressed water issues in a comprehensive way was in 1993 (Box 1). What is striking, more than 25 years later, is the extent to which the contents of that edition are valid and relevant today. The challenges of managing water resources still remain, suggesting that they have not yet been sufficiently addressed. However, if the 1993 edition emphasized the consensus that "the growing water scarcity and misuse of freshwater pose serious threats to sustainable development", there is even greater urgency today to address the problem. While the 1993 edition focused on the challenges of limited supplies and competing demands for freshwater in irrigated agriculture, the 2020 edition broadens the scope to cover water-related challenges in rainfed agriculture, including pastoral systems. It takes into account forestry, inland fisheries

BOX 1
THE STATE OF FOOD AND AGRICULTURE 1993 – WATER POLICIES AND AGRICULTURE

In the 1993 edition of *The State of Food and Agriculture*, Part III, Water Policies and Agriculture, presented issues and analysis that are highly relevant today. This may suggest that the 1993 edition was very forward-looking, but also that many of the issues identified then are still without solutions today.

The State of Food and Agriculture 1993 took as its starting point the recognition of water as an increasingly scarce and valuable resource, emphasizing that growing water scarcity and misuse of freshwater pose serious threats to sustainable development. It also looked at water quality and the implications for human health. The key reasons for scarcity were identified as population growth, misuse of water and inequitable access. It also drew attention to the possible impacts of climate change and global warming on the hydrological cycle, although scientific understanding at that time was still far from drawing clear conclusions.

The key focus of the 1993 edition was on water use in agriculture, with an emphasis on irrigated agriculture and policies and institutions. It recognized that, as the largest water user, agriculture was facing increasing competition from other sectors. It argued that agriculture had to meet the challenge of producing more food with less water in a sustainable way to ensure future global food security. In particular, the report attached importance to demand-side management to ensure greater water-use efficiency and allocation in irrigated agriculture, as opposed to the more traditional supply-side approach, aimed at expanding irrigated agriculture. However, in 1993, in considerations of managing and expanding supply, desalination and the reuse of wastewater and drainage water had not yet gained their current prominence as reliable alternative water sources.

SOURCE: FAO. 1993.[1]

and aquaculture, and recognizes the importance of restoring and maintaining environmental flows and ensuring environmental services of water-related ecosystems.

Many of the challenges related to water resources feature prominently in the 2030 Agenda for Sustainable Development (2030 Agenda). Water is closely linked to several of the Sustainable Development Goals (SDGs) and a critical determinant of their success. Sustainable Development Goal 6 (Ensure availability and sustainable management of water and sanitation for all) covers all the key dimensions of water availability and management, including equitable access to drinking water, improved quality, increased water-use efficiency, integrated water resources management and protection of water-related ecosystems. Achieving SDG 6 is expected to generate several other economic, environmental and social benefits, and thus also contribute to other SDGs, not least SDG 2 (End hunger, achieve food security and improved nutrition and promote sustainable agriculture). Progress towards SDG 2 depends critically on achieving SDG 6, given that food and agricultural productivity are highly dependent on water and ecosystems to deliver services that, in turn, depend on maintaining environmental flows. Ending hunger and malnutrition also demands access to safe drinking water (SDG Target 6.1) as well as equitable sanitation and hygiene (SDG Target 6.2). Productive agricultural systems (SDG Target 2.3) require adequate availability (SDG Targets 6.4 and 6.6) and good-quality (SDG Target 6.3) water resources. Improved water management could have wide »

FIGURE 1
WATER AND RELEVANT TARGETS OF THE SUSTAINABLE DEVELOPMENT GOALS (SDGs)

SDG	Affected by SDG 6	Affects SDG 6
1 NO POVERTY	1.1 Eradicate extreme poverty 1.2 Reduce by half the proportion of those in poverty 1.4 Ensure equitable rights, access and control over resources 1.5 Build resilience to extreme climate events and other shocks	
2 ZERO HUNGER	2.1 Ensure access to food 2.2 End malnutrition 2.3 Double productivity and incomes of small-scale farmers	2.3 Double productivity and incomes of small-scale farmers 2.4 Ensure sustainable food production
3 GOOD HEALTH AND WELL-BEING	3.3 Combat waterborne diseases 3.9 Reduce deaths and illnesses from water and soil pollution and contamination	
5 GENDER EQUALITY	5.1 End discrimination	
7 AFFORDABLE AND CLEAN ENERGY	7.2 Increase renewable energy	7.3 Improve energy efficiency
8 DECENT WORK AND ECONOMIC GROWTH	8.1 Promote sustainable economic growth	8.4 Improve resource efficiency
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE		9.4 Increase resource-use efficiency
10 REDUCED INEQUALITIES	10.1 Achieve sustainable income growth 10.2 Promote social, economic and political inclusion	
11 SUSTAINABLE CITIES AND COMMUNITIES	11.1 Provide adequate, safe and affordable housing and basic services	11.6 Reduce the adverse environmental impact of cities
12 RESPONSIBLE CONSUMPTION AND PRODUCTION		12.2 Achieve sustainable and efficient use of natural resources 12.3 Reduce food loss and waste 12.4 Reduce release of chemicals and wastes to air, water, and soil
13 CLIMATE ACTION	13.1 Strengthen resilience and adaptive capacity	13.2 Integrate climate change into policies
14 LIFE BELOW WATER	14.1 Reduce marine pollution 14.2 Manage and protect marine and coastal ecosystems 14.3 Minimize and address ocean acidification 14.5 Conserve coastal and marine areas	14.1 Reduce marine pollution 14.2 Manage and protect marine and coastal ecosystems 14.5 Conserve coastal and marine areas
15 LIFE ON LAND	15.1 Conserve, restore and sustainably use terrestrial and inland freshwater ecosystems 15.3 Combat desertification and restore degraded land and soil	15.1 Conserve, restore and sustainably use terrestrial and inland freshwater ecosystems

SOURCE: FAO.

» implications for various SDGs, while progress towards other SDGs could help achieve SDG 6. Figure 1 summarizes the potential linkages between SDG 6 and other SDGs. The column on the left refers to those expected to be mainly affected by SDG 6, while the column on the right describes which SDGs are most likely to have an impact on SDG 6. ■

HUMAN PRESSURES AND WATER AVAILABILITY – AN UNBALANCED EQUATION

Water resources are under increasing stress and degradation owing to population pressure and unsustainable consumption and production. Climate change exacerbates these factors and is expected to alter rainfall patterns, hydrological regimes and the availability of freshwater. Water scarcity and shortages are closely related to the hydrological cycle (Box 2). They derive from the growing mismatch between human demand for water and finite resources from the hydrological cycle in the form of renewable freshwater and rainwater failing to enter freshwater systems. They are increasingly a limiting factor for agriculture across small-, medium- and large-scale production systems. Scarcity and shortages also limit environmental services and ecosystem functions, essential to sustain water-related systems and human livelihoods; hence, the environment can no longer be considered a residual water user.

Population growth is a key driver of scarce freshwater resources as rising population drives increased demand for water for different human uses. Human pressures on water also increase as per capita incomes grow and societies become increasingly urban, leading to dietary changes and greater water demand from households, industry, energy and services. These trends also imply increasing challenges for rainfed agriculture, called on to meet greater demand for food resulting from continuous population growth and rising incomes. Climate change exacerbates the challenges associated with these drivers, which may jeopardize rainfall patterns and increase the risk of extreme weather events.[3] Extreme weather events and fluctuations in water availability can also trigger food price volatility, which can further exacerbate food insecurity and malnutrition. Small Island Developing States (SIDS) are vulnerable to climate-stressed groundwater resources, which affect both food prices and reliance on food imports.[4, 5] When it comes to water scarcity, population growth outweighs the impacts of climate change.[6, 7]

The challenge of feeding an increasing world population and meeting the demand for water has never been greater. The United Nations projects that world population will be 9.7 billion in 2050, compared with about 7.8 billion people in 2020.[8] As populations continue to grow, available freshwater resources per person decline, as illustrated by the historical trend shown in Figure 2. This is especially true for sub-Saharan Africa and Northern Africa and Western Asia, where annual total renewable water resources per capita declined by 41 percent and 32 percent, respectively, between 1997 and 2017. The figure also reveals starkly diverging quantities across regions. In Oceania, the average annual volume of water per person in 2017 was about 43 000 m^3, while in Northern Africa and Western Asia this value barely reaches an annual supply of 1 000 m^3. To some hydrologists, this latter value is the level below which there is water scarcity.[9, 10] According to Falkenmark and Widstrand (1992),[9] a country's ability to satisfy demand is compromised when annual water supplies per person drop below 1 700 m^3.[a] Below 1 000 m^3 per person, the population faces chronic water scarcity, and below 500 m^3 extreme water scarcity.

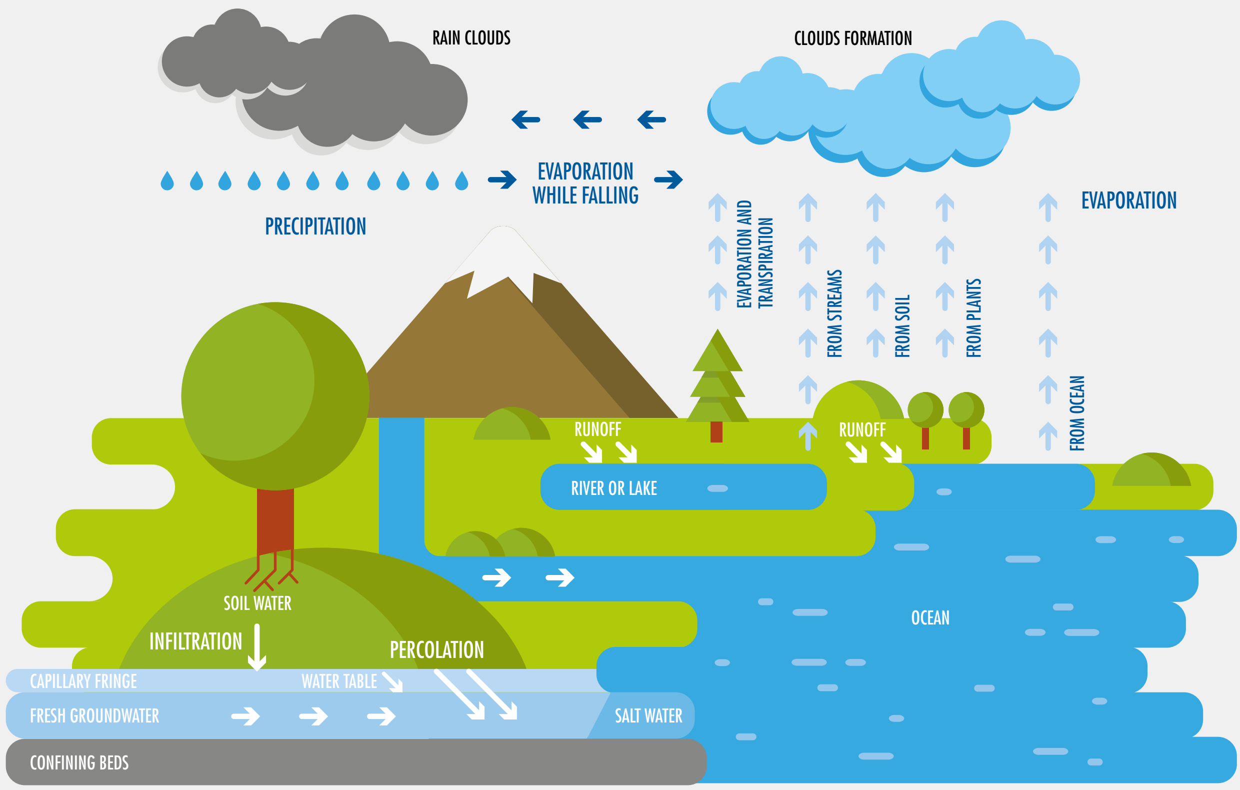
Looking at the average amount of water per person can indicate freshwater availability, but it can oversimplify the situation in specific countries. Averages at the regional and even country level may not be meaningful in large countries with major regional differences. In many countries, scarcity is not an issue at the national level, but there may be serious water shortages in specific areas and watersheds.

a This value was originally set at 600 people per flow unit, where a flow unit is equal to 1 million m^3 per year.[9] The annual value of 1 700 m^3 per person is obtained by dividing one flow unit by the number of people competing for this water.

BOX 2
THE HYDROLOGICAL CYCLE AND AGRICULTURE

Water is a renewable resource, circulating on the planet in a continuous state of flux. The hydrological cycle diverts water from the oceans through the atmosphere and back to the oceans overland and underground (see figure). The mass of water in the hydrological cycle is essentially constant; water is not created or destroyed in any of the natural hydrological processes, with minor increases in annual global availability in response to higher temperatures under climate change.

THE HYDROLOGICAL CYCLE



SOURCE: FAO. 1993, Box 8.[1]

Brazil is a case in point. On average, it is estimated that, for every Brazilian, there are almost 42 000 m³ of renewable freshwater annually.[8, 11] While parts of the country where most economic activity occurs (including irrigation) may suffer high water stress and usage, the Amazon Basin contains a large volume of water, but very little is used by people. Therefore, annual water supply per capita ignores local factors determining water access and the fact that different countries and regions use different amounts of water.

Growing competition for water resources

Population growth trends are expected to increase pressure on water resources for agriculture and other uses, including industrial and domestic. Figure 3 depicts total water withdrawals. These have kept pace

BOX 2
(CONTINUED)

Freshwater refers to water on the earth's surface in glaciers, lakes and rivers (surface water), and underground in aquifers (groundwater). Available freshwater is rare; 99 percent of water is either saline (97 percent of all water being in the oceans) or frozen (2 percent in ice caps and glaciers). Most of the remainder (1 percent) is groundwater with minute proportions in freshwater lakes, soil moisture, rivers and biological systems.

Rainfed agriculture relies on precipitation water that does not run over the surface in the form of streams (and subsequently rivers and lakes) or soak down to enter groundwater reservoirs or aquifers. Irrigated agriculture relies on drawing freshwater from surface water or groundwater sources in competition with other sectors and human activities.

Certain aspects of the hydrological cycle are critical:

- There is essentially one water resource, and only a systemic approach to water can ensure its proper management. Interlinkages between surface water, groundwater and soil moisture content are critical. Groundwater and surface water are part of the same resource and cannot be regarded as alternative sources. Promoting efficient water use in a specific domain without understanding the impact on systemic water balances may lead to unexpected or undesired results. For example, groundwater capture and recharge in alluvial plains can reduce flows in rivers.
- Water should be managed at the level of hydrological systems: basins, catchments and aquifers. Water management in one part of a system will have impacts on others. Intensifying agricultural water use upstream in a river basin can affect surface water and groundwater downstream.
- There are limits to the cleansing and dilution of pollutants in aquatic ecosystems. In the past, when disposing of effluent, many towns and cities relied on the self-cleansing and dilution potential of rivers and coastal waters. However, this was possible only where population density and related industries were minimal. In many places, these diluting functions have reached their limits, and such practices must now be carefully regulated.
- Water-related ecosystems, which deliver many environmental services, depend on the maintaining of groundwater levels and flow regimes in river systems. It is essential to recognize environmental flow requirements (see Glossary).

SOURCES: FAO. 1993,[1] and FAO. 2012.[2]

with population and economic growth, rising dramatically over time, particularly since the middle of the twentieth century. While the pace of growth has slowed in recent decades, the rise continues. Agriculture is still by far the largest water user, accounting for more than 70 percent of global withdrawals of water, which are continuing to increase. Agriculture has faced greater competition from other sectors, as industrial and municipal withdrawals have grown more rapidly, particularly since the middle of the twentieth century. In the past decade or two, industrial withdrawals have declined, while municipal withdrawals have increased only marginally since 2010. Agricultural withdrawals have continued to grow at a faster pace, although more slowly since 1980, and the share of agricultural withdrawals has increased slightly since 2000.

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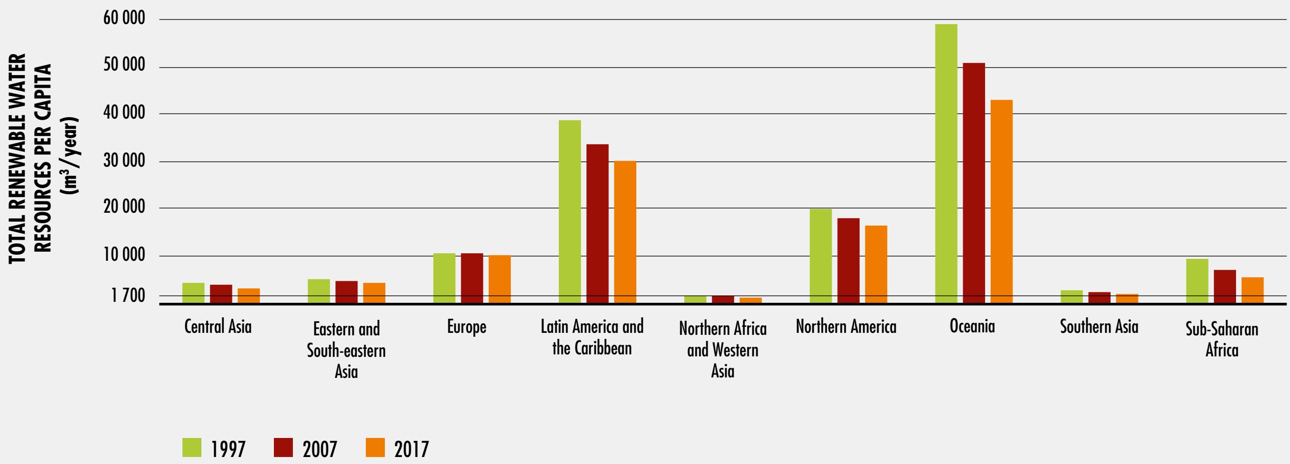
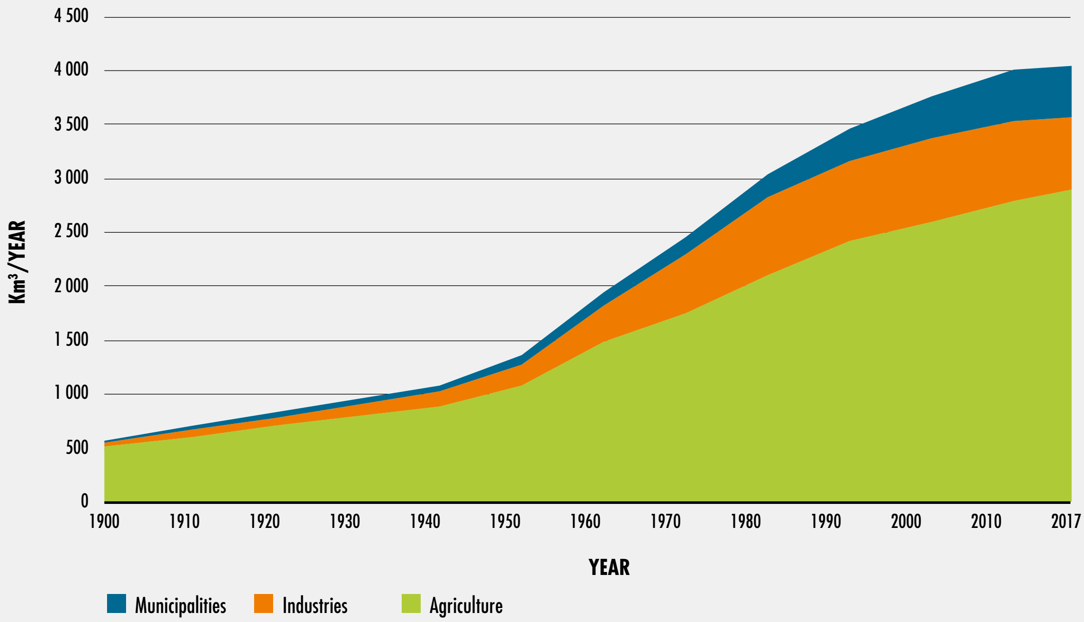
FIGURE 2
PER CAPITA RENEWABLE FRESHWATER RESOURCES BY REGION, 1997–2017



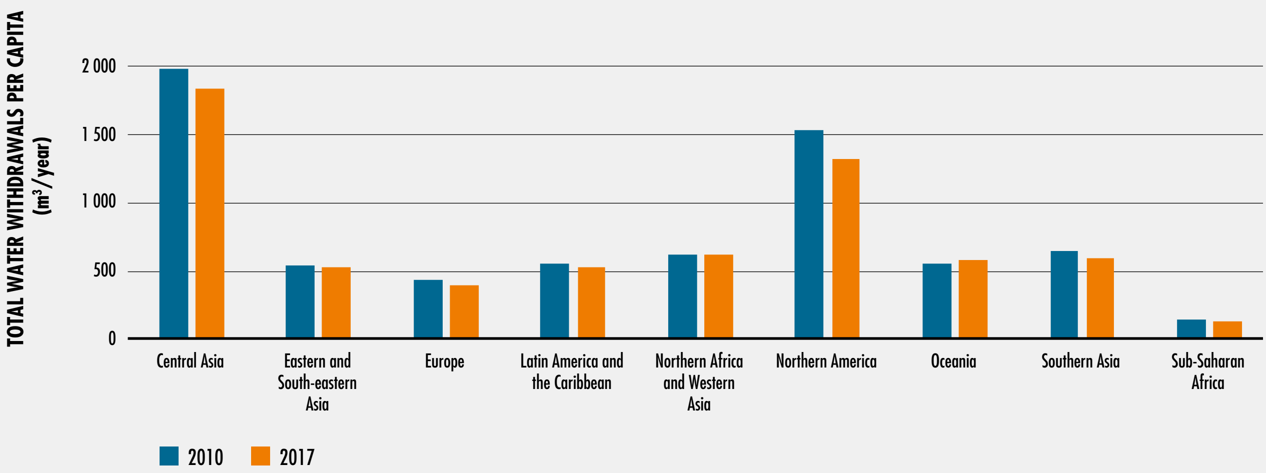
NOTES: Average renewable freshwater resources per person are measured in cubic metres per person per year. Population data refer to the World Population Prospects: The 2019 Revision from the United Nations Department of Economic and Social Affairs (UN DESA). Oceania includes Australia and New Zealand.
SOURCE: FAO elaboration based on FAO. 2020[11] and UN DESA. 2019.[8]

FIGURE 3
GLOBAL SECTORAL WATER WITHDRAWALS



NOTE: Agricultural water withdrawal refers to the annual quantity of self-supplied water for irrigation, livestock and aquaculture; industrial withdrawal is the annual quantity of self-supplied water for industrial uses, such as cooling thermoelectric and nuclear power plants (but excluding hydropower); and municipal withdrawal is water withdrawn for the direct use of the population.
SOURCE: FAO elaboration based on FAO. 2020[11] and Shiklomanov. 2000, Table 5.[12]

FIGURE 4
TOTAL WATER WITHDRAWALS PER CAPITA BY REGION, 2010 AND 2017



NOTES: Total water withdrawal refers to the annual quantity of water withdrawn for agricultural, industrial and municipal purposes. Population data refer to the World Population Prospects: The 2019 Revision from UN DESA. Oceania includes Australia and New Zealand.
SOURCE: FAO elaboration based on FAO. 2020[11] and UN DESA. 2019.[8]

» Figure 4 combines total water withdrawals and population in 2010 and 2017. In the past decade, depending on the region, per capita water withdrawals have been stable or slightly decreasing – a result of population increasing faster than water withdrawals, or at the same pace. Considerable regional differences exist, with Central Asia having the largest water withdrawals per capita, reaching almost 2 000 m^3 per person in 2017. This is followed by Northern America, where the average person withdrew more than 1 300 m^3 of freshwater in 2017. In sub-Saharan Africa, this value barely reaches 130 m^3 per person, in large part owing to economic constraints to accessing freshwater. Water withdrawal ratios also vary significantly by income level (Box 3).

Figure 4 captures water withdrawals across regions but cannot take account of local water access and competition between sectors. Rising demand from agriculture and other sectors is leading to competition for scarce freshwater, increasing the risk of conflict among local farmers and other water users up to the international level in the form of transborder conflicts. Competition and disputes over land and water exist in countries with acute scarcity and limited access to water. In the Sahel pastoralist region, overgrazing and severe pasture degradation led to limited or no fodder production in 2018. As a result, pastoralist households embarked on migration two months early, leading to higher concentrations in certain areas and conflict between farmers and herders.[13]

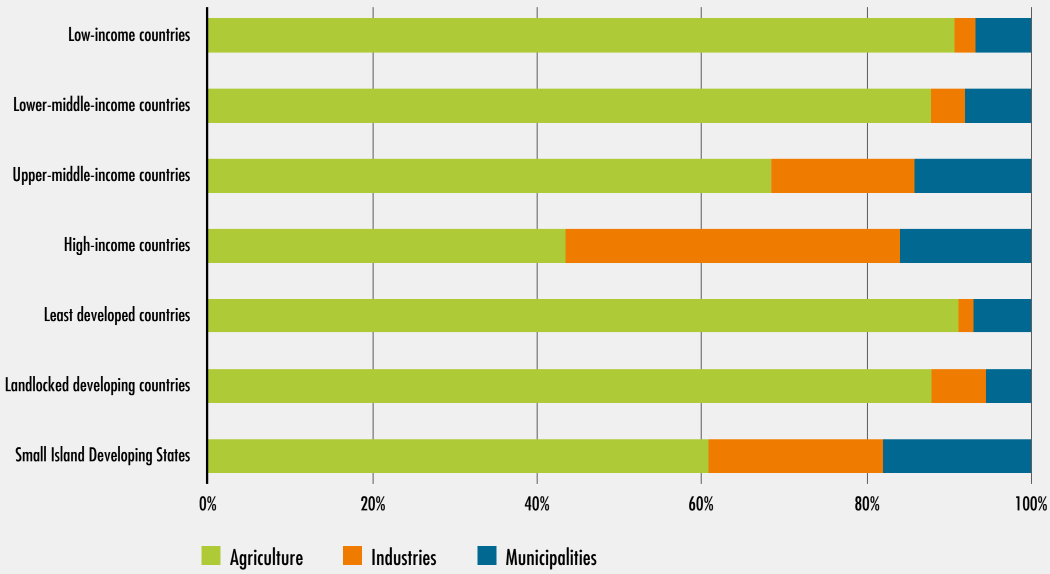
Landlocked developing countries and least developed countries are particularly affected by potential international conflicts. They often share cross-border water resources, e.g. Lake Chad, Lake Victoria and the Nile River, with competition over water, such as for irrigation, along with the impact of pollution.[14] These countries also rely heavily on inland fisheries as providers of animal protein, nutrients and vitamins.[15] Less-formal sectors such as fisheries are frequently forgotten, partly because it is difficult to demonstrate their true economic value and their ability to compete with economically powerful stakeholders such as energy and irrigation.[16] Competition among sectors also manifests itself along the Nile River,

BOX 3
COMPETING DEMANDS FOR WATER ARE DETERMINED BY COUNTRY INCOME LEVEL

One feature of the growing demand for water is increased competition among all users. Looking at water withdrawal ratios by income group and country classification can provide a general picture of the extent of this competition. The figure below shows the breakdown of sectoral water withdrawals by income level, whose ratios can vary significantly. They range from 91 percent, 2 percent and 7 percent for agricultural, industrial and municipal water, respectively, in low-income countries to 43 percent, 41 percent and 16 percent, respectively, in high-income countries. As populations and incomes expand, and the impacts of climate change are increasingly felt, competition for water is expected to intensify,[18, 19] especially in low-income and lower-middle-income countries.

In least developed countries and landlocked developing countries, agriculture also represents around 90 percent of total water withdrawals. In SIDS, the share of agricultural withdrawals is lower, accounting for about 60 percent of total withdrawals.

SECTORAL WATER WITHDRAWALS BY INCOME AND COUNTRY CLASSIFICATION, 2017



NOTE: Agricultural water withdrawal refers to the annual quantity of self-supplied water withdrawn for irrigation, livestock and aquaculture; industrial water withdrawal is the annual quantity of self-supplied water for industrial uses, such as cooling thermoelectric and nuclear power plants, but does not include hydropower; and municipal water is water withdrawn for the direct use of the population.
SOURCE: FAO elaboration based on FAO. 2020,[11] United Nations. 1998,[20] and World Bank. 2017.[21]

where Ethiopia is seeking to meet its electricity needs through construction of the Grand Ethiopian Renaissance Dam on the Blue Nile River, but Egypt fears a threat to its main source of irrigation water. International talks among water and irrigation ministers from Egypt, Ethiopia and the Sudan, with observers attending from South Africa, the United States of America and the European Union aim to prevent international conflict.[17]

TABLE 1
THE WATER FOOTPRINT OF SELECTED FOOD PRODUCTS

Food item	Water footprint (m³/tonne)				Nutritional content			Water footprint per unit of nutritional value		
	Green	Blue	Grey	Total	Calorie (kcal/kg)	Protein (g/kg)	Fat (g/kg)	Calorie (litres/kcal)	Protein (litres/g protein)	Fat (litres/g fat)
Sugarcrops	130	52	15	197	285	0	0	0.69	0	0
Vegetables	194	43	85	322	240	12	2	1.34	26	154
Starchy roots	327	16	43	387	827	13	2	0.47	31	226
Fruits	726	147	89	962	460	5	3	2.09	180	348
Cereals	1 232	228	184	1 644	3 208	80	15	0.51	21	112
Oil crops	2 023	220	121	2 364	2 908	146	209	0.81	16	11
Pulses	3 180	141	734	4 055	3 412	215	23	1.19	19	180
Nuts	7 016	1 367	680	9 063	2 500	65	193	3.63	139	47
Milk	863	86	72	1 020	560	33	31	1.82	31	33
Eggs	2 592	244	429	3 265	1 425	111	100	2.29	29	33
Chicken meat	3 545	313	467	4 325	1 440	127	100	3.00	34	43
Butter	4 695	465	393	5 553	7 692	0	872	0.72	0	6
Pig meat	4 907	459	622	5 988	2 786	105	259	2.15	57	23
Sheep/goat meat	8 253	457	53	8 763	2 059	139	163	4.25	63	54
Beef	14 414	550	451	15 415	1 513	138	101	10.19	112	153

NOTES: The blue water footprint refers to the volume of surface water and groundwater consumed (evaporated after withdrawal) as a result of production; the green water footprint refers to rainwater consumed; the grey water footprint refers to the volume of freshwater required to assimilate the load of pollutants based on existing water quality standards. The types of proteins and fats can differ across different products.
SOURCE: Mekonnen & Hoekstra. 2012, Table 3.[24]

The impacts of dietary change on water use

Competition for water is expected to grow as a result of changing dietary patterns. The observation that diets change as countries develop economically is well recognized and associated with increasing wealth, access to cheaper food, expansion of global food markets and urbanization.[22, 23] Dietary changes include a shift in preferences from unprocessed cereals towards highly processed foods, livestock products and high-value crops, such as fruits and edible oils, whose consumption is expected to continue increasing, especially in low-income and lower-middle-income countries. Such changes influence future agricultural water demand because, as reflected in Table 1, livestock products and oils require more water than do cereals, starchy roots, fruits and vegetables.[24]

Table 1 considers the average annual water footprint of selected food products based on Mekonnen and Hoekstra (2012), using the total volume of water (rainwater, surface water or groundwater) directly or indirectly to produce the product.[24] This is useful for policy in water-scarce regions when considering the benefits of specializing in some products rather than others, local production versus imports, the water-related impacts of consumption patterns, etc.[2]

Table 1 highlights the complexity of water-related impacts of diets. The fourth column shows that livestock products require substantially more water for one tonne of product, and per calorie, than do crops. The only exception are nuts, which, after beef and goat meat, consume the most water per tonne. Assessing the water requirements for protein, Table 1 shows that producing one gram of protein for milk, eggs and chicken meat is in the same order of magnitude as for pulses. For beef, the water requirement is considerably higher, indicating that differences across livestock production are also important, while butter and oil crops have a relatively small water footprint per gram of fat. In purely "accounting" terms, from a freshwater perspective, it is often more efficient to obtain calories, protein and fat through crop products than through livestock. These are averages over all types of water use, across production systems and regions where nutritional challenges differ greatly. In low-income countries, the quality of proteins and bioavailability of nutrients from different foods will be crucial to avoiding malnutrition. High-income countries increasingly overconsume livestock products, putting additional pressure on water resources. A meta-analysis of 63 publications on the water footprint of various diets in high-income countries found that reducing consumption of animal-based foods in Western diets could reduce water use by 18 percent.[25]

While studies based on global averages provide interesting insights, experts in environmental assessments of livestock production have questioned them. Estimates are often very context-specific and cannot be generalized because of differences in feed used between and within species and production systems. Part of the water footprint of animal production in Table 1 is associated with rainfall on pastureland, often not convertible to cropland, thus making livestock the only option for using rainfall for food production, improving water-use efficiency.[26] Studies also usually consider population-level intake of different foods, but do not examine dietary requirements of specific groups, such as children, women or the elderly. The conclusions of these studies should be viewed with caution, and any guidance should be context-specific and consider the dietary status of a population, and specific water constraints faced by producers, combined with the viability of different land uses.

Table 1 does not include seafood as there is very little analysis of water use in its production. Fish are an important source of proteins, healthy fats and nutrients, playing a crucial role in nutrition.[15] The seafood industry is very diverse, with vastly different water use, in particular, but not only, between aquaculture and capture systems. In China, the blue and green water (see Glossary) footprint of freshwater aquaculture associated with feed and evaporation ranges from 3 349 m^3 to 21 215 m^3 per tonne of product.[27] For marine aquaculture, levels are much lower and only associated with feed. For capture fisheries, consumptive freshwater use is negligible, but adequate water is still essential. For inland fisheries, which provide dietary diversity and underpin food security and nutrition in some areas, water volumes and timing depend largely on context and species.

As incomes rise, populations are expected to move towards more land- and water-intensive diets, in particular through consumption of more meat and dairy products.[23] The world must also move towards healthy diets – often varied with water-intensive nutritious foods, such as fruits and vegetables, legumes, nuts and moderate amounts of dairy, eggs and poultry.[28] As a result, pressures on global freshwater are expected to increase, as are the negative impacts that intensive livestock production has on water quality (see In Focus: Agriculture, water pollution and salinity, p . 44).[29] A 2015 study by Gill *et al.* reports changes in water consumption (blue, green and grey water)[b] associated with dietary transition between 1961 and 2011 in Brazil, China and India.[30] The differences across countries are considerable, with livestock products playing a major role in increasing water demand in Brazil and China, and cereals doing the same in India. In all three countries, this led to an increase in daily water consumption of more than 1 000 litres per capita, for a combined population of 3 billion people in 2019, proving that dietary transition plays a strong role in shaping water demand in agriculture. Healthy diets that include sustainability considerations at the food systems level can reduce the associated water consumption.[28] ■

b The study uses the same definitions of blue, green and grey water footprints as Mekonnen & Hoekstra. 2012.[24] (See Notes of Table 1).

IMPROVED GOVERNANCE TO ENSURE EQUITABLE ACCESS TO WATER

Rising scarcities and climate change risk greater inequality in water access. This, in turn, can undermine livelihoods, resilience and food security and nutrition through the share and quality of water allocated for WASH, agriculture, food production and ecosystem functioning, and exacerbate unequal distribution among people and sectors.[31] The human rights dimension of water access is important and was recognized by the United Nations General Assembly in 2010.[32] While the right to water focuses primarily on water for drinking, sanitation and other personal and domestic use, it extends to food and agricultural production in its interactions with other human rights, notably the right to food – of particular importance for rural women and indigenous peoples.

Rural access to water is particularly uneven owing to physical and/or economic constraints for small-scale farmers. Small farms of less than 2 hectares make up the majority of farms both worldwide (84 percent) and especially in low-income and lower-middle-income countries.[33] They are more vulnerable to water constraints because of limited access to irrigation technology and rainwater harvesting options. In Southern Asia, where more than 60 percent of farms are small,[33] Li *et al.* (2011) found drought to be a major constraint to crop yield.[34] Improving access to water for agriculture and better management are important poverty alleviation tools.[35, 36]

Small-scale farmers in irrigated and rainfed settings face barriers to irrigation equipment and water harvesting. In sub-Saharan Africa, water is present but scarce without the capital to access it,[37] although expanding small-scale irrigation can be profitable and benefit between 113 million and 369 million rural people.[38] Many factors impede uptake of irrigation technologies, including tenure and access to finance and credit.[39] Water harvesting improves crop yields in semi-arid regions of Africa and Asia, but small-scale farmers with limited market access may be reluctant to invest in water harvesting owing to low returns and an average payback of 4–5 years.[40] To further expand access to water, farmers and service providers need the skills to design, operate, maintain and repair irrigation technologies and systems, as their misuse will result in water and yield losses.[41]

Women also face severe constraints in access to natural resources, especially water, despite constituting up to half the agricultural workforce in low-income countries.[42] They often lack rights to the land they farm, and water to irrigate their fields. Women also lack influence over the use of natural resources, including water. Their labour burden exceeds that of men, as they have more unpaid household responsibilities, such as water and fuel collection and food preparation. Fetching water can be dangerous for women and girls, exposing them to the risk of violence. Irrigation can allow women greater participation in income-generating, caregiving and social activities. Water professionals, extension staff and decision makers still fail to perceive women as farmers[43] and often overlook the knowledge, workload and needs of women and the most vulnerable groups. General Recommendation No. 34 of the Committee on the Elimination of Discrimination against Women considers women's access to land and water to be fundamental human rights.[44]

Strong governance and water allocation, such as for irrigation and hydropower that engage different users, are essential in order to address competition and tensions between sectors, and to ensure reliable, high-quality water flows. In many countries, as indicated in the 2015 report by the High Level Panel of Experts on Food Security and Nutrition, decisions in water-use sectors are often taken by separate departments with "little consideration for the cumulative impacts of water."[31] Governance must balance the need for more efficient water use with equitable access that respects the human right to water. The notion of allocative efficiency is concerned with how much wealth a given natural resource base can produce, while equity relates to how the wealth is distributed in society.[45] Reconciling efficiency and equity may not be easy owing to weak entrenched water policies, such as underpricing or unregulated use.[46] Markets and efficiency considerations may dominate, favouring those who use water to produce the greatest economic returns, trading off equity against efficiency.[47, 48] Agriculture can invoke its multiple functions beyond commodity production to important social, cultural and environmental aspects. Increasing agricultural water efficiency, equity and productivity will be key to providing sufficient quality food for everyone, while respecting environmental flow requirements that sustain ecosystems, and the human livelihoods and well-being that depend on them. Yet, it has been estimated that 41 percent of current global irrigation occurs at the expense of environmental flow requirements.[49] Reconciling irrigation with environmental flows will thus be pivotal for attaining the 2030 Agenda.

If water were abundant, managing demand would be less challenging, as it could be met at little cost. With greater scarcity, use creates increasing rivalry, as one user limits its potential use by others. Water should be recognized as an economic good that has value and a price,[50] as well as vital for the ecosystems upon which all depend. Its unique characteristics – essential, non-substitutable, finite *and* a human right[51] – have made this difficult (Box 4), and water must be managed from economic and social standpoints. Its allocation cannot be left to market forces alone. However, this does not imply that as a basic human right, water must be free, a common misinterpretation.

There is a need for fair pricing that aims at cost recovery, a primary goal, but ensures access for the poor, along with meeting environmental requirements.[52] A reasonable price sends out a clear signal to users that water must be used wisely. Policies may offer cross-subsidies (one group of consumers pays more to lower the price for another group) for equity reasons, or water use may be subsidized (e.g. for irrigation). A well-functioning, efficient, equitable and sustainable market depends on these criteria. Governments have prime responsibility in this.

As water becomes scarcer and demand grows, the policy focus has shifted from increasing supply towards economic, legal, institutional and other interventions to manage demand (Box 1). Management can deliver additional water to meet society's needs, while addressing the causes of problems, such as pollution and over-exploitation of aquifers. Solving water scarcity in agriculture requires controlling supply with vigorous demand management. ■

WATER, FOOD SECURITY AND FOOD SYSTEMS

The concept of food systems can be useful for understanding the relationship between food security and nutrition, food production and consumption, and water. A food system encompasses the entire range of actors in the production, aggregation, processing, distribution, consumption and disposal of food products that originate from agriculture, forestry and fisheries, and parts of the broader economic, societal and natural environments in which these activities are embedded.[59] A sustainable system delivers food security and nutrition for all, without compromising the economic, social and environmental bases that generate food security and nutrition. Sustainable and equitable water management is essential to food systems, to achieving food and nutrition security, and to ending hunger.

Global attention has focused primarily on water quantity, but water quality is also important from a food-security perspective. Pollution affects the availability of freshwater for economic activities,[60] including food production.[61–63] Polluted water affects health and well-being through food safety and health risks.[64] It also undermines the sustainability of fisheries, land and ecosystems, including the ability to provide food security and nutrition.[31] (For a further discussion of water quality, please refer to the In Focus: Agriculture, water pollution and salinity, p. 44.)

The following subsections look at different components of the food system, to highlight the entry points through which water management affects food security and nutrition. Beyond the food system, an increasingly important source of competition for water is the water–energy–food nexus, and biofuel production (Box 5).

BOX 4
THE INHERENT CHARACTERISTICS OF WATER MAKE IT DIFFICULT TO MANAGE

Historical practice and political, cultural and religious beliefs have treated water as a free commodity, often creating **market failures** – where markets do not allocate resources efficiently.[53] In such situations, there are opportunities to make some people better off without making others worse off. An example of market failure is when large irrigation systems, urban supply or hydropower plants impose high prices on customers. They have little incentive to innovate.[1] Water use can also generate **negative externalities,** where one individual, firm or nation can have an impact on another without compensation. An example is the detrimental effect water use may have on water quality and environmental degradation.

Considering the importance of water for society, it is often subsidized on a huge scale, although most water services – hydropower, irrigation, drainage, etc. – need public infrastructure and large investment to reach economies of scale, leading to natural monopolies. The choice between a public or private monopoly, and its degree of autonomy from government, varies widely across countries. For political, cultural and equity reasons, the costs of water services are usually not charged to users, threatening efficient maintenance of water infrastructure and future investment. Government intervention is needed to correct these market failures and negative externalities, while securing environmental flow.

In some cases, water is a **common** resource. A group (often a local community or pastoralists) uses and manages water collectively, and different members may hold some rights with fixed or fluid boundaries. When the rules or community control are weak, "open access" can apply – an incentive for free-riding behaviour leading to over-exploitation of resources (also referred to as "the tragedy of the commons").[54] The work of Ostrom (1990) has shown that collective action and clear rules are crucial to governing common resources.[55] Open access often occurs where commons are public- or state-owned, and law or community institutions governing their use are not recognized in law. Communities or groups may be deprived of their right to customary use and to exclude external users. Water policy and law need to account for the complexity, diversity and flexibility of water tenure, and recognize the rights and responsibilities of groups or communities to govern their resources. (See, for example, FAO. 2016[56] and Morgera *et al*. 2020.[51])

The interface between land tenure and water rights may impact sustainable water management. Irrigation projects and water points for groups, such as pastoralists, can undermine water rights, resulting in conflict between groups.[57, 58]

Water at the centre of primary production

Agriculture accounts for about 70 percent of water withdrawals worldwide, but about 90 percent in low-income and lower-middle-income countries (see figure in Box 3). Increasing scarcity of freshwater and growing competition, particularly in arid and semi-arid regions, is a sharp constraint on agricultural production. Rainfed agriculture is the primary source of global production, representing more than 80 percent of land under cultivation (see Chapter 2) and 60 percent of global crop production.[19] Increasing productivity in rainfed agriculture can reduce pressure on scarce freshwater from irrigation. This involves increasing the productivity of rainwater, although the water-related challenges facing production systems – rainfed and irrigated – are largely, but not wholly, different.

Rainfed agriculture is completely reliant on rainfall. With climate change causing precipitation and temperature changes,[85] rainfed agriculture is highly vulnerable to the challenges of water management. There is a need to harness the water resource potential through water harvesting, soil moisture conservation and supplementary/deficit irrigation, as well as a need »

BOX 5
THE WATER–ENERGY–FOOD NEXUS, AND BIOFUEL PRODUCTION

A particular dimension of water competition is the water–energy–food nexus. Reservoirs or dams with irrigation and hydropower functions are an example of the water–energy–food nexus, reflecting the interdependence between the sectors and the trade-offs that occur. Water released for irrigation lowers reservoir levels and reduces hydropower generation, while hydroelectricity production may decrease water for irrigated food production. Fifty-four percent of global hydropower capacity (about 507 000 MW) competes with irrigation, notably in central United States of America, Northern Europe, India, Central Asia and Oceania.[65] The multiple causes largely depend on the temporal and spatial allocation of water, including inconsistent timing of hydropower and irrigation, and low streamflow. The upstream–downstream water conflicts in the Syr Darya river basin in Central Asia provide a good illustration of how timing and spatial dimensions come into play in the water–energy–food nexus. The upstream country, Kyrgyzstan, controls most of the reservoirs regulating the river flow and stores water during summer for hydropower in winter, which then conflicts with the downstream countries' needs for irrigation during summer.[66] Inland fisheries can also be compromised or lost when flows are affected by controlled water release from dams.[67–70]

Hydropower may complement irrigation when reservoirs increase availability for food production.[65, 71] A recent study of the Himalayan river basin showed that hydropower increased irrigated crop production and improved flood damage control.[72] An assessment of water, food and energy trade-offs of multipurpose reservoirs in a tributary of the Mekong River revealed considerable irrigation potential with small hydropower loss.[73] However, the study did not account for loss of fisheries in the Sesan River, an important local fishery and source of food security. Many reservoirs are built today for multiple purposes – such as electrification in Africa – recognizing that spatial and sectoral interdependence, in the face of climate change, should inform policies for enhancing water, energy and food security.[65, 74]

Another important example of the water–energy–food nexus is the link between biofuel demand and agricultural water use. Biofuels have been promoted as a cleaner alternative to fossil fuels, sparking a surge in production in the early 2000s. Global biofuel production has grown, but not without concerns for the land and water used in production and the implications for food security.[75–78] Where land and water are limited, growing crops for biofuel may reduce food production.[79]

Water, rather than land, may be the limiting factor for biofuel feedstock.[80] Biofuels require 70–400 times more water than do the fossil fuels they replace,[81] although the amount varies by feedstock grown as well as location. Xie *et al.* (2017) found wide variation in the life-cycle water footprints of cassava ethanol, sweet sorghum ethanol and *Jatropha curcas* seed biodiesel – all grown in different regions of China – attributable to climate and soil variations.[82]

Water is consumed all along the biofuel chain – from cultivation of feedstocks to the industrial phases of production. The majority of water use occurs during cultivation, and it is important to establish whether feedstock is grown under rainfed or irrigated systems.[83] Rainfed production of biomass does not substantially alter the water cycle, but biomass produced on irrigated lands has potentially negative impacts on groundwater and surface water resources. Studies in the United States of America found that biofuels from irrigated feedstocks have the largest water consumption, by up to two orders of magnitude, compared with rainfed feedstocks.[84] Water used in industrial biofuel processing is a strong competitor for local use. After use, the water may be available for other purposes, but the return flows often have negative impacts owing to chemical and thermal pollution.[83]

The future of biofuels depends on choosing crops that yield more biofuel energy while using less agricultural land, fertilizer and water.

» to make better use of water.[86] Improved rainwater management and farm practices can help retain water in the soil. A lack of rainfall also affects irrigated agriculture – as irrigation water comes from rainfall – but farmers with access to irrigation have more influence on volumes and timing to manage soil moisture more effectively. An additional dimension is linked to forms of aquaculture and livestock production, whereby the water productivity of aquaculture and livestock depends on efficient and sustainable use of water in crop production, as explained in the following sections.

Water for livestock production

Water in the livestock sector can be divided into direct use (service and drinking water) and indirect use (production of feed, fertilizer, pesticides and other inputs).[87] Precipitation patterns are critical for land under permanent meadows and pastures grazed by livestock, much of it not convertible to cropland because of climate, slope, soil depth or other factors. Mottet *et al.* (2017) estimated that livestock graze about 2 billion hectares of meadows and pastures.[26] In dryland areas, such as the Sahel, livestock may be the only option for turning sparse and erratic biomass into edible products. Precipitation patterns also play a major role in increasing soil carbon storage. Manure can increase water-use efficiency in arable lands, enhancing resilience, yields and soil carbon storage.[88]

As the sector uses a large share of agricultural land, either as pastureland or for feed production, it also consumes large amounts of water. An integrated approach is crucial to improving water productivity and the efficiency of all food production sectors. Reducing the amount of irrigated feed and animal water consumption are the two main strategies to reduce livestock's impact on water scarcity.[89] Other factors influencing water consumption are animal species and breeds, and the moisture content and production of feed. A major challenge in global or regional assessments of livestock water use is the very large diversity of production systems.[89] The Livestock Environmental Assessment and Performance (LEAP) Partnership has recently developed assessment guidelines that take into account a wide range of conditions.[87]

Water for inland fisheries

Sustaining inland fisheries requires limiting adverse impacts from other sectors on water. This requires adequate environmental flows, water quality and habitat conservation. Different flow requirements among fish species will lead to changes in species assemblages and, hence, fish catches.[67] Conversion of a river to a reservoir may well cause a complete shift and, often, the elimination of some aquatic fauna. To maintain inland fisheries and mitigate losses, it may be necessary to replace lost species with others better adapted to a standing-water environment.[68]

Water and forests

Water management challenges and solutions related to food go beyond primary agriculture and must be considered at the broader landscape level. Forests are an integral component of the water cycle and can be crucial in sustainable water management and water-related ecosystems, such as the return of rainfall to the atmosphere, which helps to stabilize and extend crop growing seasons. Moisture retention and release by forests, even in dry periods, is essential in areas affected by water scarcity and drought. Forest restoration in dryland areas in Burkina Faso, for example, has helped restore the productivity of degraded land for agriculture and offered a means to diversify food sources, thereby enhancing food security.[90] Given the importance of forests for the water cycle, water-related benefits from forests are best ensured through a holistic, comprehensive and integrated landscape approach. Forest–water relationships are spatially dependent. Their extent and location within the landscape can produce a range of water-related environmental benefits. Forests in upper catchments provide not only local but landscape benefits, often delivering high-quality water downstream. At the basin scale, major forested areas in some of the world's largest basins, such as the Amazon, Congo and Yangtze river basins, are important sources of water vapour for areas downwind and, therefore, crucial to rainfed agriculture. Moisture evaporated from land may fall up to 5 000 km downwind.[91]

Water use along the food supply chain – critical for food safety and water quality

Little is known about total water use by the food processing industry. The industrial sector accounts for less than 20 percent of water withdrawals worldwide (Figure 3), but this figure is about 40 percent in high-income countries (see the figure in Box 3). As food processing is a subsector of the industrial sector, its water withdrawals are much smaller than those of agriculture. Research on water use in food processing tends to be product-specific, such as on tomato sauce, juice or potato products,[92, 93] identifying the most water-intensive processing steps rather than the quantity of water used at various levels. The manufacturing food industry is water-intensive. It uses potable water and generates a significant amount of wastewater per unit of product, more than 70 percent of which is discharged.[94] The quantity for a particular food product depends on a range of factors: the origin of the product (animal or plant); processing conditions (dry or wet); type of processing (minimally processed, fully cooked or dried); the technology; cleaning procedures; and recycling activities. The volume and strength of effluents also vary significantly.[95]

Water quality is crucial for food production and transformation. Food processing can require water for a number of operations, such as washing, evaporation, extraction and filtration[96] and, many, if not most, food-borne illnesses can be traced back to poor-quality water in food production, processing and preparation.[31] While quality water is essential to deliver nutritious, safe food, the sector does generate wastewater.[96] Improper disposal of effluents into land and water ecosystems also harms the quality of water itself.[96–98] Water waste carries contaminants such as nitrogen, oxygen-depleting substances and pathogens, which make their way into lakes and rivers.[99] This reduces water quality, affecting biodiversity, and lowering fish production and quality.[100]

Without proper treatment, disposing of contaminants into water may expose humans to them, and limit access to safe, drinkable water, especially for the most vulnerable people. People are also affected by eating contaminated food products, such as fish.[101, 102] To address water pollution and protect ecosystems, wastewater treatment technologies (such as digesters or activated sludge processes) are needed to avoid discharge into water resources.[97]

As manufacturing demand for water increases, equally important are water savings in food processing, often the main driver that motivates food companies to support water conservation programmes. Cultural and operational changes are among the first-line approaches, with little capital investment resulting in water reductions of up to 30 percent.[61] Examples include awareness and monitoring programmes, and taps that automatically shut off when not in use. Other options can achieve more significant water reductions, in the range of 50–80 percent, depending on the technology.[103, 104] However, capital investment is higher, and consideration needs to be given to the impact of the changes on finished product quality and safety.[61] Internal strategies to increase water efficiency and productivity include: (i) reduced use through consumption analysis (water mapping); (ii) improved planning; (iii) water recycling; (iv) reuse after treatment; and (v) equipment and plant layout design.[95]

Water use by consumers – the link between water access and food security and nutrition

Safe and reliable WASH practices are a basic necessity for human development and a healthy life. Lack of access to safe and clean water for WASH is a key underlying cause of malnutrition, particularly in children. Diarrhoeal disease is directly linked to a poor WASH environment, particularly in low-income countries, where access to clean water is a major issue. According to the World Health Organization (WHO), in most low-income countries, diarrhoea is the third main cause of child death, after acute respiratory infections and malaria, as well as of deaths across all age groups.[105] In a poor WASH environment, food that is eaten may pass through the body without being absorbed owing to diarrhoea or other enteropathy. Water-related diseases undermine productivity and economic growth, reinforcing deep inequalities and trapping vulnerable households in cycles of poverty.[106, 107]

When access to household water sources is limited, irrigation water sometimes fills the need. Although some studies have shown household use of irrigation water can lead to positive effects on WASH and nutrition, the quality is not always sufficient for human consumption, with possibly adverse health effects.[108–110] This is particularly true where irrigation water for domestic consumption is unplanned. There may be benefits when multiple uses are incorporated into the irrigation system; for example, the overall time that household members, often women, spend collecting water decreases, freeing them for other productive activities and caregiving, leading to better nutritional outcomes.[108] The importance of WASH for human health, well-being, and food security and nutrition is further discussed in the In Focus: Improving access to safe drinking water in rural areas, p. 20. ■

LAYING OUT THE SCOPE OF THE REPORT

This chapter has emphasized the urgency of addressing increasing water shortages and water scarcity, as well as unequal access to water across stakeholders, and laid out the main challenges to ensuring sustainable and inclusive water management. It has highlighted the role of management along the entire food supply chain for the purposes of food security and nutrition. From this overview, it is clear that agriculture occupies an enduring and central role in managing water, and that water remains a binding constraint for many small-scale producers. Therefore, the report places the main emphasis on water management in agriculture – the main user of water globally and in most countries – covering both irrigated and rainfed agriculture as well as livestock production systems, inland fisheries and aquaculture. It balances the dual agendas of water access in agricultural production and ensuring economic, social and environmental sustainability.

Chapter 2 looks at trends and patterns in water shortages and water scarcity, affecting irrigated and rainfed agriculture, respectively, and presents an overview of the effect on different production systems. It uses an indicator of water stress as a proxy for scarcity of freshwater affecting irrigated cropland, and an indicator of severe drought frequency as a proxy for water shortages owing to inadequate rainfall, affecting rainfed cropland and pastureland. It shows the first spatially disaggregated representation of SDG Indicator 6.4.2 on water stress, and links it to irrigated production systems. Chapter 3 looks at agriculture water management strategies and technologies in irrigated and rainfed agriculture, livestock production systems, inland fisheries and aquaculture, while Chapter 4 focuses on governance and institutions for improved water management. Chapter 5 presents the overall policy framework for improved governance of water resources, and draws conclusions and policy implications. ■

IN FOCUS

IMPROVING ACCESS TO SAFE DRINKING WATER IN RURAL AREAS

Water is key to food security and nutrition. Water of sufficient quantity and quality is critical for agricultural production, and for the preparation and processing of food. Along with sanitation and good hygiene practices, access to safe drinking water is also crucial to good nutrition. Poor-quality water can cause a number of waterborne diseases, transmitted by ingestion of contaminated water, and can lead to malnutrition, morbidity and sometimes death. Important waterborne diseases include diarrhoeal diseases, cholera, shigella, typhoid, hepatitis A and E, and poliomyelitis. According to the WHO, diarrhoeal diseases alone account for an estimated 3.6 percent of the global burden of disease and are responsible for 1.5 million deaths per year. An estimated 58 percent of such deaths – 842 000 deaths per year, including 361 000 children under the age of five – are attributable to unsafe water supply, inadequate sanitation and lack of hygiene, mainly in low-income and lower-middle-income countries.[111]

The novel coronavirus disease (COVID-19) pandemic has also highlighted the importance of safe water, beyond waterborne diseases, as one of the simple precautionary measures – frequent handwashing – helps prevent transmission, but is

PAKISTAN
A young girl collects clean drinking water from a communal tap in a camp for persons internally displaced by floods.
©FAO/Truls Brekke

unlikely to be followed or effective without a safe water source. According to a 2019 report by the United Nations Children's Fund (UNICEF) and WHO, in 2017, 1.6 billion people had handwashing facilities without water or soap at the time of the survey, and 1.4 billion people had no handwashing facility at all.[112] In most countries with disaggregated data, access to handwashing was more limited in rural than urban areas.

SDG Target 6.1 states: "By 2030, achieve universal and equitable access to safe and affordable drinking water for all." According to the 2019 report by UNICEF and WHO, one in three people globally do not have access to safe drinking water, and more than half of the world's population do not have access to safe sanitation services.[112] Access to drinking water can be described as water available on the premises or within a certain travel time.

In 2017, 90 percent of the world's population had access to at least basic drinking water services – i.e. collection from an improved source, if available, of less than 30 minutes for a round trip – compared with 82 percent in 2000. Lack of access to drinking water can be a problem in urban and rural areas, but almost always affects a larger share of the rural population. Eight out of ten people lacking basic services live in rural areas, almost half of them in least developed countries. In those areas, 19 percent are without basic access compared with 3 percent in urban areas. In 17 countries (most of them in sub-Saharan Africa), more than half the rural population do not have access to drinking water (see Figure A).[112] Not having access to safe drinking water on the premises at home entails – especially in rural areas – considerable time to access it, and it is often women's time. According to a recent United Nations report, this is true for all world regions with data available except Eastern and Southern Europe, and Latin America and the Caribbean, where the role of water collection is almost equally distributed between the sexes.[113]

The objective should be for everyone to have access to safe water in their home. A more ambitious measure is safely managed water, meaning rural households accessing water on the premises, available when needed and free from contamination.[c] For water to be considered safely managed, all three criteria must be met. This is the measure embodied in SDG Indicator 6.1.1, which assesses the proportion of population, 71 percent, using safely managed drinking water. In urban areas, 85 percent of the global population use safely managed water; in rural areas, the figure is only 53 percent, with numbers much lower in least developed countries, landlocked developing countries and SIDS (see Figure B).

Among the regions, sub-Saharan Africa has the lowest level of access to safely managed water, with only 12 percent of its rural population having access to safely managed drinking water. Given that a further 34 percent have only basic access (requiring a round trip of less than 30 minutes), for more than half of rural people in the region the options are either water collection that takes longer than 30 minutes or from unimproved sources or surface water. Accessing safe drinking water is a challenge for more than 300 million people in rural areas of sub-Saharan Africa. This has implications in terms of health risks and time spent fetching water. A case study reported that in households in Cameroon, Chad and Senegal without drinking water, children are considerably more likely to have diarrhoea than those in households with access to water.[114] The link between prevalence of diarrhoea among children and malnutrition is well established, highlighting that water quality is important for food utilization and nutrition, even where food is available.

Many countries are moving forward to improve coverage. The 2019 UN-Water Global Analysis and Assessment of Sanitation and Drinking Water (GLAAS) finds that countries are setting targets for higher levels of service such as safely managed drinking water and sanitation.[115] About half have set drinking-water targets for universal coverage by 2030 that are higher than basic services. Insufficient funding remains a serious constraint to achieving national targets.

c Improved water sources, according to the 2019 report by UNICEF and WHO, include: piped water, boreholes or tubewells, protected dug wells, protected springs, rainwater, and packaged or delivered water.[112]

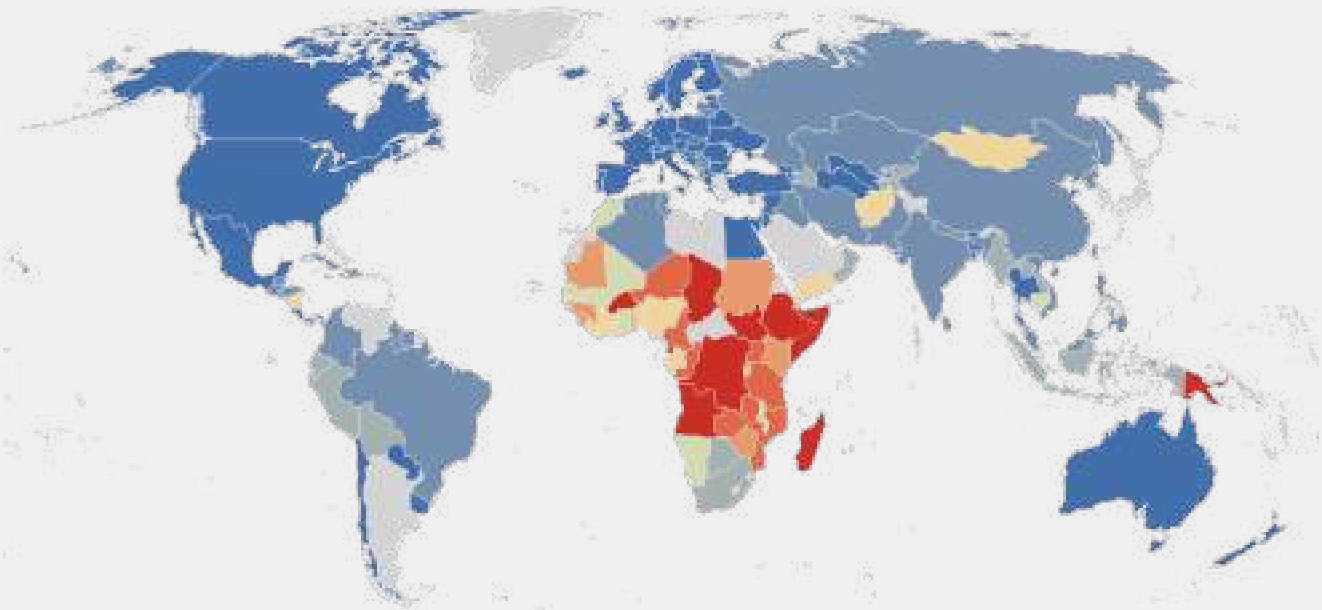
IN FOCUS
IMPROVING ACCESS TO SAFE DRINKING WATER IN RURAL AREAS

It will take time to guarantee safely managed water services, especially in rural areas. Therefore, interim solutions are needed in order to improve water quality, both for those who lack basic water services and those who can access water but at high risk of contamination. UNICEF and WHO (2019) estimate that almost half of the world's rural population do not have access to improved drinking water, free from contamination.[112] Water quality is a major challenge to ensuring access to safely managed water in rural areas in accordance with SDG Target 6.1. A concerted effort is needed to address the issue.

Countries include the WASH sector as part of national development plans; and for drinking water, more than 80 percent of countries report their urban and rural policy or plan addresses safely managed services. For rural drinking water, 91 countries have national plans, and 77 of them have costed such plans. However, of these, only nine have allocated sufficient financing to implement the plan, with similar challenges for urban drinking-water plans. Data from GLAAS (2019) also indicate that a large majority of countries lack human resources to implement national WASH plans.[115] This will make it challenging to reach intended targets by 2030, even with some advances before then.

Policymakers and communities may need to look at improving water quality through intermediate solutions, such as household water treatment and safe storage (HWTS) options. Based on data from between 2005 and 2009, the practice is widespread in the Western Pacific (66.8 percent) and South-eastern Asia (45.4 percent) regions, but less common in the

FIGURE A
SHARE OF RURAL POPULATION WITHOUT AT LEAST BASIC ACCESS TO DRINKING WATER, 2017



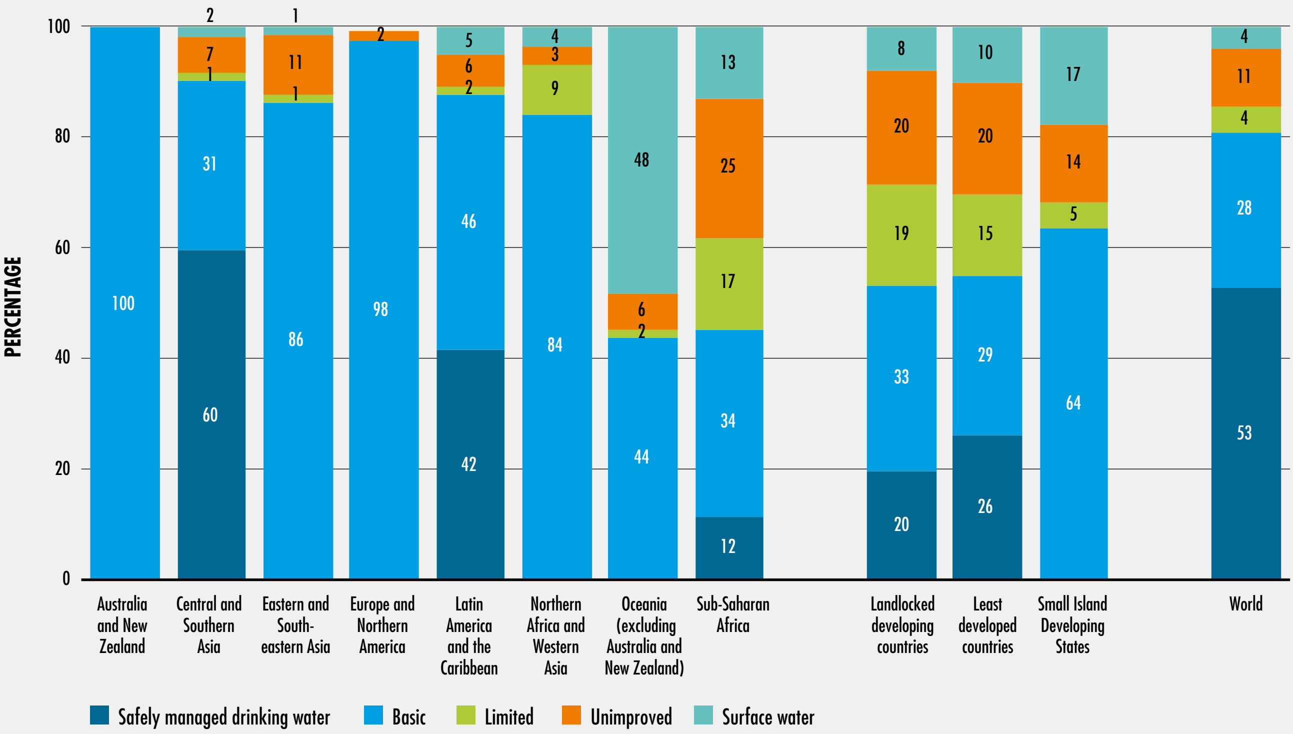
SOURCE: FAO elaboration based on UNICEF & WHO. 2019, Annex 3.1.[112]

Eastern Mediterranean (13.6 percent) and Africa (18.2 percent). In sub-Saharan countries, where large numbers of people are forced to depend on unsafe water, household water treatment is recommended to reduce the incidence of diarrhoea.[116]

Examples of HWTS identified by WHO as promising are filtration with ceramic filters; chlorination with storage in an improved vessel; solar disinfection in clear bottles; thermal disinfection (pasteurization) in solar cookers or reflectors; and combination systems employing chemical flocculation and chlorination.[117] With all these options, HWTS interventions will be effective only if sustained. Daniel *et al.* (2018) highlight that the socio-environmental drivers of adoption of household water treatment in developing countries are complex and interactive.[118]

Many countries have laid out a path to better rural health and nutrition by improving access to safely managed water services. However, policymakers will need to dedicate more resources to implement national WASH plans. Household water treatment and safe storage has a role in providing vulnerable people with a tool to improve their own water safety. Realizing that potential will require solutions that are microbiologically effective, accessible to targeted populations, and used consistently and sustainably.[119] From a policy perspective, this is an area that could benefit from setting explicit targets and providing resources. In 2012, the WHO found that only 43 percent of countries have specific HWTS targets, but that a subset are taking important policy initiatives to scale up HWTS.[120] The WHO also highlighted where there can be greater progress, with additional support to strengthen key policy elements.

FIGURE B
SHARE OF RURAL POPULATION WITH ACCESS TO DRINKING WATER, 2017



SOURCE: UNICEF & WHO. 2019, Figure 50.[112]

SENEGAL
Women of the association Japo Ande Liggeye supported by the local non-governmental organization, Symbiose, draw water from a cistern to water their garden.
©FAO/Benedicte Kurzen/NOOR

CHAPTER 2
STATUS OF WATER SHORTAGES AND SCARCITY IN AGRICULTURE

Key messages

➔ More than 3 billion people live in agricultural areas with high to very high water shortages or scarcity, of whom 1.2 billion people – roughly one-sixth of the world's population – live in severely water-constrained agriculture areas.

➔ From the 1.2 billion people, nearly half live in Southern Asia, and about 460 million live in Eastern and South-eastern Asia. Without immediate action, many more will be affected. For many, migration may become a necessity.

➔ Water constraints affect agricultural production systems in different ways. Recurring drought is a limiting factor in rainfed areas, as is water stress to irrigated agriculture, affecting the marginalized disproportionately, such as women and pastoralists.

➔ Several factors shape a country's ability to confront water shortages and scarcity: its exposure to water constraints; its development level; its political, socio-economic and cultural structures; and its capacity to invest in agriculture.

➔ The location and magnitude of climate change effects are uncertain, but the impacts are likely to be substantial, calling for robust and flexible water management policies that are equitable and inclusive.

CHAPTER 2

STATUS OF WATER SHORTAGES AND SCARCITY IN AGRICULTURE

As discussed in Chapter 1, the right quantity and quality of water are central to food security, nutrition and health for all. Water is also the lifeblood of ecosystems, upon which all humans depend. As water becomes scarcer, further competition and disputes among users are likely, as are inequalities in access to water, mainly affecting the rural poor and other vulnerable populations. The 2030 Agenda reflects growing concern over water scarcity and misuse in SDG Target 6.4, calling for greater water-use efficiency and sustainable withdrawals. Severe droughts, exacerbated by climate change, cause water shortages, affecting crop and livestock yields, especially for the rural poor.

Thanks to efforts by FAO, monitoring progress towards SDG Target 6.4 is now possible through SDG Indicator 6.4.2 on the level of water stress; and this chapter presents new spatial estimates for irrigated areas. As water shortages is the primary constraint to agricultural production and productivity in rainfed areas, the chapter assesses the impact of recurring drought on rainfed cropland and pastureland. Agriculture is the world's largest water user, and most of the poor depend on it for their livelihoods, food security and nutrition. Those engaged in different agricultural production systems also face different water-related challenges and opportunities. The chapter sheds new light on the global distribution of the main agricultural systems – irrigated, rainfed (low- and high-input), and pastureland – and briefly discusses their vulnerability and exposure to water risks. The chapter then discusses how climate change exacerbates water shortages and scarcity. It also introduces governance, institutional frameworks and the policy environment of responses to water shortages and scarcity. It ends with a review of water quality issues from agriculture and presents possible policy responses and management strategies. ■

WATER SHORTAGES AND SCARCITY ARE A GLOBAL CONCERN

Water shortages are driven primarily by biophysical factors (e.g. rainfall), reflecting a lack of water of acceptable quality, while scarcity arises from water shortages and the multitude of factors driving water demand (e.g. population increase), depicted through different indicators. This report draws on two indicators: FAO's historic drought frequency indicator and SDG Indicator 6.4.2 on the level of water stress to measure water shortages and scarcity in rainfed and irrigated areas, respectively.

FAO developed SDG Indicator 6.4.2 on water stress to measure the pressure of human activities on natural freshwater resources, based on total freshwater withdrawals by all sectors and taking into account environmental flow requirements. As water stress indices only address surface water and groundwater withdrawals, SDG Indicator 6.4.2 at the basin level is a proxy for scarcity in irrigated areas. To measure the severity of water shortages in rainfed cropland and pastureland areas,[d] this report draws on FAO's historical drought frequency, estimating the probability that severe drought will affect more than 30 percent of cropland or grassland,[e] based on the 1984–2018 series. A 25 percent probability in rainfed

d For this report, pastureland is defined as grassland and woodland areas, following FAO and IIASA (2020),[1] which, in turn, include grassland, shrub-covered area and herbaceous vegetation.

e According to this definition, severe agricultural drought occurs when the vegetation health index falls below 35 percent, illustrating the severity based on vegetation health and the effect of temperature on plant conditions. For more information on the vegetation health index's construction and methodology, see FAO. 2018.[2]

cropland means that severe drought causes crop failure in more than 30 percent of cropland in one out of every four years.

Figures 5, 6 and 7 bring together both dimensions – historical drought frequency and SDG Indicator 6.4.2 on water stress – and affected production systems. (For an overview of the methodology, see the notes in the Technical Annex, p. 127.) Figure 8 supplements Figure 7 on water stress in irrigated areas, illustrating the contribution of agriculture to water stress by considering consumptive water (see Glossary) as a share of renewable freshwater resources, after environmental flow requirements. In Figure 8, low water stress does not necessarily mean that the agriculture sector is not under stress, as it ignores competition for water from other sectors.[f]

Combined with spatial population data – based on Figures 5–7 – the report infers that about 1.2 billion people live in areas where severe water shortages and scarcity challenge agriculture, from very high drought frequency in rainfed cropland and pastureland areas or very high water stress in irrigated areas. Of these 1.2 billion people, slightly more than half – 660 million – live in small urban centres surrounded by agricultural areas, while the remaining 520 million live in rural areas.[g] This means about one in six people on the planet face severe water shortages and scarcity in agriculture, with roughly 15 percent of the rural population being at risk.[3]

From the 1.2 billion people, around 520 million live in Southern Asia, where in countries such as Pakistan and Sri Lanka about 80 percent live in affected agricultural areas.[h] About 460 million people in affected agricultural areas live in Eastern and South-eastern Asia, 200 million of them in rural areas. In Central Asia and in Northern Africa and Western Asia, about one-fifth of the population live in agricultural areas with very high water shortages or scarcity. In Europe, Latin America and the Caribbean, Northern America and Oceania, only 1–4 percent live in extremely water-constrained areas. In sub-Saharan Africa, only about 5 percent of the population live in affected areas. There, most areas are rainfed, suggesting that water constraints are driven by severe drought or lack of irrigation. While 5 percent may be perceived as negligible, it implies that about 50 million people live in areas where severe drought has catastrophic impacts on cropland and pastureland in one year out of every three. The pastoral zone is particularly affected, as more than half of the rural population are poor, the main causes seemingly being climate variability and high vulnerability to drought.[4]

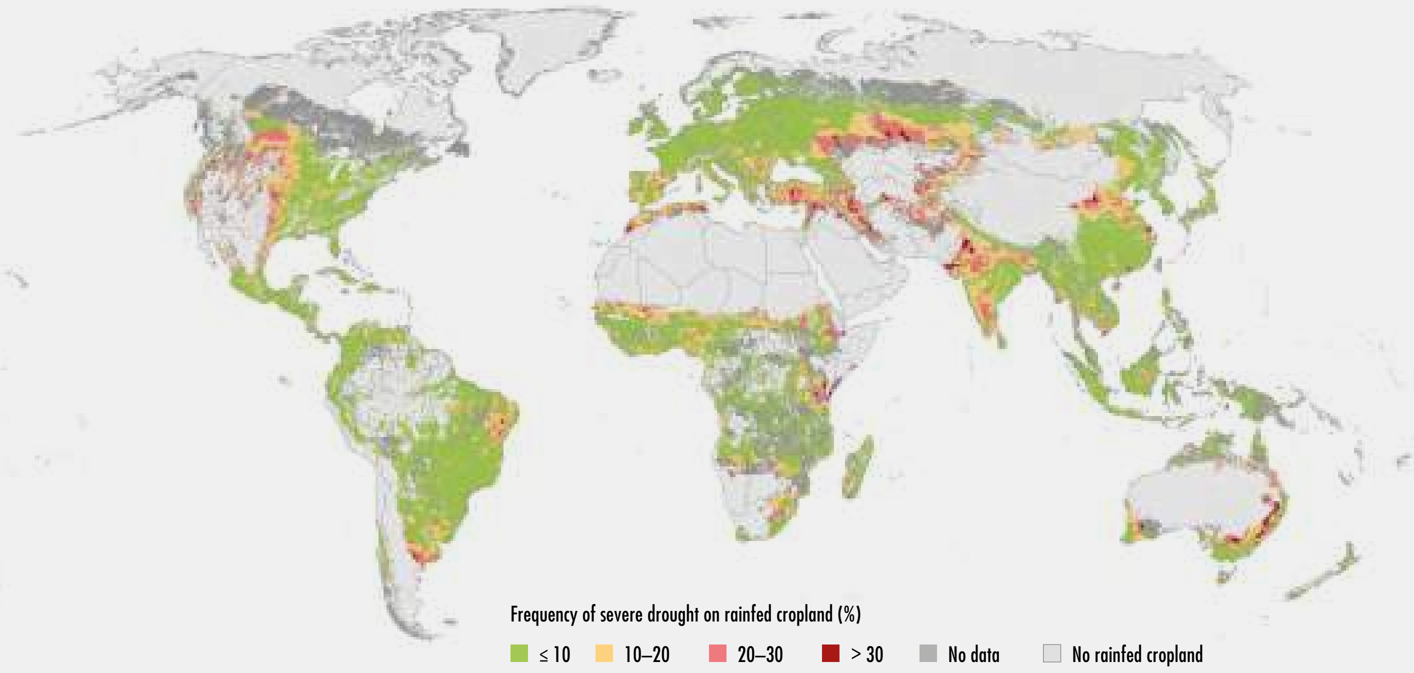
If areas with high (in addition to very high) severe drought frequency or water stress are also considered, the number of people affected increases to 3.2 billion, of whom more than 40 percent (1.4 billion) live in rural areas. This estimate may be a global assessment of the future potential impacts of climate change on water constraints. Water in these areas is likely to be a constraint to agricultural livelihoods and for most households, and unless demand and user practices change or alternate water

f For SDG Indicator 6.4.2 at country and basin level, see Figures A3 and A4 in the Statistical Annex.

g The aggregate number is obtained by calculating the population in all 10 km × 10 km pixels that report cropland or pastureland production. Given the size of the pixel, small urban centres are included, as well as peri-urban areas that practise agriculture. Thus, the population included is not strictly rural.

h For a breakdown by country of the number of people in agricultural areas experiencing severe water constraints, see Table A1 in the Statistical Annex.

FIGURE 5
HISTORICAL DROUGHT FREQUENCY ON RAINFED CROPLAND, 1984–2018



NOTES: The map depicts the frequency with which more than 30 percent of cropland (where crop areas occupy at least 5 percent of the pixel area) was affected by severe drought as follows: low when the probability of severe drought affecting cropland is less than or equal to 10 percent; medium when it ranges between 10 and 20 percent; high for between 20 and 30 percent; and very high when it surpasses 30 percent. The indicator includes two crop-growing seasons, combined by selecting the highest drought value of the two. When there is only one season, the single value is used instead. "No data" accounts for pixels for which no level of drought is available but there is rainfed cropland, according to FAO & IIASA. 2020.[1] The historical frequency of severe droughts is based on the entire time series (1984–2018).
Source: FAO elaboration based on FAO. 2019,[7] and FAO & IIASA. 2020.[1]

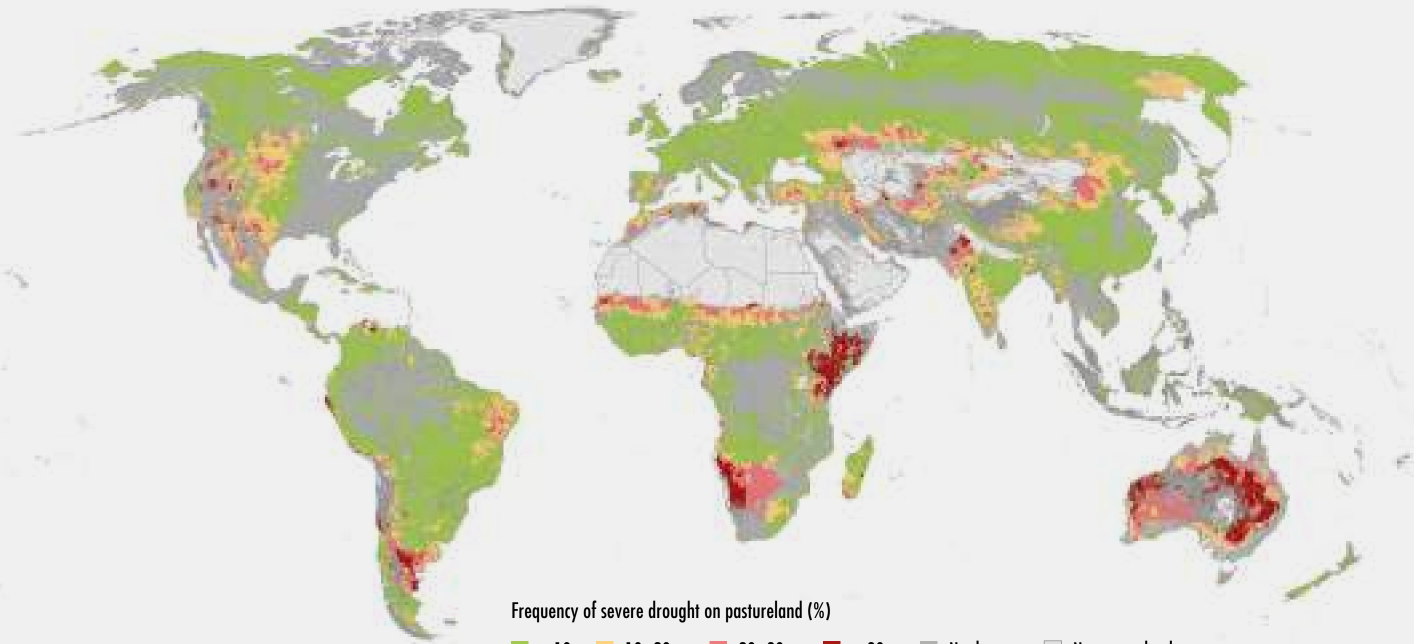
resources are found, people may be driven to migrate. Georeferenced reviews of studies have concluded that drought, dry spells, precipitation variability and weather extremes do influence migration, mainly through effects on agricultural productivity.[5] Orderly and regular migration can contribute to economic development and improve livelihoods. However, it can be disruptive during a crisis. Male outmigration may increase the domestic burden for women, shifting responsibilities in the home, with women taking on additional burdens such as caring for livestock.[6]

In terms of hectares affected, 128 million hectares of rainfed cropland and 656 million hectares of pastureland face frequent droughts, while 171 million hectares of irrigated cropland are subject to high or very high water stress. This means that about 11 percent of rainfed cropland and 14 percent of pastureland experience severe recurring droughts, while more than 60 percent of irrigated cropland is highly water stressed. More than 62 million hectares of cropland and pastureland experience high to very high water stress *and* drought frequency, affecting about 300 million people.

Heterogeneity in water constraints within and across regions

The wide range of colours in Figures 5–7 within and across countries highlights the need to employ spatial datasets when measuring water constraints. These can show differences

FIGURE 6
HISTORICAL DROUGHT FREQUENCY ON RAINFED PASTURELAND, 1984–2018

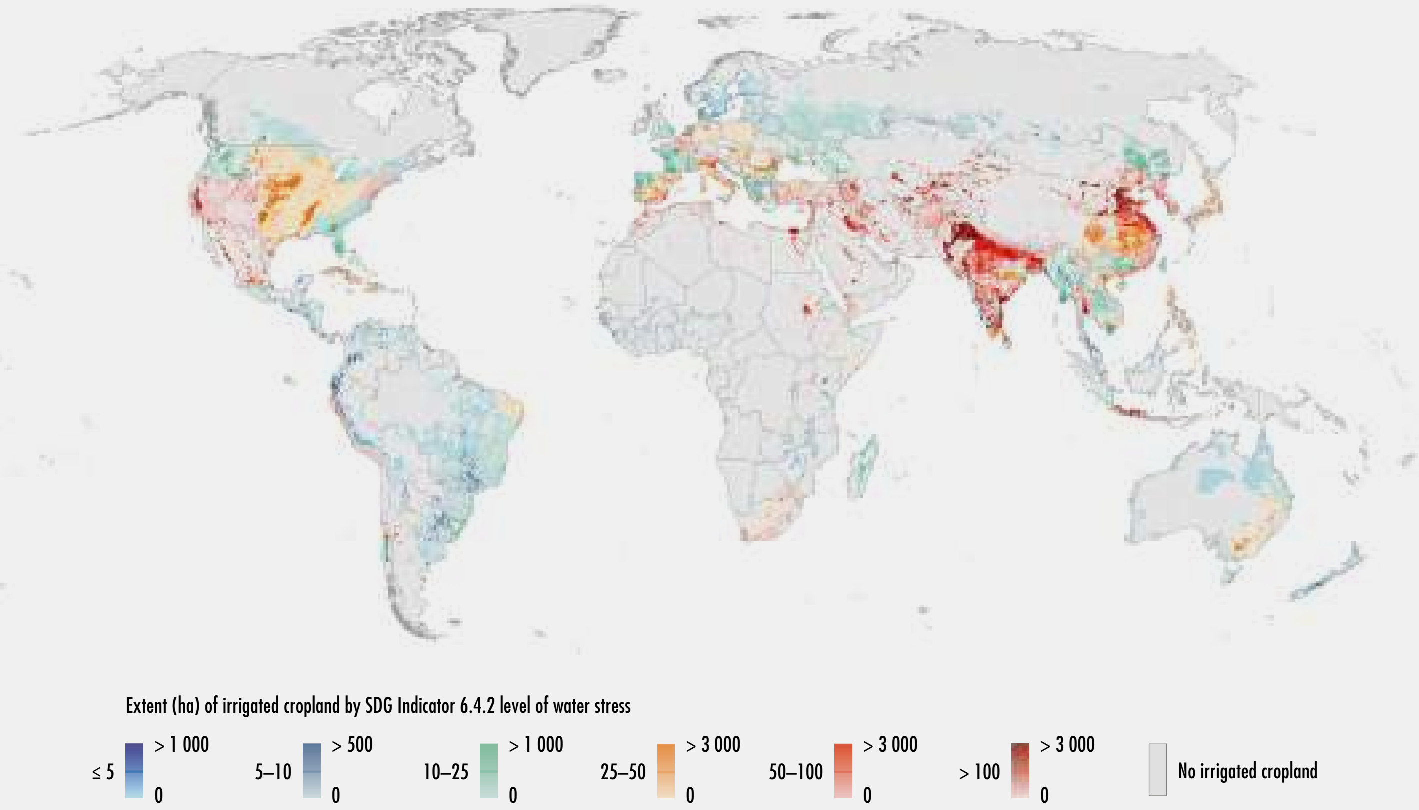


NOTES: Pastureland includes areas classified as grassland and woodland (as per FAO & IIASA. 2020),[1] which, in turn, include grassland, shrub-covered areas and herbaceous vegetation (as per Latham *et al.* 2014).[8] The sum of pastureland area in a pixel may be smaller than the pixel size. The map depicts the frequency with which more than 30 percent of grassland was affected by severe drought as follows: low when the probability of severe drought affecting pastureland is less than or equal to 10 percent; medium when it ranges between 10 and 20 percent; high for between 20 and 30 percent; and very high when it surpasses 30 percent. The indicator includes two crop-growing seasons, combined by selecting the highest drought value of the two. When there is only one season, the single value is used instead. "No data" accounts for pixels for which no level of drought is available but there is pastureland. The historical frequency of severe droughts is based on the entire time series (1984–2018).
Source: FAO elaboration based on FAO. 2019,[7] and FAO & IIASA. 2020.[1]

at subnational level, information that national-level assessments may hide but which is essential in order to identify hotspots and the most appropriate interventions. Some Andean countries (Argentina, Bolivia [Plurinational State of], Chile and Peru) and the dry corridor in Central America (El Salvador, Guatemala, Honduras and Nicaragua) are a case in point. In Peru, while the national level of water stress is very low (about 1 percent),[9] Figure 7 shows that the coastal area of the Pacific, with very low runoff, is extremely water stressed. This is also where most people live and economic activity occurs (including irrigation and mineral development),[9] making the average estimate of water stress irrelevant in policy support information. For country-level data on the area subject to drought or water stress for different production systems, see Tables A1 and A2 in the Statistical Annex.

The same area can have distinct levels of water stress and drought frequency – with the latter depending on the map layer used (cropland or pastureland) – emphasizing the need for multiple indicators and distinguishing production systems. Most countries in the Sahel region report no water stress, but Figures 5 and 6 report medium to high likelihood of severe drought there. Most vulnerable communities live in drought-prone areas and are highly dependent on agriculture for their livelihoods and food security and nutrition. Those relying on livestock

FIGURE 7
SDG INDICATOR 6.4.2 – LEVEL OF WATER STRESS ON IRRIGATED AREAS, 2015

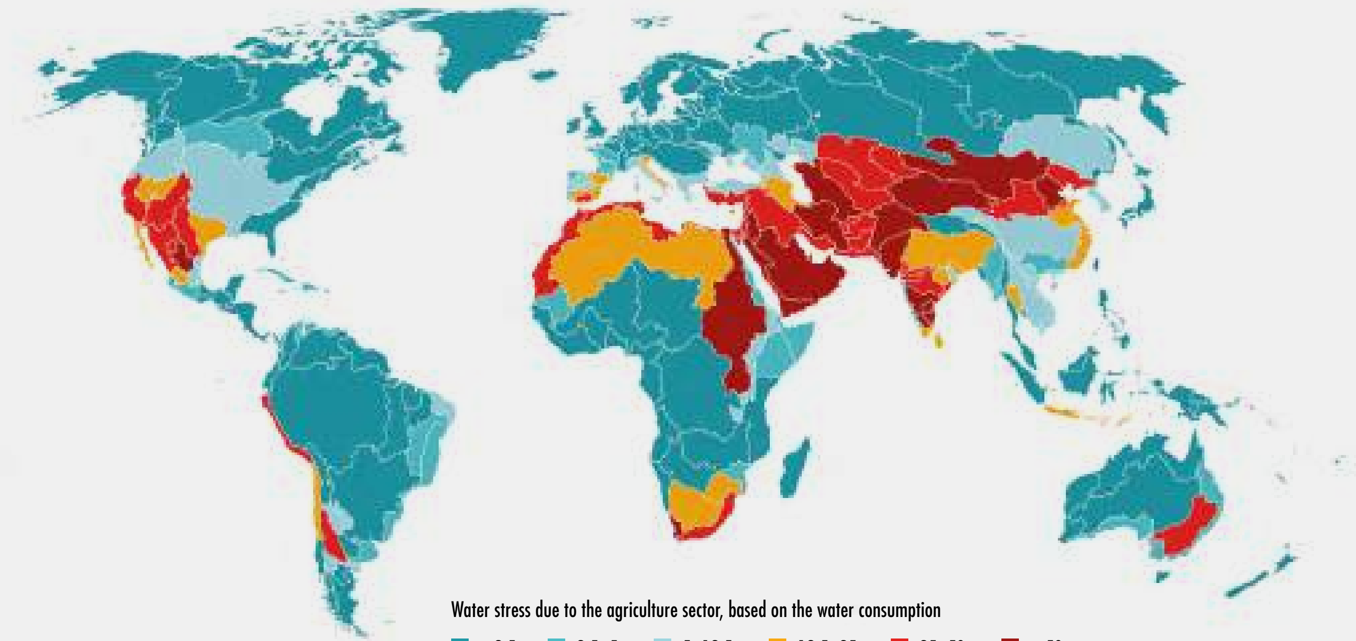


NOTES: The colour gradient shows the extent of irrigated cropland per pixel, with darker colours representing a higher number of irrigated hectares in a 10 km × 10 km pixel. SDG Indicator 6.4.2 is defined as the ratio between total freshwater withdrawn by all major sectors (agricultural, industrial and municipal) and total renewable freshwater resources, after considering environmental flow requirements. SDG Indicator 6.4.2 measures the level of water stress as follows: no water stress when the proportion of water withdrawal by all sectors in relation to available water resources is less than or equal to 25 percent; medium when it ranges between 25 and 50 percent; high for between 50 and 100 percent; and very high when it surpasses 100 percent. The level of water stress refers to 2015. For more information on the index construction and methodology, see FAO. 2018.[9]
Source: FAO elaboration based on FAO. 2020,[10] and FAO & IIASA. 2020.[1]

are particularly vulnerable, as it takes a long time to rebuild herds decimated by drought.[12] Drought causes almost 90 percent of all damage and loss to livestock.[13]

The probability of severe drought is also likely to impact irrigated areas, owing to decreased water supply and quality. In Tajikistan, the 2011 drought severely affected irrigated agriculture, as water levels in the Nurek reservoir fell sharply. As a result of low rainfall, production of wheat, barley and rice in irrigated areas fell by at least 75 percent compared with previous years.[14] Irrigation systems relying on open water resources (rivers, lake and reservoirs) are also more vulnerable to drought, which reduces the quantity of surface water delivered. In Africa, where about 80 percent of irrigated systems rely on surface water,[15] aquifers must act as primary buffers against drought. To derive a more comprehensive picture of the water challenges facing these countries, water stress and historical drought frequency are better understood when put together. ■

FIGURE 8
CONTRIBUTION OF THE AGRICULTURE SECTOR TO THE LEVEL OF WATER STRESS, BY BASIN, 2015



NOTES: The contribution of agriculture to water stress is defined as the ratio between freshwater consumed by agriculture and total renewable freshwater resources, after considering environmental flow requirements. The indicator measures the contribution of agriculture to water stress at the basin level as follows: no water stress when the proportion of agricultural water withdrawal is less than or equal to 12.5 percent; medium when it ranges between 12.5 and 25 percent; high for between 25 and 50 percent; and very high when it surpasses 50 percent. The level of water stress refers to 2015.
SOURCE: FAO. 2020.[11]

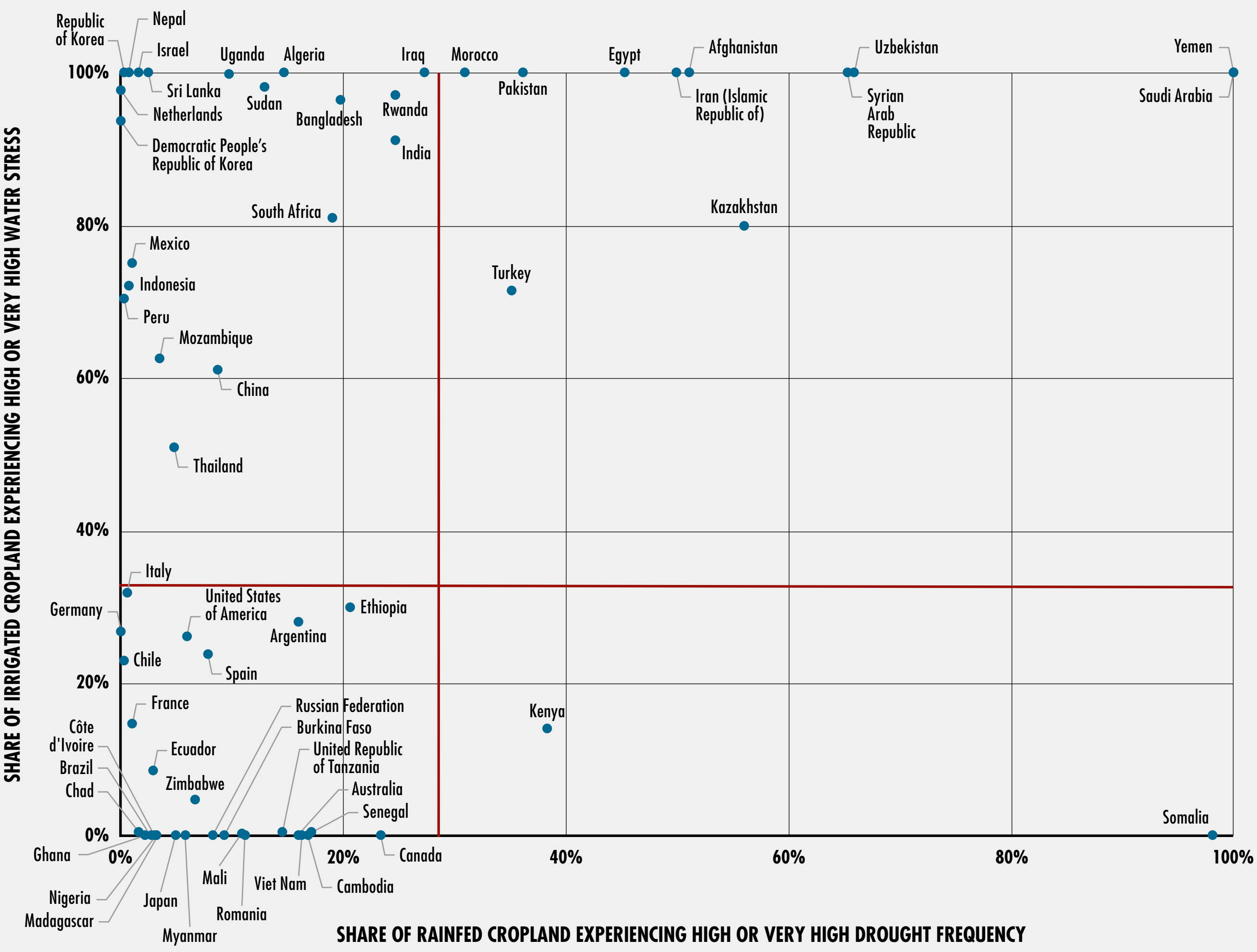
WATER SHORTAGES AND SCARCITY IN CHANGING CONTEXTS

Facing multiple water challenges – defining country profiles

Figure 9 brings together the characteristics of a country's agriculture sector and associated water challenges, displaying country profiles to frame the water constraints for each country and to identify appropriate solutions. The figure illustrates the share of rainfed and irrigated cropland subject to high or very high drought frequency or water stress, respectively, for selected countries. There are cut-off points of 33 percent for both indicators to give a sense of the gravity of the challenge in the two dimensions. However, it is where countries appear along the continuum that matters most.

Countries in the first quadrant (top right) of Figure 9 face the dual challenge of high incidence of severe drought frequency and water stress. Of the selected countries, 11 are in this situation, all in Northern Africa and Asia. For nine of them, 100 percent of their irrigated land suffers from high or very high water stress. For these countries, sound water accounting (see Glossary), clear allocation, the adoption of modern technologies and a shift to less-water-demanding crops with less irrigation will be necessary, along with »

FIGURE 9
PLACEMENT OF SELECTED COUNTRIES BASED ON THE SHARE OF RAINFED AND IRRIGATED CROPLAND EXPERIENCING HIGH TO VERY HIGH DROUGHT FREQUENCY OR WATER STRESS, RESPECTIVELY



NOTES: Countries were selected by population (more than 12 million people). Countries with 0–1 percent of cropland under high or very high water constraints were excluded (i.e. Angola, Cameroon, Colombia, Democratic Republic of the Congo, Guatemala, Guinea, Malawi, Malaysia, Niger, Philippines, Poland, Ukraine, United Kingdom of Great Britain and Northern Ireland, Venezuela [Bolivarian Republic of] and Zambia). The figure only considers hectares with an available level of historic drought frequency or water stress. The horizontal axis represents a country's share of rainfed cropland where the probability of severe drought is high or very high (i.e. greater than 20 percent). The vertical axis is a country's share of irrigated cropland under high or very high water stress (i.e. total water withdrawals more than 50 percent of renewable freshwater). A level of 0.33, or 33 percent, is taken as a threshold to separate countries with more than one-third of cropland under high or very high probability of severe drought or water stress. The level of water stress refers to 2015,[10] and historical drought frequency is based on the entire time series (1984–2018).[7] Global disaggregation of agricultural production system statistics is based on the 2010 version of the Spatial Production Allocation Model (SPAM) dataset by the International Food Policy Research Institute (IFPRI).[17]
SOURCE: FAO elaboration based on FAO. 2020;[10] FAO. 2019;[7] FAO & IIASA. 2020;[1] and IFPRI. 2019.[17]

» investment in increasing water supplies, such as through desalination.

Other countries, without the dual challenge of drought and water stress, may have more options. Many countries report a relatively low incidence of severe drought but high water stress (upper-left quadrant). Policymakers may choose to focus on shifting irrigated production towards water conservation – including water-saving crop methods and a change in planting dates and cultivars – or investing in non-conventional sources, such as desalinated water. This requires removing barriers and creating an enabling environment through legislation and regulation to facilitate financing to scale up implementation (further discussed in Chapters 4 and 5).
For countries with a small amount of cropland experiencing severe drought and water stress (bottom-left quadrant), water challenges may still be a concern but are likely at the subnational level. Countries with low access to irrigation and a small share of irrigated cropland may indicate no water stress, but that does not mean water is not scarce. They have the potential to expand irrigation either through infrastructure to extract more surface water and underground water, or by drawing on rainfall (e.g. through harvesting systems, small dams, reservoirs, etc.). Africa's agricultural water remains comparatively underdeveloped, despite viable potential to expand irrigated areas. At least 1.4 million hectares could be developed using existing or planned dams for hydropower, and at least 5.4 million hectares would be viable for small-scale irrigation.[16] This depends on financing, energy sources and prices, and labour availability (see Chapter 3).

One broad observation from Figure 9 is that, in terms of affected share of hectares, high water stress is an issue for more countries than is high incidence of severe drought. However, the rainfed cropland area in many countries is much larger than the irrigated area. Hence, even a small proportion of rainfed area at risk of drought can translate into millions of hectares. Figure 10 compares the share of rainfed and irrigated cropland under high or very high water constraints. In South Africa, despite irrigated areas being proportionately under more stress (Figure 9), in terms of hectares, the rainfed area at risk of drought is twice that of irrigated areas under water stress. Therefore, Figure 9 needs to be interpreted only for the production system to which it applies – irrigated or rainfed cropland – large or small, as it may be.

Figure 10 further indicates that water constraints alone do not drive countries' policy priorities. In Viet Nam, all affected cropland is rainfed, although more than one-third of its total cropland is irrigated. Irrigated agriculture plays a very important role in the country's socio-economic development for poverty reduction, food security and nutrition, gender equity in rural areas, and improvement to cropping patterns and the environment. For these reasons, in recent decades, Viet Nam has invested heavily in new infrastructure and the rehabilitation of existing irrigation.[18]

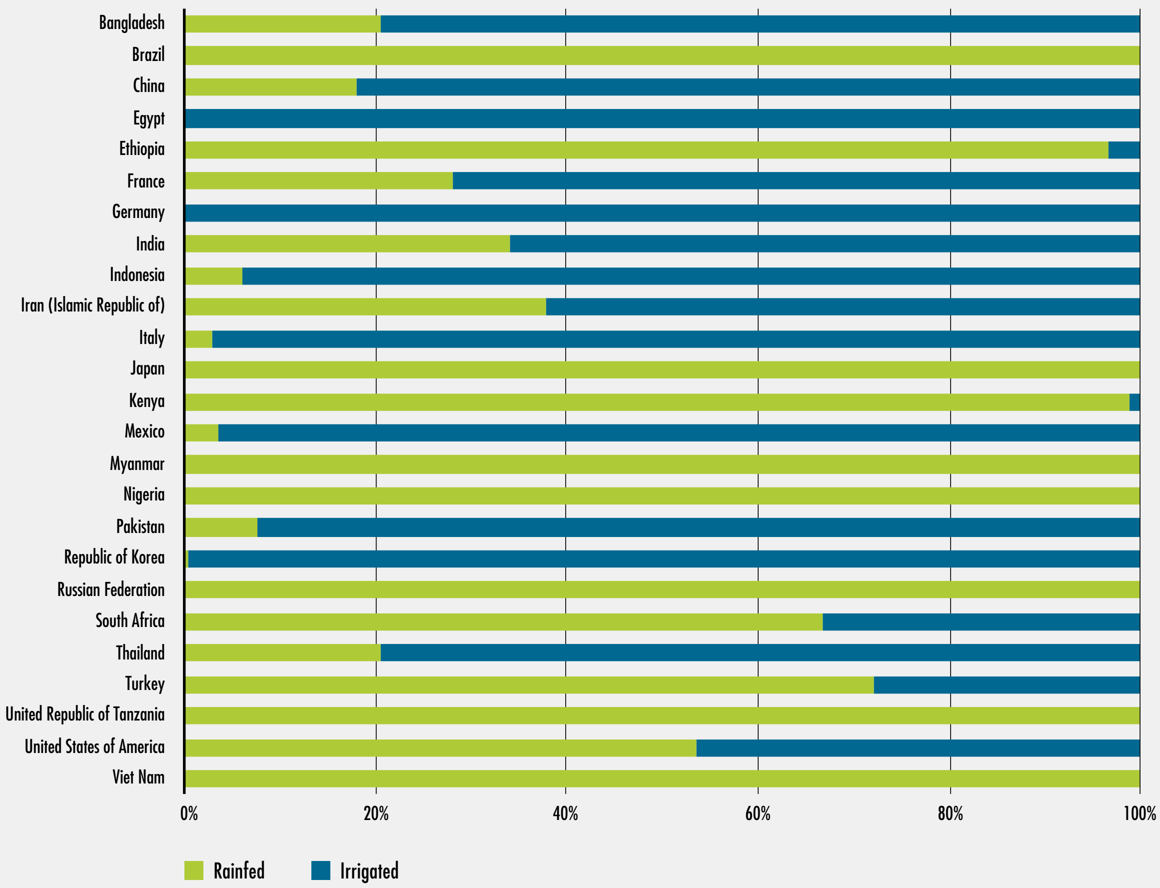
Considerable variation exists in agricultural production systems

Figure 9 identifies the water challenges countries are facing in irrigated and rainfed cropland. It is reasonable to consider the inherent differences between irrigated and rainfed production as these will determine agricultural activities and farmers' investment decisions. Farmers in rainfed areas are completely dependent on the amount and timing of rain and must make production decisions at the start of each season, based on expectations. However, farmers with access to irrigation have more control of water volumes and timing. In irrigated settings, lack of access to irrigation, varied water rights, annual stream flows, aquifer productivity, and competing water demands are important determinants of successful crop production.[19, 20] Compared with rainfed areas, irrigated areas are often associated (although not always) with higher productivity (Box 6).[21–23] For this reason, when assessing water systems at risk, irrigated and rainfed settings are often analysed separately.[i]

Even within irrigated and rainfed settings, there are different production systems and a continuum of technologies from full irrigation to full rainfed production.[25] While some farmers practise rainwater management to enhance production – diverting, capturing, storing or

i See, for example, FAO & Earthscan. 2011.[24]

FIGURE 10
SHARE OF WATER-CONSTRAINED CROPLAND BY PRODUCTION SYSTEM, FOR SELECTED COUNTRIES



NOTES: Countries were selected based on population (more than 50 million people). Only hectares with high or very high drought frequency (for rainfed cropland) and high or very high water stress (for irrigated cropland) were considered.
SOURCE: FAO elaboration based on FAO. 2020;[10] FAO. 2019;[7] FAO & IIASA. 2020;[1] and IFPRI. 2019.[17]

reapplying rainfall instead of simply allowing it to flow without intervention – others may not. Not all farmers who irrigate their fields do so the same way, some irrigating more frequently and intensively than others. They may use different techniques and extract water from varied sources, which may influence its quality.[26] (See In Focus: Agriculture, water pollution and salinity, p. 44.)

These differences are crucial determinants of successful production and likely to become more relevant as water shortages and scarcity increase. It is important to distinguish between separate production systems, which may be affected differently and have varied capacities to respond to water constraints. This report distinguishes between three systems delineated by water supply and farmers' inputs, based on the SPAM dataset by IFPRI: (i) irrigated; (ii) high-input rainfed crop production; and (iii) low-input rainfed crop production.[27] For further discussion on the SPAM methodology, see Box 7.

»

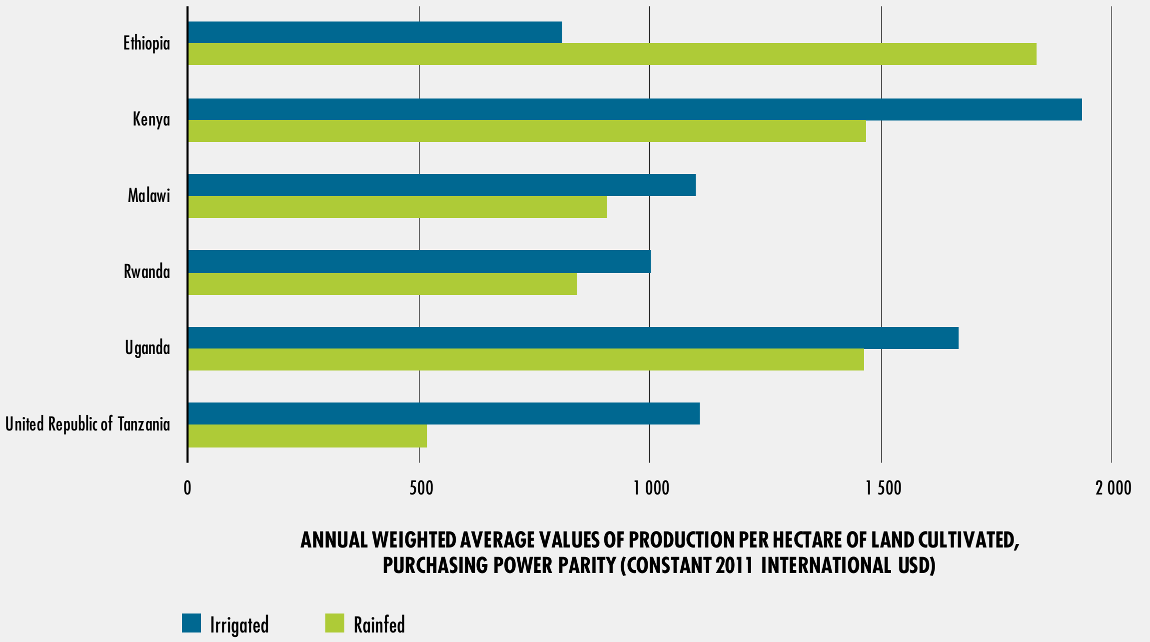
BOX 6
LAND PRODUCTIVITY IN IRRIGATED AND RAINFED AGRICULTURE IN SUB-SAHARAN AFRICA

Agricultural productivity is complex as output depends on a range of different inputs, including land, labour, fertilizers, chemicals and irrigation. A recent study by the World Bank highlights how irrigation predictably leads to a fall in the overall volatility of agricultural output, raising cropping intensity and encouraging the cultivation of high-value crops.[28] Irrigation is an important source of global agricultural output growth.[28, 29]

This box examines differences in land productivity – value of crop production per hectare of land cultivated* – between irrigated and rainfed agriculture using household survey data in rural areas of Ethiopia, Kenya, Malawi, Rwanda, Uganda and the United Republic of Tanzania between 2004 and 2014. As expected, irrigated areas are more productive (see the figure in this box), except in Ethiopia.

Across the six countries, Ethiopia reports the lowest percentage of households using irrigation (9 percent), after Uganda and the United Republic of Tanzania. Almost half the irrigated area in Ethiopia relies on traditional forms and only a negligible amount uses high-tech systems, such as sprinkler and micro-irrigation.[32] The mix of crops can also help explain higher rainfed productivity. In Ethiopia, high-value crops such as coffee, oilseed and pulses are mostly rainfed,[33] while industrial crops such as sugar cane, cotton and fruit are mostly irrigated.[32, 33] Both farm systems produce vegetables and cereals; however, teff – arguably the most important cereal crop in Ethiopia – is predominantly rainfed and more valuable than other cereal crops.[33, 34] This finding suggests irrigation alone does not determine higher productivity and, depending on the level of other inputs (including crop varieties and irrigation services), irrigation may provide only marginal benefits relative to rainfed agriculture.

LAND PRODUCTIVITY VALUES IN IRRIGATED AND RAINFED AREAS, 2004–2014



* Values of crop production are not net of production costs and may come from different sources, e.g. crop sales, crops saved for seed. As a general caveat, household surveys tend to underestimate the share and contribution of medium-sized and large farms.[30, 31]
NOTES: Estimates for Uganda were averaged across survey results for 2010, 2011 and 2014. For Malawi, these are based on 2004, 2011 and 2013. The United Republic of Tanzania estimates are from surveys in 2009, 2011 and 2013. For Ethiopia (2014), Kenya (2005) and Rwanda (2014), only one survey wave was used.
SOURCE: FAO. 2020.[35]

BOX 7
A LOOK BEHIND SPAM'S DIFFERENT PRODUCTION SYSTEMS

Building on the FAO Global Agro-Ecological Zones (GAEZ) project and work by the International Institute for Applied Systems Analysis (IIASA),[36] IFPRI's SPAM dataset distinguishes four production systems, based on the water supply and inputs used by farmers:

- **Irrigated production** refers to the crop area with either full or partial control irrigation, employing modern inputs such as modern varieties, fertilizer, and advanced management such as soil and water conservation.
- **High-input rainfed production** uses high-yield varieties and some animal traction and mechanization. Such settings usually apply fertilizer with chemical control of pests, disease and weeds. Most produce is sold in the commercial market.
- **Low-input rainfed production** uses traditional varieties and mainly manual labour without (or with little) application of nutrients or chemicals for pest and disease control. Production is mainly, but not entirely, for own consumption.
- **Subsistence rainfed production** refers to low-input production by small-scale farmers for their own consumption. This category covers farmers who need to grow crops to survive but do not have sufficient inputs or suitable cropland conditions.

The allocation of irrigated cropland is based on the Global Map of Irrigated Areas (GMIA, version 5.0), developed by FAO and the University of Frankfurt.[37] Shares between high- and low-input rainfed production are based on general assumptions for individual countries and crops, and using fertilization as a proxy for high-input use. Where irrigated, fertilized and non-fertilized crop areas are known, it is possible to estimate the share of high-input rainfed cropland by deducting irrigated from fertilized areas.[27] Allocating cropland between low-input and subsistence rainfed production is based on expert opinion and crop suitability criteria, not actual input use. Therefore, this report opted to merge the data of low-input and subsistence rainfed production.

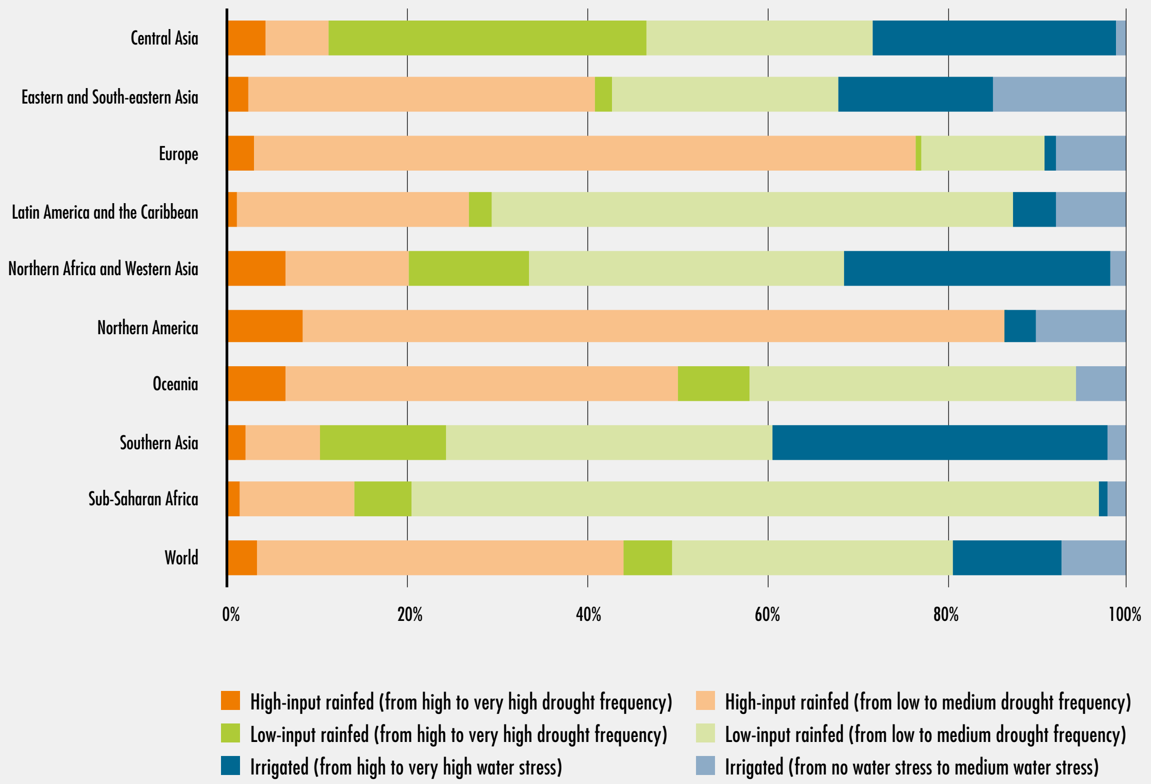
This methodology assumes that most, if not all, irrigated systems employ modern inputs and advanced management, even without supporting data. Revisiting the use of modern agricultural inputs in sub-Saharan Africa, Sheahan and Barrett (2017) found that farmers rarely use agronomic synergies together, for example, from coupling irrigation, improved seeds and inorganic fertilizer.[38] The GAEZ project also acknowledges that different levels of inputs and management may be applied under irrigated conditions.[36] Acknowledging this is important in order to avoid classifying irrigated systems as high-input production systems, and to detect interventions that promote efficient and productive irrigation as well as to protect and sustainably manage water. Furthermore, employing modern inputs does not automatically translate into higher productivity, as policy distortions may lead to suboptimal choice of crops and inefficient resource use, particularly of water.

Another limitation with this dataset is that it categorizes cropland as either rainfed or irrigated, whereas different farms consider water management across a spectrum ranging from purely rainfed to purely irrigated.[26] In between, there are farmers who use supplemental irrigation on only part of a field, while others irrigate very often.[25]

Despite these limitations, this dataset allows estimation of crop area under each production system for a large sample of countries. Therefore, it can be used as a proxy for agricultural development levels in different areas.

» Different production systems are an indicator of the level of a country's agricultural development as well as its ability to address water constraints. In countries with more land under high-input rainfed and irrigated production, farmers have greater access to modern inputs and infrastructure, including irrigation, and crops can tolerate higher temperatures with higher yields and greater stability.[24, 28] Based on Figures 5 and 7, Figures 11 and 12 display the relative share of each production system and incidence of water shortages and scarcity in each world region,

FIGURE 11 SHARE OF CROPLAND BY PRODUCTION SYSTEM AND LEVEL OF WATER SHORTAGES AND SCARCITY, BY REGION



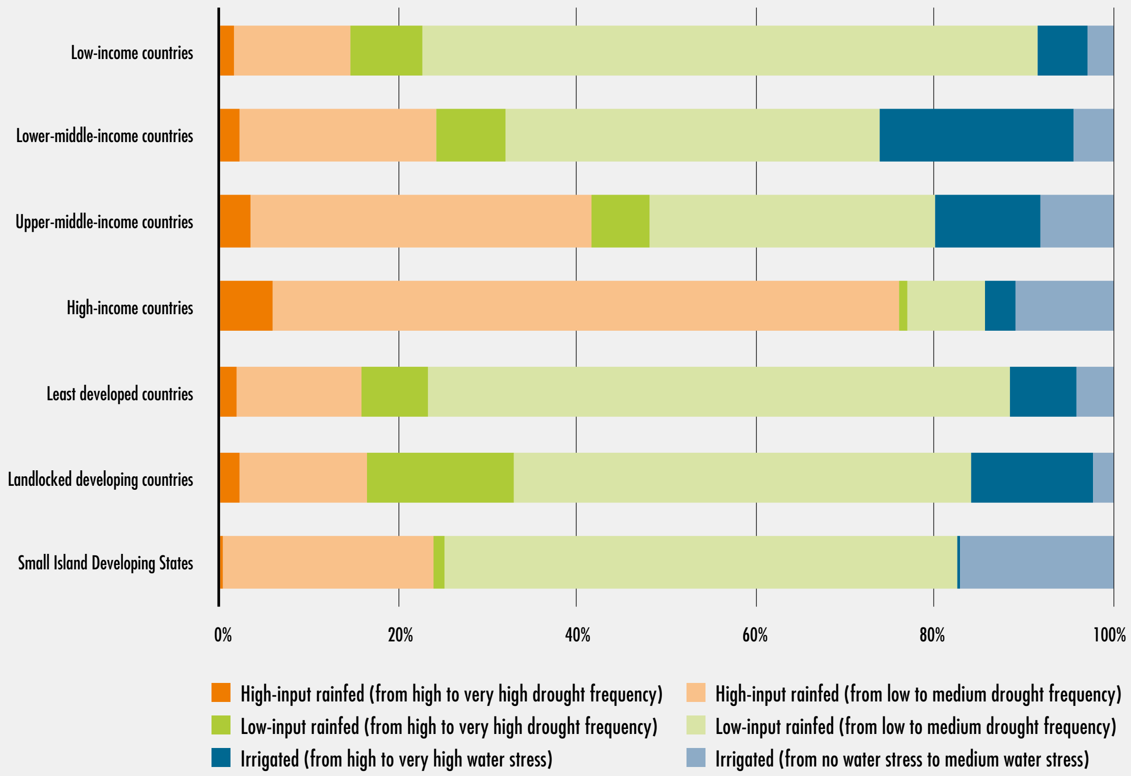
NOTES: High to very high drought frequency refers to a probability of severe drought higher than 20 percent, affecting more than 30 percent of cropland. High or very high water stress refers to total withdrawals being more than 50 percent of renewable freshwater. Only cropland hectares with available levels of drought frequency and water stress are considered. The level of water stress refers to 2015,[10] and the historical drought frequency is based on the entire time series (1984–2018).[7] Global agricultural production system statistics are based on the 2010 version of IFPRI's SPAM dataset.[17] Oceania includes Australia and New Zealand.
SOURCE: FAO elaboration based on FAO. 2020;[10] FAO. 2019;[7] FAO & IIASA. 2020;[1] IFPRI. 2019.[17]

income grouping and country classification. The bar colouring indicates the level of water shortages or scarcity in each system.

Production systems, type and extent of water shortages and scarcity vary considerably across different regions (Figure 11). Central Asia stands out as facing recurring agricultural drought on more than half of its low-input rainfed cropland, and almost all of its irrigated areas are under high or very high water stress. Northern Africa and Western Asia are similarly challenged in both dimensions, and irrigated farming systems face water-stress conditions in all Asian subregions.

High-income countries, such as in Europe and Northern America, have a considerable amount of cropland under high-input rainfed production. They have temperate climates and the highest public expenditure on agricultural research and development (R&D) and investment as a share of gross domestic product (GDP).[39] Agriculture is also highly capital-intensive and efficient.[39]

FIGURE 12
SHARE OF CROPLAND BY PRODUCTION SYSTEM AND LEVEL OF WATER SHORTAGES AND SCARCITY, BY INCOME LEVEL AND COUNTRY GROUPING



NOTE: High to very high drought frequency refers to a probability of severe drought higher than 20 percent, affecting more than 30 percent of cropland. High or very high water stress occurs when withdrawals are more than 50 percent of renewable freshwater. Only cropland hectares where drought frequency and water stress data are available are considered. The level of water stress refers to 2015,[10] and the historical drought frequency is based on the entire time series (1984–2018).[7] Global agricultural production system statistics are based on the 2010 version of IFPRI's SPAM dataset.[17] Income data refer to the World Bank's List of Economies,[58] and country grouping data refer to United Nations Standard Country or Area Codes for Statistical Use.[59]
SOURCE: FAO elaboration based on FAO. 2020;[10] FAO. 2019;[7] FAO & IIASA. 2020;[1] IFPRI. 2019;[17] United Nations. 1998;[59] and World Bank. 2017.[60]

Conversely, in sub-Saharan Africa, more than 80 percent of cropland is rainfed with low-input levels, while only 3 percent is irrigated or equipped for irrigation. Capital intensity and agricultural research are much lower than in high-income countries.[39] Farmers – particularly women – have difficulty accessing irrigation equipment, mechanization, and improved seed and fertilizer, and/or they lack the skills and technology to retain water in the soil. Despite these challenges, a relatively small share of rainfed cropland in sub-Saharan Africa suffers frequent drought.

Not all low-income and lower-middle-income countries lack access to irrigation and modern inputs (Figure 12). For example, countries in Southern Asia employ modern inputs on, and irrigate 40 percent of, their cropland despite many having a low level of development. Most irrigated areas are under high or very high water stress. In these water-scarce countries,

BOX 8
THE POTENTIAL ROLE OF TRADE IN MANAGING WATER SCARCITY

Virtual water is the volume of water required to produce a food product, which is thus virtually embedded in the product.[41] International commodity trade implies long-distance virtual transfers of water. With increasing trade between nations and continents, and dietary shifts towards more water-intensive food products, water is often used to produce exported goods. For water-scarce regions, importing water-intensive commodities, instead of producing them with local water, can be an effective way to meet water deficiencies. Virtual water can be an alternative source of water, provided there is equitable and inclusive access to those imports.

Virtual water trade could also play an important role in saving global resources if trade occurs between regions with higher water productivity and those with lower productivity. The total "water saved" through trade is about 5 percent of global agricultural water use.[42, 43] Jackson *et al.* (2014) assert that the impact should not be overestimated, and their findings are in line with the share of international trade vis-à-vis consumption.[44] Liu *et al.* (2019) conducted a comprehensive review on studies of food-trade water savings and losses, finding the savings are reduced, often not being driven by scarcity.[45] Yet, the authors found that global food trade has reduced pressure on freshwater. For some countries, such as Algeria, Mexico and Morocco, water savings through trade can be very high.[42–44] Another recent study has found that countries with higher per capita GDP are better able to mitigate water stress by importing food.[46]

Yano *et al.* (2016) provide a global analysis on whether a region's international food trade patterns alleviate or contribute to water scarcity.[47] The authors find that, while Southern Asia is a net importer of virtual water, the region exports more food produced from scarcer water than is used to produce imported foods. It is not using its water resources sustainably in international trade, worsening water scarcity. South America, a net virtual water exporter, produces food products with abundant water resources, suggesting its international trade patterns do not contribute to water scarcity. Regions that alleviate water scarcity through international trade include parts of Asia, Northern Africa, Eastern Africa, Western Africa and Central America. Dalin *et al.* (2017) show that about 11 percent of non-renewable groundwater used for irrigation is embedded in international food trade, of which two-thirds is exported by India, Pakistan and the United States of America.[48] Some countries, such as China, Iran (Islamic Republic of), Mexico and the United States of America, are particularly at risk because they produce and import food irrigated from rapidly depleting aquifers.

water productivity R&D is important, coupled with sustainable production to maintain soil moisture and supplemental irrigation to overcome increasing dry spells during plant growth. There is also the potential to engage in virtual water trade to reduce usage and depletion of water resources (Box 8). In countries with little incentive to use irrigation more efficiently to save water, public policies – through, *inter alia*, improved access to extension services, credit and technology – will shape those incentives. Managing competing demands for water is also key, particularly in lower-middle-income countries with a large irrigated area under water stress, and where urbanization is likely to continue, and expanding cities, industries and tourism may take priority for water supply. This will reduce the water available for irrigated, urban and peri-urban agriculture, such that crop production will compete with growing demand from other users for land and water,[24] with greater reliance on food imports likely. Given that a significant share of urban water is non-consumptive, its reuse in agriculture after treatment has great potential, particularly in water-scarce countries.[40]

For countries sharing similar characteristics and constraints in their development efforts, least developed countries have an almost equivalent allocation of production systems as those in the low-income group – i.e. heavy predominance of low-input rainfed production and a low share of cropland under irrigation (Figure 12). The minimal irrigated area is already under high or very high water stress. This is a challenge shared by landlocked developing countries, with the added concern that more of their rainfed farming systems suffer drought, leaving them particularly vulnerable to climate change effects. Up to 95 percent of their total food derives from domestic production,[49] and almost 70 percent of their cropland uses low levels of inputs, highlighting the opportunity and necessity for agricultural transformation. Not having an outlet to the sea makes access to technologies, markets, information and credit more difficult and costly.[50, 51]

SIDS also share unique geographical, economic and social circumstances as a result of their isolation or limited natural resources. Their land area and remoteness limit agricultural production, with low diversity of agricultural commodities, and increase import dependence.[52, 53] These countries use more irrigation as well as high inputs in rainfed settings, partly because some SIDS are working to improve irrigation, groundwater extraction and rainfall catchment.[54] They have very few issues with recurring droughts or water stress. However, with climate change and overuse of natural resources, they are under threat from sea-level rise, coastal erosion and less freshwater for agriculture.[52] As a result of climate change, rainfall is projected to steadily reduce in the Caribbean and Pacific SIDS, a serious problem for the sustainability of rainfed systems.[55]

Heterogeneity in input use, irrigation and management practices can also be significant within regions and countries, affecting farmers' capacity to cope with water shortages and scarcity. The World Bank's Living Standards Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA) explores variations of within-country input and irrigation use that macrolevel statistics mask. In Ethiopia, the share of households using chemicals ranges from 16 percent to 55 percent by region (compared with a national average of 40 percent). This large spread also applies to inorganic fertilizer, with ranges from 20 percent to 70 percent (60 percent nationwide).[35] Spatial datasets also illustrate the heterogeneity of input levels across and within regions (see Figures A1 and A2 in the Statistical Annex).

Various factors explain this heterogeneity. They include input and output prices, market access, investments in infrastructure and agricultural extension services. Policies should start by supporting farmers – via secure land and water tenure, credit and extension services – to reduce water-related risks. In Bangladesh, more-secure tenure rights, improved access to agricultural extension and electricity facilitate drought mitigation.[56] Given that one of the main obstacles to addressing water challenges is the ignoring of gender issues and women's access to natural resources, the Grameen Bank in Bangladesh gives small loans to poor women, to help make decisions on allocating resources under changing economic and climate conditions.[57] ■

THE IMPACT OF CLIMATE CHANGE

Extreme water shortages or scarcity affect almost 1.2 billion people globally. Climate change will add to this problem through increased water stress and recurring droughts, placing additional stress on agricultural systems that already have to satisfy rising demand from population growth and dietary changes. Both the livelihoods and the food security and nutrition of rural and urban communities are at risk. The rural poor are the most vulnerable[61] owing to their high dependence on natural resources, limited resilience and protection against climate-related risks and shocks, and power imbalances over access to natural resources such as water and land.

Multimodel assessments have explored how climate change might affect future global water risks. One study found that climate-driven changes in evaporation, precipitation and runoff would result in a 40 percent increase in the number of people who will have to survive on less than 500 m^3 of water per year, considered "extreme" water scarcity (see Chapter 1,

p. 5).[62] Another study found that an additional 0.8 billion to 3.9 billion people will experience water stress by 2050.[63] The authors found that exposure to water scarcity would increase steeply with a temperature rise of up to 2 °C above pre-industrial levels in many regions (including Northern and Eastern Africa, Arabian Peninsula and Southern Asia) and then stabilize by 4 °C. The authors' assumption was that beyond this point, there would be no further areas where precipitation would decrease significantly.

Schewe *et al.* (2014) found that, with warming of 2 °C compared with the present day,[i] the annual mean discharge (i.e. runoff accumulated along the river network) would drop and increase scarcity in several regions, among them the Mediterranean, the Near East and large parts of Southern and Northern America.[62] By contrast, India, Eastern Africa and high latitudes in the Northern Hemisphere could expect to receive more water in a warming world. There is considerable uncertainty within these models, some suggesting global water scarcity will double while others predicting only modest change. The models do not factor in interannual and seasonal availability and variability of water. Fung, Lopes and New (2011) find climate change effects differ substantially across river basins, and seasonality in runoff may be more pronounced in a +4 °C compared with a +2 °C world.[64] Even where annual average runoff increases, dry seasons can become more stressed.

Climate change will also play a strong role in water shortages. A recent study finds that 129 countries will experience increased drought mainly owing to climate change.[65] Drought is likely to become more frequent and severe by the end of the twenty-first century in some parts of Southern America, Western and Central Europe, Central Africa and Australia.[66] Drought can produce negative economic growth, and the consequences for human development and women's empowerment may be long-lasting or even permanent. In sub-Saharan Africa, women exposed to drought in early childhood are significantly less wealthy as adults, have reduced adult height and receive fewer years of formal education.[67] A great concern is that these impacts can be transmitted across generations, with children of women affected by drought more likely to have low birth weight. Climate change also affects flood hazards. Dankers *et al.* (2014) found an increase in flooding owing to climate change over more than half the global land surface.[68]

Although there is uncertainty on their location and magnitude, the effect of these changes on water availability will have a sizeable impact on crop yields for rainfed and irrigated areas.[69] Direct climate impacts on heavily irrigated regions could see reversion of from 20 million to 60 million hectares of cropland from irrigated to rainfed management.[70] Freshwater in other regions could ameliorate these losses, but will require substantial infrastructure investment (e.g. supplemental irrigation). Trade may be an adaptation measure to climate change with policy ramifications (Box 8).[71] Climate change also affects freshwater ecosystems, fish and other aquatic populations that have low buffering capacity and are sensitive to climate-related shocks and variability.[72] Exceptionally, climate change effects can be beneficial to inland fisheries (e.g. for some native and exotic fish species).

Water management will be key to equipping people and societies to make adjustments across systems, sectors and scales to withstand, recover from and anticipate the impacts of climate change.[73] There is a need for more scientific information and data at the local level to be included in multi-stakeholder decisions.[74] The evidence for climate change may be enough to define approaches or investment levels.[61] Where uncertainty poses challenges on the action to be taken and where to focus investments, the best water management options are robust, the "no regrets" type of policies. These demonstrate satisfactory performance across a range of possible futures, and make agricultural production more resilient to future impacts, alongside equitable and inclusive measures.[61] A good example is contingency planning to adapt to droughts of varying intensity and duration. If complemented by flexibility, this approach will retain the ability to respond to future events, changes in climate and hydrology patterns, and residual risk.[73] Recognizing that most climate

i The term "present day" refers to the 1980–2010 average, about 0.7 °C warmer globally than in the pre-industrial era.[62]

change impacts are likely to alter the water cycle, climate-smart agriculture strategies – guiding actions to re-orient agricultural systems to support development and food security and nutrition in a changing climate – should be viewed through a water lens. ■

ADDRESSING WATER SHORTAGES AND SCARCITY – THE WIDER CONTEXT

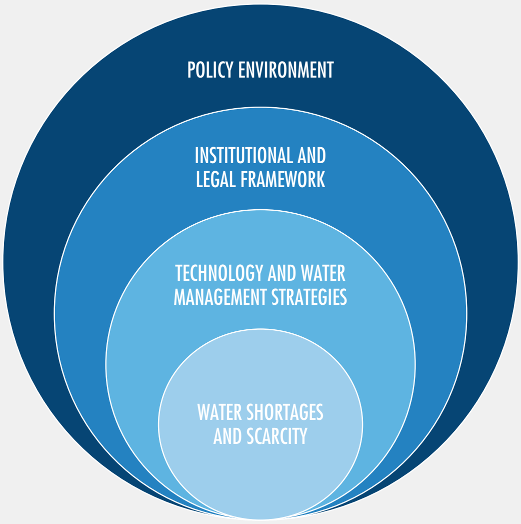
This chapter has shown how almost one-sixth of the world's population live in areas with very high severe drought frequency or very high water stress. Water requirements will only increase owing to population and economic growth, dietary changes and climate change. Thus, there is a need to adapt water and sectoral policies, as well as management strategies, to use water in ways that meet the needs of people and the environment today, tomorrow and beyond. This is a significant governance challenge, involving important trade-offs and opportunities.

The most appropriate solution for one farmer, country or region may not be the same as that for another, as situations vary widely across production systems – rainfed and irrigated – and analysis and proposals for improvement can be highly specific. In irrigated settings, the water scarcity challenge will require both supply management, with selective development and use of unconventional water resources (seawater desalination, brackish water and reuse of wastewater), and vigorous demand management, with actions to optimize existing supplies.[75] Demand management requires recognition of the economic value of water along with cost recovery, although with concern for affordability and security of the human right to water and food, particularly for the poor. There is also a need to address water supply through conservation of water-related ecosystems. In rainfed systems, on-farm conservation to increase infiltration and water storage in the soil may be the most relevant option to increase production. Water harvesting and storage systems can also contribute to increasing water availability and agricultural production at household and community levels, and to overcoming drought.[76]

The most appropriate mix of supply and demand management will depend on local conditions, and it is unlikely that a single set of options can be the optimal solution.[76] Nor is a particular option desirable in all contexts. Policy options and related strategies will largely be shaped by elements such as a country's level of development, water constraints, and the governance, political, socio-economic and cultural structures.[75, 77] Various stakeholders view water scarcity differently, and they implement different adaptation and mitigation strategies as a function of their power and capacities. A critical concern is to ensure environmental flows, ecosystem services and non-consumptive use of freshwater, often not considered owing to a lack of proper economic valuation.[72] Supporting necessary water management strategies calls for an inclusive enabling environment based on a set of mutually supportive policies and a comprehensive legal framework with coherent incentives and regulatory measures, such as secure land and water tenure. It also means creating and strengthening institutions and mechanisms that transcend traditional boundaries between sectors.[75] Governance mechanisms are needed for cross-sectoral coordination and policy coherence, involving a variety of users and stakeholders to identify key trade-offs and synergies, and for efficient, sustainable and equitable water resources management. Water demand and supply strategies should also have a financing strategy to cover the necessary investment.

Figure 13 illustrates how these dimensions come into play. The challenge of greater water shortages and scarcity (first circle, starting from the bottom) calls for integrated water management and technologies (second circle). These include, *inter alia*, desalination, pollution control and greater water-use efficiency, conditioned by technical planning and investment economics at the organizational and

FIGURE 13
PLACING WATER SHORTAGES AND SCARCITY RESPONSES WITHIN THE BROADER POLICY CONTEXT



SOURCE: FAO elaboration based on FAO. 2012, Figure 2.[76]

management levels. In turn, these are influenced by the institutional and legal framework (third circle) – encompassing water rights, licensing, regulations, incentive measures and the institutional set-up – and the overall policy environment (fourth and last circle) – including societal choices, priorities, sectoral policies (e.g. agriculture, municipalities and industry) and trade-offs.[76] Chapter 3 reviews available technologies and agriculture water management strategies (second circle) to adapt to increasing water shortages and scarcity. The latter dimensions in the third and fourth circles are discussed in more detail in Chapters 4 and 5. ■

CONCLUSIONS

This chapter has shown that almost 1.2 billion people live in areas with issues of severe water shortages or scarcity in agriculture, putting their lives and livelihoods at risk. Water constraints vary spatially and over time; some countries and regions are more vulnerable than others. The majority of these 1.2 billion people live in Southern Asia, where about 80 percent of the population in countries such as Pakistan and Sri Lanka live in affected agricultural areas. Other parts of Asia and Northern Africa are also disproportionately affected.

This chapter has further traced different dimensions of water shortages and scarcity – recurring droughts and water stress – and how they impact the agriculture sector and different population groups, depending on the extent to which they rely on irrigation or rainfall and employ high levels of inputs. The severest challenges are very high drought frequency and very high water stress in rainfed and irrigated agriculture, respectively. Challenges are particularly severe in low-input rainfed agriculture, which tends to be the dominant production system in low-income countries and among poor and vulnerable groups. It is likely that the additional food to satisfy future demand will come from increasing productivity on existing land. As populations and economies grow, consumption patterns move towards more water-intensive foods, and the impact of climate change deepens, adaptive technical solutions will be needed to improve water productivity in rainfed and irrigated settings while protecting environmental flows (see Chapter 3). In turn, this will require the adoption of appropriate institutions and incentives (presented in Chapter 4). In some cases, there is potential to engage in virtual water trade to reduce water use and depletion of water resources. ■

IN FOCUS

AGRICULTURE, WATER POLLUTION AND SALINITY

Good water quality is a critical element of the SDGs. It is essential for human well-being, for use in agriculture – including livestock, inland fisheries and aquaculture – industry and municipalities, and to support freshwater ecosystems and the services they provide. Pollution and salinity are a global challenge that has increased in high- and low-income countries, undermining economic growth as well as socio-environmental sustainability and the health of billions of people.[78] Agriculture and water quality are closely associated in a bi-directional relationship. When not managed correctly, agricultural practices can increase pollutant loads (i.e. nutrients, salts, sediments, agrochemicals and pathogens) in groundwater and surface water. In many countries, agriculture is the main source of water pollution. Agriculture can also be heavily impacted by poor water quality, leading to increased costs and lower profitability. It can thus be both the cause of pollution and its victim.

Water pollution from agriculture – cause

Agricultural pressure on water quality comes from crop and livestock production systems and aquaculture. All of these have expanded and intensified to meet increasing demand from population and economic growth and changing diets.[78] While crops and livestock are the main sources of pollution, aquaculture is also a problem. Chile, for example, has consistently applied biosecurity measures to its salmon production systems. Yet, expanding production continues to raise serious sanitary and environmental issues, including the spread of the infectious salmon anaemia virus.[79] In response, the industry has set ambitious targets in an effort to gradually reduce the use of antibiotics in salmonculture, and research is ongoing to help ensure that aquaculture is both socially and environmentally sustainable. Pollutants from agriculture (cropping systems, livestock and aquaculture) can reach water resources in many ways. Typical pollution pathways are: (i) from soil solution to deep percolation and groundwater recharge; (ii) from runoff, drainage water and floods to streams, rivers and estuaries; and (iii) from natural or human-induced soil erosion to sediment-rich streams.[78] Water pollutants are commonly characterized as point or non-point (diffuse) pollution, according to their source and pathway to the receiving environment. This is an important function of water quality policy and pollution regulation:

- **Point-source pollution** originates from an identifiable agricultural operation and is directly discharged to receiving waterbodies at a discrete location, such as confined intensive livestock operations. Examples include waste (manure, slurry and wastewater) from feed lots and other intensive larger-scale livestock operations; aquaculture; irrigation drainage; and disposal of animal carcasses.

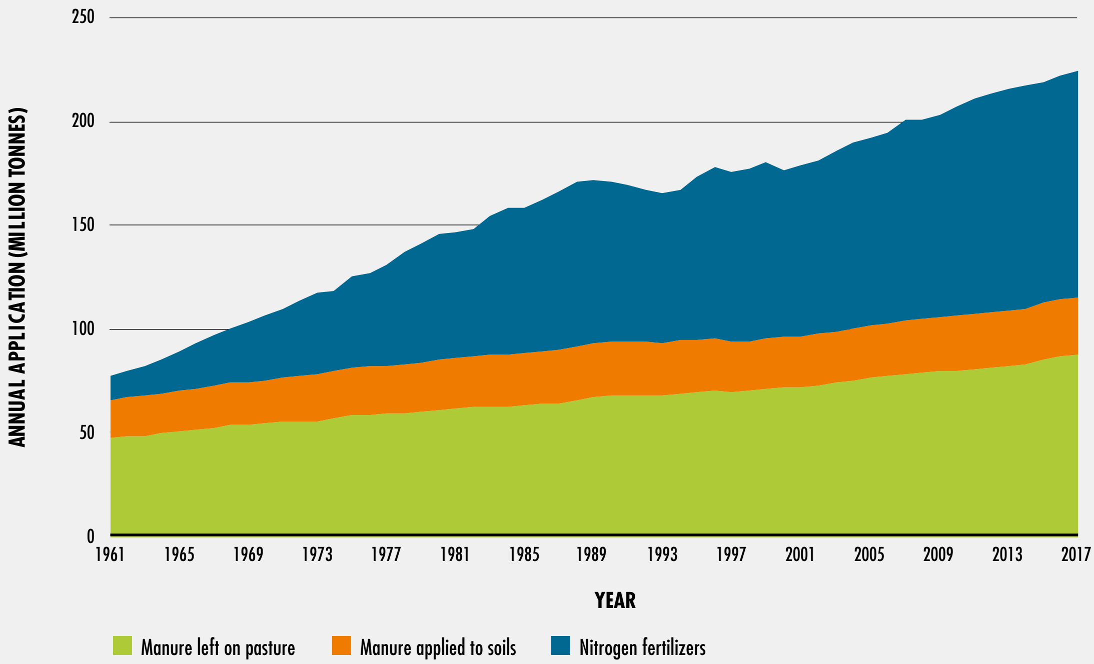
- **Non-point-source (or diffuse) pollution** has multiple non-identifiable agricultural origins, which are not easy to measure because of its diffuse nature. Examples include manure spreading; movement of soil particles, fertilizers, pesticides, bacteria, micro-organisms and antimicrobial compounds via leaching; and surface and subsurface runoff from cropland and grazing systems.

The main agricultural contributors to water pollution, and the main targets for control, are nutrients, pesticides, salts, sediments, organic carbon, pathogens, heavy metals and drug residues.[78] These typically come from diffuse sources and pathways.[78, 80]

Use of chemical fertilizers and livestock manure to provide nutrients (nitrogen, phosphorus and potassium) to cropland has increased markedly in recent decades (see Figure A). Where excess nitrogen and phosphorus are not fully used by growing crops, they can be lost through runoff, thereby affecting water quality.[81] Out of the 115 million tonnes of livestock manure deposited or applied to soils in 2017, about one-third was lost to leaching or washed off via surface runoff.[82]

Other agrochemicals such as pesticides, which include insecticides, herbicides, fungicides and plant regulators, are also widely used in agriculture.[78] Since 1990, global use of pesticides has increased by 80 percent; however, in the past decade, their use has stabilized.[83] Pesticides reach water resources through five major pathways: (i) being carried away via surface runoff; (ii) drifting outside the intended area when sprayed; (iii) leaching through the soil profile; (iv) spill; and (v) being carried off by eroding soil.[84] The use of pesticides has allowed agriculture to expand. »

FIGURE A
GLOBAL NUTRIENT INPUTS TO AGRICULTURAL SOILS FROM LIVESTOCK MANURE AND SYNTHETIC FERTILIZERS, 1961–2017



NOTES: The categories "manure left on pasture" and "manure applied to soils" provide estimates of nitrogen inputs from livestock manure and losses occurring through leaching and volatilization. The category "manure applied to soils" excludes that left on pastures and is limited to agricultural soil applications after treatment in manure management systems.
SOURCE: FAO. 2020.[83]

SENEGAL
A farmer spraying a cabbage crop with an organic pesticide.
©FAO/Olivier Asselin

» However, where improperly used, they can pollute water with toxic substances that affect humans.

The availability and use of antimicrobial drugs in terrestrial and aquatic animals and in crop production is also essential to both health and productivity.[85] However, antimicrobial resistance – when micro-organisms (bacteria, fungi, viruses and parasites) develop resistance to antimicrobial substances, such as antibiotics – is an emerging pollutant issue, impacting negatively on land and water resources and thus biodiversity, as well as on human health and livelihoods.[86] About 700 000 human deaths each year are related to antimicrobial resistance.[87] While this phenomenon can occur naturally through microbial adaptation to the environment, it has been exacerbated by inappropriate and excessive use of antimicrobials.[85] Of particular concern is the fact that two-thirds of the estimated future growth in antimicrobial usage is expected to be in the animal production sector.[88] Antimicrobials are often only partially metabolized in livestock and can, therefore, be excreted to the environment almost unchanged.[89] The major pathways through which antimicrobials can reach waterways in agricultural areas are: (i) through direct discharge of untreated wastewater (i.e. from livestock operations); and (ii) indirectly via surface runoff from either cropland fertilized with untreated livestock manure or slurry, or grazing areas receiving direct manure deposits from livestock.

Salinity and agriculture

Salt-affected soils occur in more than 100 countries, and their worldwide extent is estimated at about 1 billion hectares.[90] Dissolved mineral salts occur naturally in water in different concentrations depending on the source (e.g. groundwater), location and time of year.[91] Salts may degrade water quality in freshwater bodies, such as wetlands, streams, lakes, reservoirs and estuaries, as a result of salt mobilization and concentration.[78] They can also impair plant growth as they accumulate in the root zone so that the crop is no longer able to extract sufficient water from the salty soil.[92]

Agriculture-induced soil salinization is a major problem and can occur through various processes: (i) overuse of groundwater in coastal areas, resulting in seawater intrusion into freshwater aquifers; (ii) excessive irrigation raising water tables from saline aquifers, increasing seepage of saline groundwater into water courses and thus their salinization;[78] and (iii) irrigated water that is transpired by plants or evaporated from the soil, leaving most dissolved salts in the soil, causing salinization if drainage is not in place. Where salinization occurs, additional irrigation is needed to flush the salts out of the crop roots, further exacerbating water scarcity.[90]

Drainage (natural or artificial) to remove excess surface and subsurface water from irrigated land is a feature of well-designed irrigation schemes. It helps maintain favourable moisture conditions for optimal crop growth, avoids waterlogging, reduces poor mechanical behaviour and controls soil salinity. The development of irrigation needs to be coupled with expanded drainage and conservation, and recycling of freshwater in drainage water reuse.[k] Excessive fertilizer application may also increase the concentration of salts in drainage water in irrigated areas, and in runoff and percolation in rainfed areas.[78] Compared with irrigated crops, the contributions of aquaculture and livestock to water salinization (excluding animal feed production) are minor, with only localized effects where livestock and aquaculture production are more intensive.[78]

Measures to address soil salinization include leaching of salts by excess irrigation, use of chemicals, applying organic matter, and biological steps such as salt-tolerant plants, grasses and shrubs.[90] Egypt and Iraq have installed surface and subsurface drainage systems to control rising water tables and arrest soil salinity. Through the Global Soil Salinity Map, FAO is working with several countries to understand soil salinity drivers, indicators and classification methods in order to prepare country data for national mapping of soil salinity.[94]

Water pollution impacts on agriculture – victim

Poor water quality threatens human and environmental health, agricultural productivity, and aquatic ecosystems. Unsafe use of wastewater in agriculture can lead to accumulation of microbiological and chemical pollutants in crops,

k For a comprehensive guide on drainage and salinity management, see Tanji & Kielen. 2002.[93]

livestock products and soil and water resources, and, ultimately, severe health impacts among food consumers and farm workers. It may also exacerbate antimicrobial resistance. Okorogbona *et al.* (2018) found that vegetable crop growth, including that of cucumber, was negatively affected by untreated wastewater and poor-quality groundwater. When irrigated with rainwater, cucumber plants reached a height double their previous size.[95] Water quality also affects total water consumption and general livestock health. Livestock can generally tolerate poor water quality, but some specific compounds (i.e. dissolved solids) can affect growth, lactation and reproduction, causing an economic loss to producers.[96] Similarly, poor water quality can affect aquaculture production. Eutrophication of waterbodies from agricultural runoff can initially drive fish productivity. However, if left unchecked, it causes environmental degradation and the loss of those fisheries.

Suspended organic and inorganic sediments in water cause problems in irrigation systems by clogging gates, sprinkler heads and drippers.[92] They can also result in water-induced corrosion or encrustation of pipelines and pumps, and fill canals and ditches, causing costly dredging and maintenance problems. Sediment also tends to further reduce the water infiltration rate of soils that are already less permeable.[92] Irrigation schemes applying source water with a high concentration of salts can create a salinity problem in the receiving cropland if salt accumulates in the crop root zone to levels that plants cannot tolerate.

Solutions to water pollution from agriculture

Water pollution from agriculture is complex and multidimensional, and managing it effectively requires a range of responses. Such responses must meet the growing demand for food while maintaining or minimizing contaminant loss into water systems. This will require action by policymakers and farmers alike, but at the lowest overall cost to society, including farmers' compliance costs and policy-related transaction costs, taking into account equity and social considerations.[97]

The adoption of best agricultural practices and technologies is essential in order to prevent pollution emissions from farms (e.g. by reducing nitrate and phosphorus leaching).[78] Examples of beneficial practices include: (i) soil and water conservation methods, such as zero or minimum tillage, and other land husbandry methods that reduce erosion, such as terracing and agroforestry; (ii) vegetative filter strips that prevent surface runoff, restore wetlands and field drainage; and (iii) planting riparian buffer zones that reduce the leaching of nutrients into watercourses. Restored wetlands have also been shown to be effective at reducing the loss of nitrogen from cropland to surface water,[98–101] as the vegetation takes up nitrogen and wet soils enhance denitrification. They can also help restore aquatic biodiversity and associated fauna and flora.

The large amount of livestock manure produced globally also represents an agronomic and economic opportunity. Improving livestock and water productivity as well as soil fertility and nutrient management – the amount, placement, form and timing of the application of plant nutrients to the soil – [102] is paramount. The LEAP Partnership guidelines to assess nutrient flows and impact assessment for eutrophication, and acidification for livestock supply chains, provide a framework that can be adjusted to national contexts.[103]

If poorly managed, these practices and systems can lead to pollution of water systems. There may be some private interests for farmers in minimizing pollution of water courses, such as uncontaminated drinking water for livestock; however, generally, these ecosystem services are undersupplied by farmers. Influencing both farm and landscape practices may require regulation, economic instruments, education and awareness raising, cooperative agreements, and research and innovation.[78] In China, a 2005–2015 national campaign brought together 65 000 extension agents, 1 000 collaborators and 130 000 agribusiness personnel, who engaged with almost 21 million farmers to implement integrated soil–crop management practices.[104] These practices increased average yields (of maize, rice and wheat) by almost 12 percent, generating a net grain output increase of 33 million tonnes. Application of nitrogen decreased by 15–18 percent, saving 1.2 million tonnes of nitrogen fertilizers. The increased grain output and decreased nitrogen fertilizer use were equivalent to USD 12.2 billion.

Typical regulatory instruments include water quality standards, pollution discharge permits, mandatory best environmental practices, restrictions on agricultural practices or the location of farms, and limits on the marketing and sale of dangerous products.[78] Recent analysis suggests that a combination of approaches – regulations, economic incentives and information – works better than regulations alone.[97, 105] Economic instruments, such as pollution taxes, targeted subsidies, charges and water quality trading, could be strengthened and used more extensively to increase the cost-effectiveness of pollution control, promote innovation and ensure access for poorer households. While application to diffuse pollution is challenging, several innovative approaches can provide practical solutions.

The "polluter pays" principle can be the starting point in securing water quality. It makes pollution costly, and either influences behaviour to reduce it, or generates revenues to alleviate pollution and compensate for social costs (e.g. through pollution charges). There are several challenges to its application, including difficulties in identifying and targeting polluters, and in determining reliable estimates of pollution costs.[105] Part of the solution relies on measurement of the costs and benefits of water pollution reductions, as well as deciding who bears the costs and who benefits.

Central government has a critical role to play in the transition to more effective management of diffuse water pollution risks.[105] Recommendations include:

- overarching national policy guidance and a strong direction on water quality improvements to send the right signals to local authorities, stakeholders and investors;
- regulatory frameworks and enforced minimum water quality standards to set the benchmark for better performance, and innovations and investments in water quality;
- a space for stakeholders – across agriculture and environment sectors and water users – and community engagement resources to manage perceived and actual risks, and to reach consensual solutions;
- notice of policy changes and providing multiple options to implement minimum standards to pave the way forward and reduce objections from stakeholders;
- government seed funding and space for experimentation to diffuse to a wide range of households, particularly the most vulnerable, innovative technical and policy approaches that minimize water quality management costs (e.g. include pilots for wastewater reuse).

NIGER
A farmer transferring water harvested from a well into a bucket for watering crops.
©FAO/Giulio Napolitano

CHAPTER 3 AGRICULTURAL RESPONSES TO WATER CONSTRAINTS

Key messages

➔ Innovative water management in cropland, livestock, inland fisheries and aquaculture has great potential to promote climate resilience and sustainable food systems, especially if combined with optimal input use, good soil and crop management, and an enabling environment.

➔ Water harvesting and conservation, combined with best agronomic practices, can increase yields in rainfed cropland. According to one study, these practices could boost global rainfed kilocalorie production by up to 24 percent and, if combined with irrigation expansion, by more than 40 percent.

➔ Cost-effective and sustainable investment in irrigation rehabilitation and modernization can raise water productivity in irrigated areas.

➔ Animal production presents many opportunities for increased water productivity, through better use of pasturelands, feed and drinking water, improved animal health, and integration of crop, livestock and aquaculture systems.

➔ Investing in non-consumptive uses of water, such as in aquaculture, and non-conventional sources, such as water reuse and desalination, is increasingly important to offset scarcity.

➔ Harnessing information and communication technologies empowers farmers, improving water management and productivity, income, food security and nutrition, and environmental sustainability.

CHAPTER 3

AGRICULTURAL RESPONSES TO WATER CONSTRAINTS

Chapter 2 has shown that numerous regions are experiencing severe water constraints from drought or water stress. Population growth, rising incomes, increasing urbanization, dietary changes and climate change may exacerbate water risks, affecting production systems in ways yet to become apparent. Ensuring that agriculture and food systems meet the needs of a rising population in an inclusive and sustainable manner will require major transformations. These may involve technical change and innovation but will also be widely influenced by governance, institutional frameworks and the policy environment (further discussed in Chapters 4 and 5). This chapter reviews technologies and management methods to address water shortages and scarcity in agriculture, and achieve food security and nutrition sustainably. It assesses options for different production systems – rainfed or irrigated cropland, livestock, inland fisheries and aquaculture – with distinct water challenges in mind. The chapter concludes by examining the role of aquaculture in reducing water constraints and ensuring a sustainable food system. ■

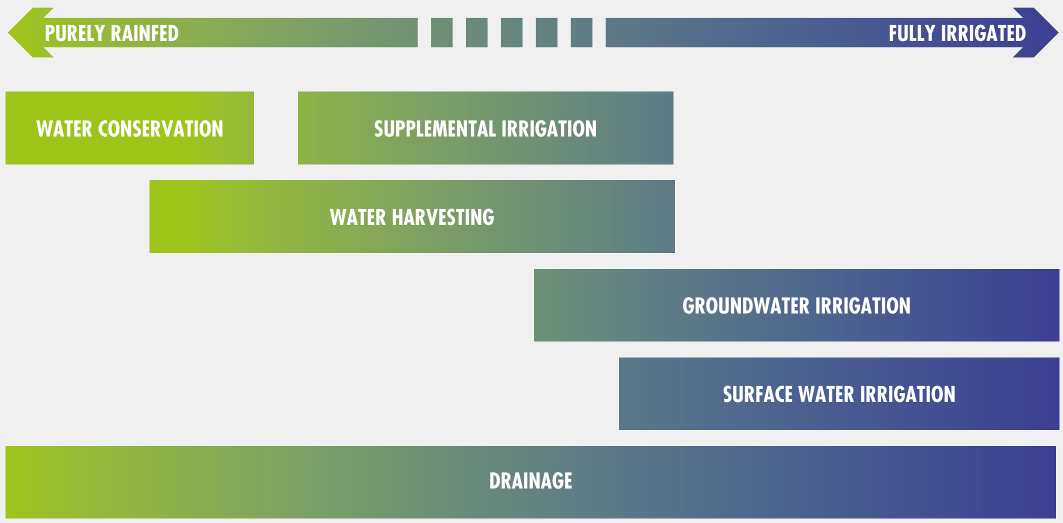
RETHINKING PATHWAYS OUT OF WATER SHORTAGES AND SCARCITY

Almost one-sixth of the world's population lives in areas with very high water stress or severe drought frequency, threatening economic growth, food security and nutrition, and livelihoods. These challenges must be addressed alongside climate change, which will exacerbate water shortages and scarcity, and negatively impact agricultural production, especially in low-latitude and tropical regions.[1–3] More sustainable management of irrigated areas is critical, but water management in rainfed cropland and pastureland areas is also an important part of the solution. Yield-improvement opportunities exist in both irrigated and rainfed systems, and across crops and geographical locations.[4–6]

Improved water management is crucial to reducing yield gaps. Adoption by farmers will depend on, *inter alia*: (i) water accessibility; (ii) water risk; (iii) level of uncertainty under a changing climate; (iv) cost of other inputs; and (v) net benefits of water management strategies. Secure but limited water access incentivizes farmers to improve water-use efficiency and reduce usage. The greater the water risk, the more farmers are encouraged to change water use and management. Changes may also involve varying other inputs, including labour and energy. The cost, and associated net benefits, will ultimately influence the decision to adopt new water management strategies.[7]

Not all water risks can be addressed by farmers alone or depend exclusively on farmers' decisions. Some will rely on public-sector intervention and initiatives. Small yield variations owing to erratic precipitation can be addressed through normal on-farm business decisions, but more catastrophic water risks that cause great damage may require government involvement.[8] Farmers may not understand the current status and future trends in water supply and demand. Public investment in water accounting – the systematic assessment of water status and trends – and dissemination of results together with awareness-raising campaigns are vital for policies on water risks, climate change and engaging farmers in sustainable water use (see Chapter 4).[9, 10] Governments can also play an important role in removing barriers, such as low

FIGURE 14
AGRICULTURAL WATER MANAGEMENT ALONG THE SPECTRUM FROM RAINFED TO IRRIGATED



NOTES: Predominantly green boxes include water management practices by farmers reliant on rainfall but who may still apply some form of irrigation. Predominantly blue boxes refer to irrigation by farmers in purely irrigated settings, or farmers in rainfed areas with some access to irrigation.
SOURCE: FAO elaboration based on the Comprehensive Assessment of Water Management in Agriculture. 2007, Figure 1.1.[11]

market access, that deter farmers from managing water resources.

The following sections review technical options and farmer management strategies in rainfed and irrigated agriculture. There is no clear demarcation between rainfed and irrigated systems, and managing water includes a spectrum of options – from entirely rainfed to fully irrigated conditions, to supporting livestock, forestry and fisheries, and interacting with important ecosystems.[11] Figure 14 depicts water management options along the spectrum from fully rainfed (green) to fully irrigated (blue). The grading from green to blue refers to practices where farmers use both rainfall and irrigation water, and are not fully reliant on rainfall or irrigation, but somewhere in between.

The continuum starts from farmers in fully rainfed settings who apply on-farm conservation to store rainwater in the soil (see Water conservation box in Figure 14). Along the continuum, farmers in rainfed areas capture rainwater or manage runoff (from a surface source or an aquifer) for supplemental irrigation to enhance crop production. This additional freshwater has other uses in integrated aquaculture and livestock systems. (For further discussion on the role of aquaculture and integrated farming systems, see the In Focus: Aquaculture in the context of sustainable water use in food systems, p. 79.) In fully irrigated systems, farmers have access to affordable surface water or groundwater (see predominantly blue boxes). Drainage is an important supplement across the whole continuum. Farmers in rainfed settings may minimize drainage to the water table by increasing root water uptake. In irrigated systems, when farmers apply too much water, drainage will determine the water table and soil salinity. (See the In Focus: Too much water? Flooding, waterlogging and agriculture, p. 104.)

Innovative water management practices should aim at (i) reducing water consumption in agriculture to increase water available to other users and (ii) improving production systems' resilience to growing water shortages and scarcity. Water management should be combined with better agronomic practices (drought-tolerant varieties, proper crop planting, etc.), improved environmental sustainability through reduced sediment loads and pollutants, improved soil health, reduced surface runoff, and increased recharge to shallow groundwater. Investments need to be economically, socially and culturally viable, calling for strong institutions and governance to guarantee equitable distribution of benefits, enhanced food security and nutrition, and sustainable livelihoods. The Principles for Responsible Investment in Agriculture and Food Systems endorsed by the Committee on World Food Security can serve as framework to guide stakeholders on any type of agricultural investment.[12] ■

REALIZING THE POTENTIAL OF RAINFED CROP PRODUCTION

Rainfed production dominates agriculture, covering about 80 percent of total cropland (see Figure 11, p. 37). Farmers, particularly small-scale farmers, have limited influence over the amount and timing of water.[13] The main challenge is to manage and adapt to weather variability, temperatures and rainfall patterns. Global analyses estimate that extreme weather events affecting rainfall and temperature can explain 18–43 percent of yield variation for key crops, including maize, rice, soybean and wheat.[14] As water shortages increase, and population and economic growth accelerate, there will be pressure on all agricultural systems, especially rainfed ones, to use water more productively. Chapter 2 further distinguished between low-input and high-input rainfed production systems. While the challenge of addressing water shortages remains the same in both categories, what differs is their capacity to address it. Farmers in high-input systems can more easily invest in improved water management and agronomic practices to ensure the most efficient use of scarce rainfall.

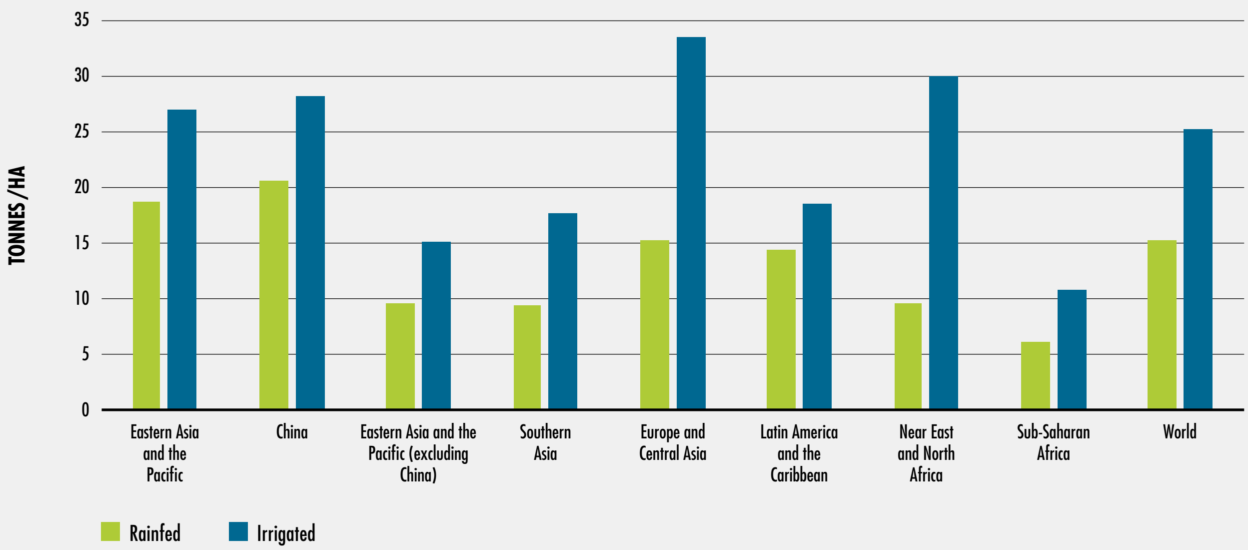
Yields in rainfed agriculture remain lower than those in irrigated areas (Figure 15), and substantial yield gaps persist globally and regionally.[5, 15] Such gaps are expected to largely mirror the classification of low-input and high-input systems. There is great opportunity to increase yields in Africa, Eastern and South-western Europe, and parts of Asia, where gaps are largely due to a combination of water and nutrient shortages.[5, 15, 16] In temperate regions, such as Western Europe and Northern America, where a substantial amount of cropland is rainfed and largely high-input (see Figure 11, p. 37), yields of cereals often exceed 6 tonnes per hectare, against a global average of 4 tonnes per hectare.[17] In Central and Western Europe, supplemental irrigation maintains yields during dry summers.[18] Yields in Eastern Europe remain lower, suggesting that unlocking the vast potential of the region will depend on new agricultural water management and technological change.

While some countries in tropical areas often exceed 5 tonnes per hectare for cereals, others do not surpass 2 tonnes per hectare. This suggests that the biophysical constraints causing low yields in rainfed farming, particularly in tropical low-income countries, can be overcome, *inter alia*, by appropriate water management, combined with best agronomic practices.

Making best use of rainfall for improved rainfed crop productivity

There are two broad strategies for increasing yields in rainfed agriculture: (i) collecting or harvesting more water, infiltrating it into the root zone; and (ii) conserving water by increasing plant uptake capacity and/or reducing root-zone evaporation and drainage losses. Where the issue is excess water, strategies focus instead on relocating practices to divert it. Figure 16 illustrates options, described along a continuum

FIGURE 15
VEGETABLE YIELDS BY REGION, 2012



SOURCE: FAO. 2018, Table S 2.1.[19]

from production fully dependent on rainfall to situations in which farmers rely partly on supplemental irrigation.

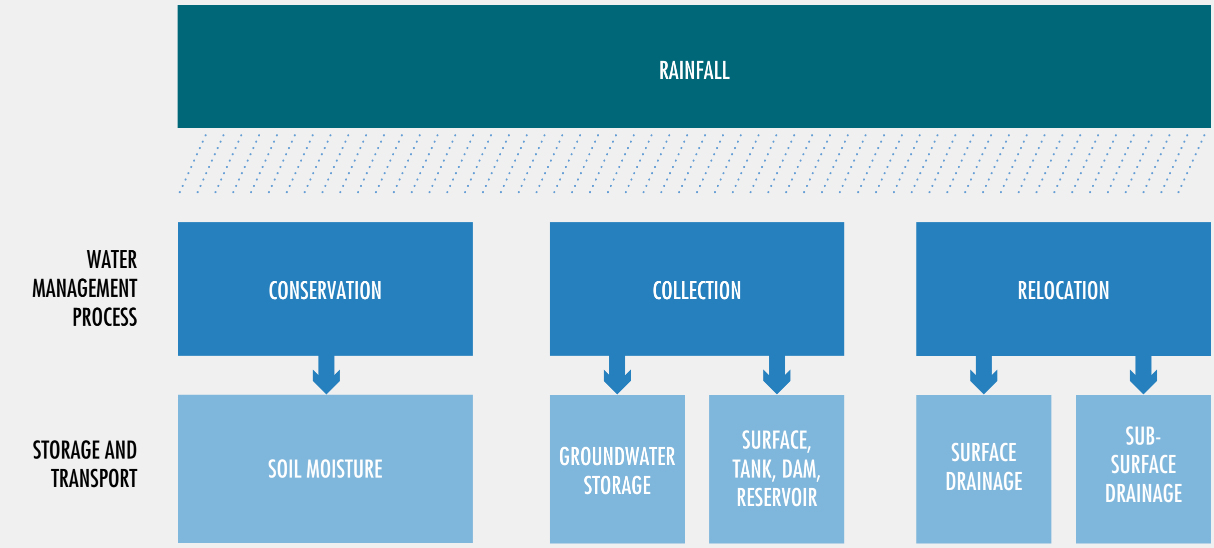
Key to making the best use of rainwater are soil and water conservation technologies – first box on the left in Figure 16 – which control the water available to a crop by affecting the water content in the root zone. Terracing, agroforestry, contour cultivation and conservation agriculture can modify and enhance soil-water content to retain moisture and prevent erosion.[21] Organic mulching, a natural or artificially spread layer of plant residues or other organic materials on the surface of the soil, can also minimize evaporation. As residues decay over time, they increase the water-holding capacity of soil, improving efficiency.[22] Organic mulching also provides soils with nutrients and restricts weed growth by blocking light penetration of the soil surface, contributing to increased water efficiency.[22, 23]

Water harvesting involves collecting rainwater or runoff (see the Collection box in Figure 16), which can either be diverted directly, spread on fields, or collected and stored.[l] Effective water harvesting – combined with best agronomic practices – can boost crop yields, especially during low rainfall.[25, 26] Combined with small-scale on-farm ponds, water harvesting can also integrate fish production and livestock watering with crop production. These are more climate-resilient measures and offer greater income to small-scale farmers.[27–29]

A distinction is often made between *in situ* water harvesting, which refers to the capture of local rainfall on farmland, and *ex situ* water harvesting, which refers to rainfall capture outside the farm. *Ex situ* water harvesting uses water to mitigate dry spells, protect springs,

l For an overview of proven good practices in water harvesting from all over the world, see Liniger & Studer. 2013.[24]

FIGURE 16
MAIN WATER MANAGEMENT PRACTICES IN RAINFED AGRICULTURE



SOURCE: FAO elaboration based on Barron. 2020.[20]

recharge groundwater, enable off-season irrigation and permit multiple uses.[21] These practices include surface microdams, subsurface tanks, ponds, and diversion and recharging structures. Communities or individual farmers usually manage these systems, and they require information, training and awareness raising to properly implement and maintain these practices.[24] For example, in Tigray, a water-constrained region in northern Ethiopia, the government has prioritized different *ex situ* systems, the majority run by individual farmers. These have helped increase crop and livestock productivity, crop diversification and access to water points.[30] However, outcomes depend on farmer and stakeholder participation during planning, implementation and utilization.[31] In the Sahel, FAO is implementing the "One million cisterns" programme to promote rainwater harvesting and storage systems for vulnerable communities.[32] The objective is to allow millions of people in the Sahel, especially women, access to safe drinking water, enhance agricultural production, improve food and nutrition security, and strengthen their resilience.

Water collected through harvesting can be later applied as supplemental irrigation when rainfall is scarce (Box 9). *In situ* water harvesting covers different technologies – microcatchments, bunds, broad-beds and furrows – as well as management options such as tillage or adding organic matter.

Combining water conservation and harvesting can be highly effective. Rost *et al.* (2009) estimate that a 25 percent reduction in evaporation and a 25 percent collection of runoff could increase crop production by 19 percent.[38] Jägermeyr *et al.* (2016) have shown that soil moisture conservation alone could boost global rainfed kilocalorie production by 3–14 percent.[39] The authors also found that a combination of *in situ* and *ex situ* water harvesting could further

BOX 9
THE ROLE OF SUPPLEMENTAL IRRIGATION IN PRODUCTIVITY AND RESILIENT RAINFED SYSTEMS

Where rainfall is insufficient, supplemental irrigation provides essential soil moisture and, thus, increases water productivity.[21, 33] If supplemental irrigation were applied to all rainfed cropland, global cereal production could be increased by 35 percent, the largest potential being in Africa and Asia.[34] Even relatively small supplemental irrigation can lead to substantial increases in crop yield. An example from the Syrian Arab Republic shows yield improvements of up to 400 percent.[35]

In the State of West Bengal, India, small rainwater storage ponds for supplemental irrigation have doubled mustard yields and increased paddy yields by 20 percent.[36] They have also increased farmers' incomes by 34 percent. More farmers are considering cultivating a range of highly profitable vegetables during the dry season. The approach has also released more water for gardening, livestock, raising fish and domestic uses.

In Zimbabwe, supplemental irrigation reduces the risk of complete crop failure from 20 percent to 7 percent, and increases water productivity by almost one-third, especially when combined with inorganic nitrogen.[37] Therefore, supplemental irrigation is a key strategy, despite still being underused, for unlocking rainfed yield potential and water productivity.[21]

increase kilocalorie production by 7–24 percent. Under the ambitious scenario (all measures combined, including irrigation expansion), this could increase global kilocalorie crop production by 41 percent.

Access to cost-effective rainwater management and supplemental irrigation technologies can give farmers in rainfed holdings the security to invest in fertilizers and high-yielding varieties. Aside from water management, the performance of a crop is the result of inherent attributes (i.e. genetic gains, as with improved varieties) and agronomic practices, including various inputs. Without agronomic practices, *in situ* water harvesting and soil and water conservation may generate only marginal, if any, crop yield gains.[40, 41]

Water relocation is another important supplement to water harvesting and conservation (last box on the right in Figure 16). Farmers combine harvesting and conservation with drainage to avoid floods during heavy rainfall, while terracing systems can also work as drainage structures on sloping cropland.

Almost 20 percent of global cropland is suitable for water harvesting, and for soil and water conservation, with hotspots in large parts of Eastern Africa and South-eastern Asia.[42] Water harvesting in these cropland areas can increase production by 60–100 percent. These practices may reduce surface and groundwater flows; therefore, water accounting should precede any implementation. In many rainfed areas, efforts towards sustainable rainfed production have been in place for decades. In Ethiopia, public investments, farmer in-kind contributions through labour and international development inputs have gone into soil and water conservation for more than 40 years. As a result, about 20 percent of the country's cropland employs terracing.[43] The extent of cropland under improved management practices at the local and global levels remains unknown. Global data are also scarce for agricultural areas equipped for surface and subsurface drainage. ■

TABLE 2
GLOBAL AVERAGE WATER PRODUCTIVITY OF SELECTED FOOD CATEGORIES

Food category	Water productivity			
	Mass (kg/m³)[i]	Calories (kcal/m³)[ii]	Protein (g/m³)[ii]	Economic value (USD/m³)[iii]
Sugar crops	5.49	1 566	0.0	0.141
Vegetables	4.22	1 013	50.6	1.173
Starchy roots	2.92	2 411	37.9	0.445
Fruits	1.15	527	6.1	0.433
Cereals	0.68	2 197	54.8	0.113
Oil crops	0.45	1 296	65.1	0.103
Pulses	0.30	1 027	64.7	0.106
Nuts	0.12	298	7.8	0.179

[i] Values for crop products derived from the global average blue and green water footprint from Mekonnen & Hoekstra. 2011.[45] Physical water productivity in weight basis, containing moisture. All products are primary products (e.g. sugar crops include sugar cane and sugar beet but exclude processed products, such as raw and refined sugar). These data are averaged over 1996–2005.
[ii] Calculated from water productivity and nutritional content of food items.
[iii] Calculated from water productivity and producer price of product. Nutritional content and producer price from FAOSTAT.[17]
SOURCE: Mekonnen & Neale. 2020.[50]

IRRIGATED SYSTEMS – UNDERSTANDING HETEROGENEITY IN YIELDS

Irrigation is important for adapting to climate change as well as increasing land and water productivity. Irrigated areas occupy only about 20 percent of total cropland (see Figure 11, p. 37), but generate more than 40 percent of total production in terms of value.[44] In some areas, irrigation contributes to more than half the value of agricultural production. This is the result of higher productivity in irrigated areas relative to rainfed agriculture, and higher and more stable yields with more intensive cropping, as well as cultivating higher-value crops.[44] The scope for efficiency gains and for increased land and water productivity is considerable. The challenge is how to improve performance without compromising sustainability.

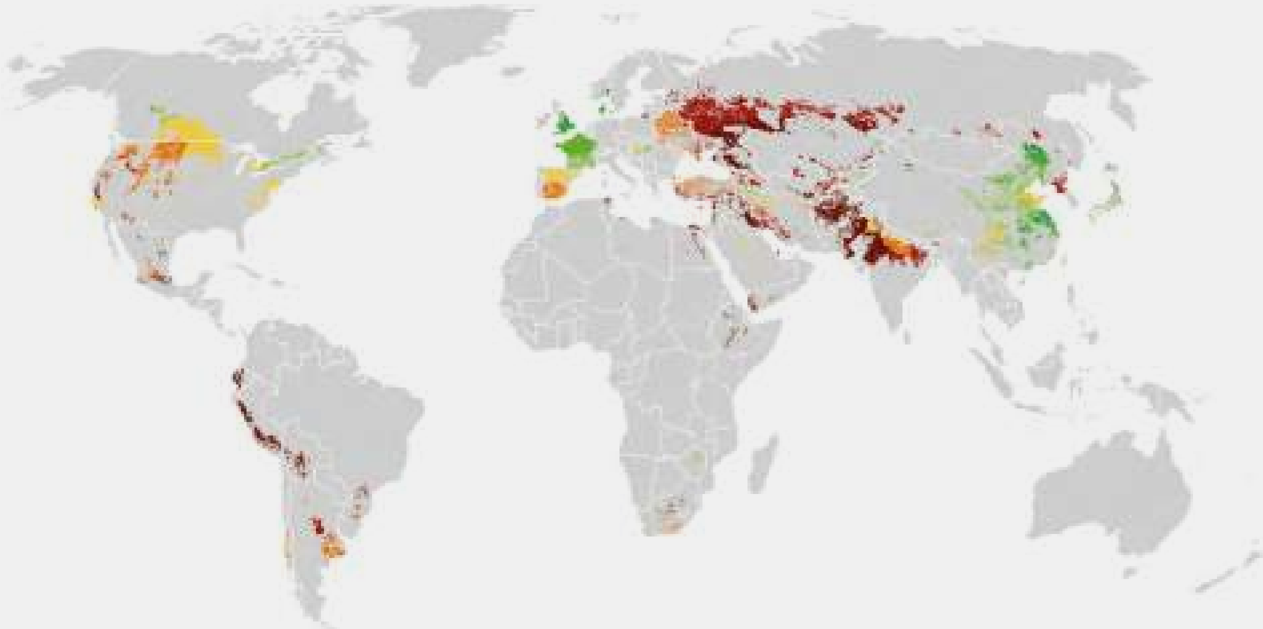
Increasing water productivity in irrigated agriculture

Making more productive use of irrigation water can produce more crops with less water, by either increasing crop yield, reducing seasonal evapotranspiration, or achieving a combination of both. Globally, there is a large disparity in water productivity among crops (Table 2), reflecting large variation in yield, nutritional outcome and US dollars per litre of water consumed. Figure 17 illustrates the economic water productivity of irrigated cereals, the green patches indicating high water productivity, with less water per unit of value, while the yellow-red fields represent low productivity.

Water is one of several inputs when producing a commodity, and some agroecological zones are better suited to certain crops than are others. For wheat, the most water-consuming crop in Figure 17,[45] almost all regions report low economic water productivity. The only exception is parts of Europe, where wheat accounts for half of total cereal production in terms of value.[17] A similar pattern emerges for barley, where besides Europe and some parts of »

FIGURE 17
ECONOMIC WATER PRODUCTIVITY OF SELECTED IRRIGATED CROPS, BY REGION

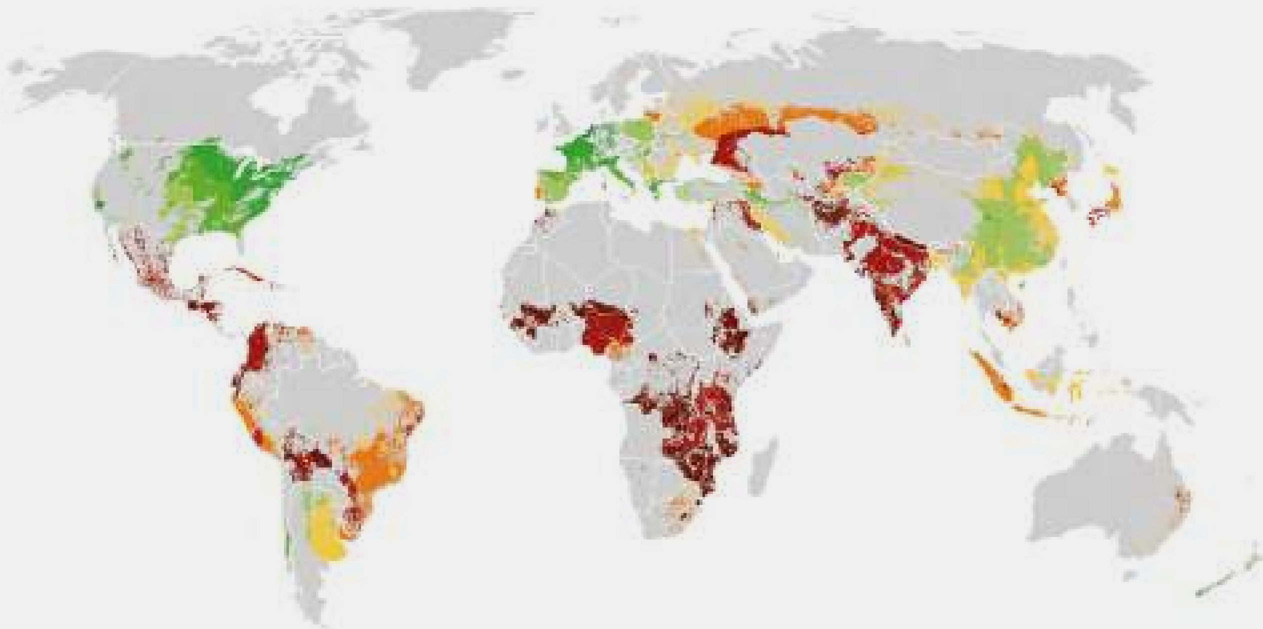
A. BARLEY



Economic water productivity (USD/m³)

≤ 0.05 | 0.05–0.075 | 0.075–0.1 | 0.10–0.15 | 0.15–0.2 | 0.2–0.25 | 0.25–0.35 | > 0.35

B. MAIZE

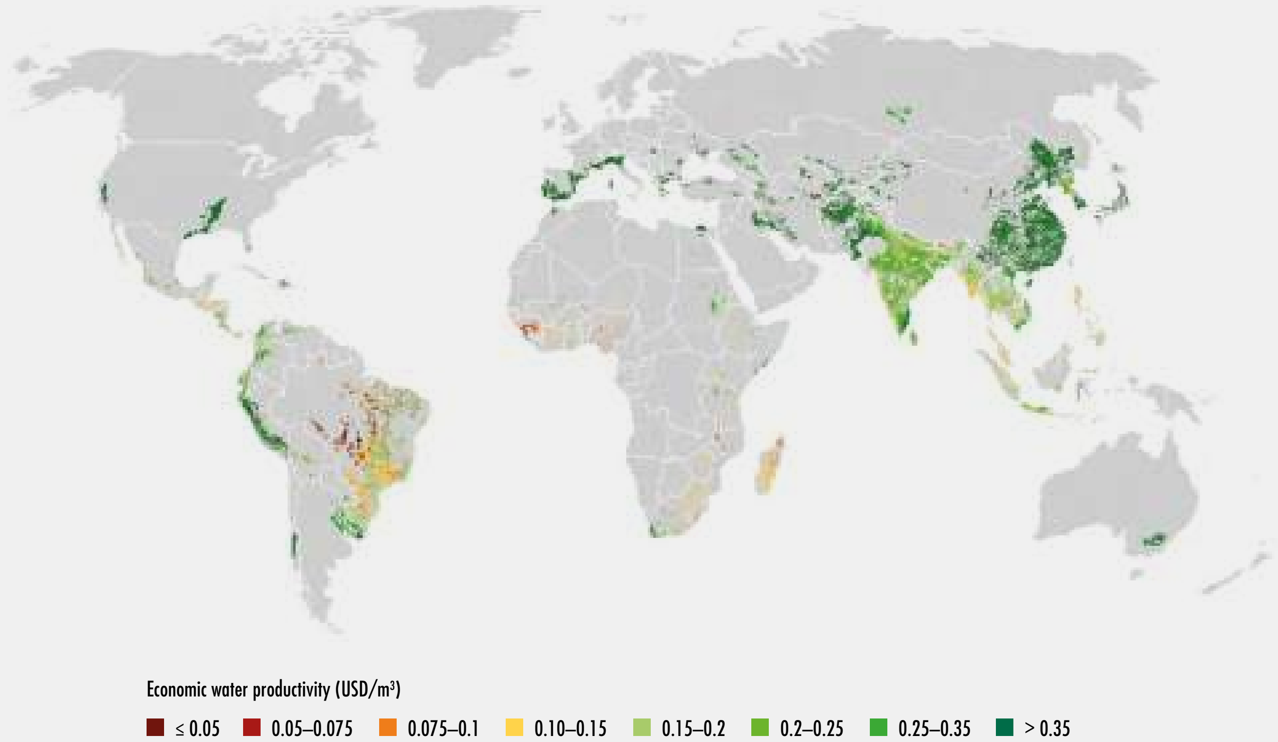


Economic water productivity (USD/m³)

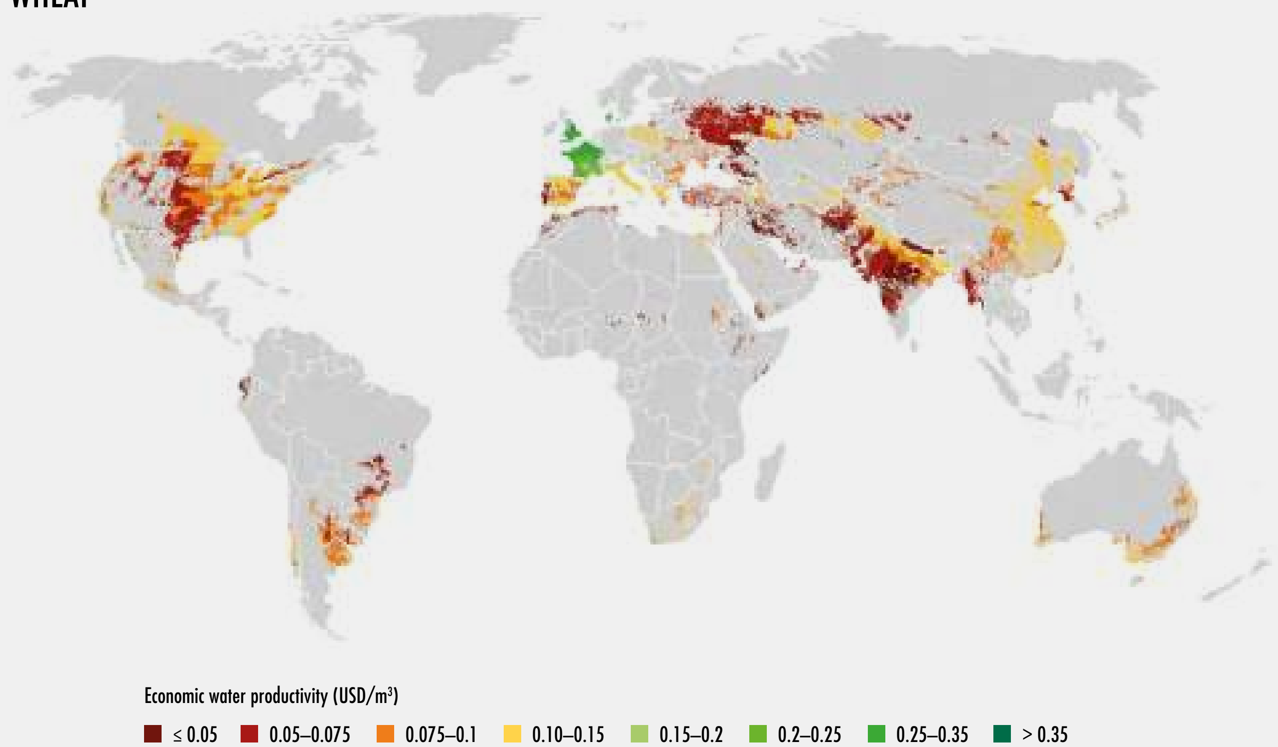
≤ 0.05 | 0.05–0.075 | 0.075–0.1 | 0.10–0.15 | 0.15–0.2 | 0.2–0.25 | 0.25–0.35 | > 0.35

FIGURE 17
(CONTINUED)

C. RICE



D. WHEAT



NOTES: Economic water productivity is defined as crop USD value per unit of water consumed (total evapotranspiration over the crop growing season). Values were converted from physical water productivity (kg/m³) to economic water productivity (USD/m³) using the average global price of each crop from FAOSTAT.[17] The data are averaged over 1996–2005.
SOURCE: Mekonnen & Neale. 2020,[50] based on Mekonnen & Hoekstra. 2011.[45]

» China, the red patches in other regions suggest low productivity. For maize, high-income countries in Northern America and Europe are highly productive, while low-income and low-middle-income countries in Asia, South America and sub-Saharan Africa report lower water productivity. This is a concern in Africa, where food insecurity and malnutrition are substantially higher,[46] and maize represents more than one-third of total cereal production in terms of value.[17] For rice, a different pattern emerges, as Asia and South America are as productive as parts of Europe and Northern America. In Asia, rice accounts for almost two-thirds of total cereal production,[17] and is central to the livelihoods of millions of small-scale farmers.

Better access to inputs, efficient irrigation, improved crop varieties, and better soil and water management can explain higher water productivity for most crops in high-income countries of Northern America and Western Europe. In contrast, in addition to operating under conditions of poor soil and poor water management, farmers in sub-Saharan Africa may have limited access to high-yielding crop varieties, fertilizers, pesticides, mechanization and markets. Variability in crop water productivity within regions and countries is due to a range of factors, including: (i) climate conditions, such as evaporation, amount and timing of rain and/or irrigation water, and air temperature; (ii) soil properties, texture and organic matter content; (iii) crop cultivars, as crop varieties and cultivars have different crop yield and water needs; (iv) soil and water management practices, which influence the amount of water available in the soil, or the ability of roots to extract it and reduce soil evapotranspiration; and (v) other agronomic practices, such as timing of crop sowing or planting and fertilizer application.[47–49]

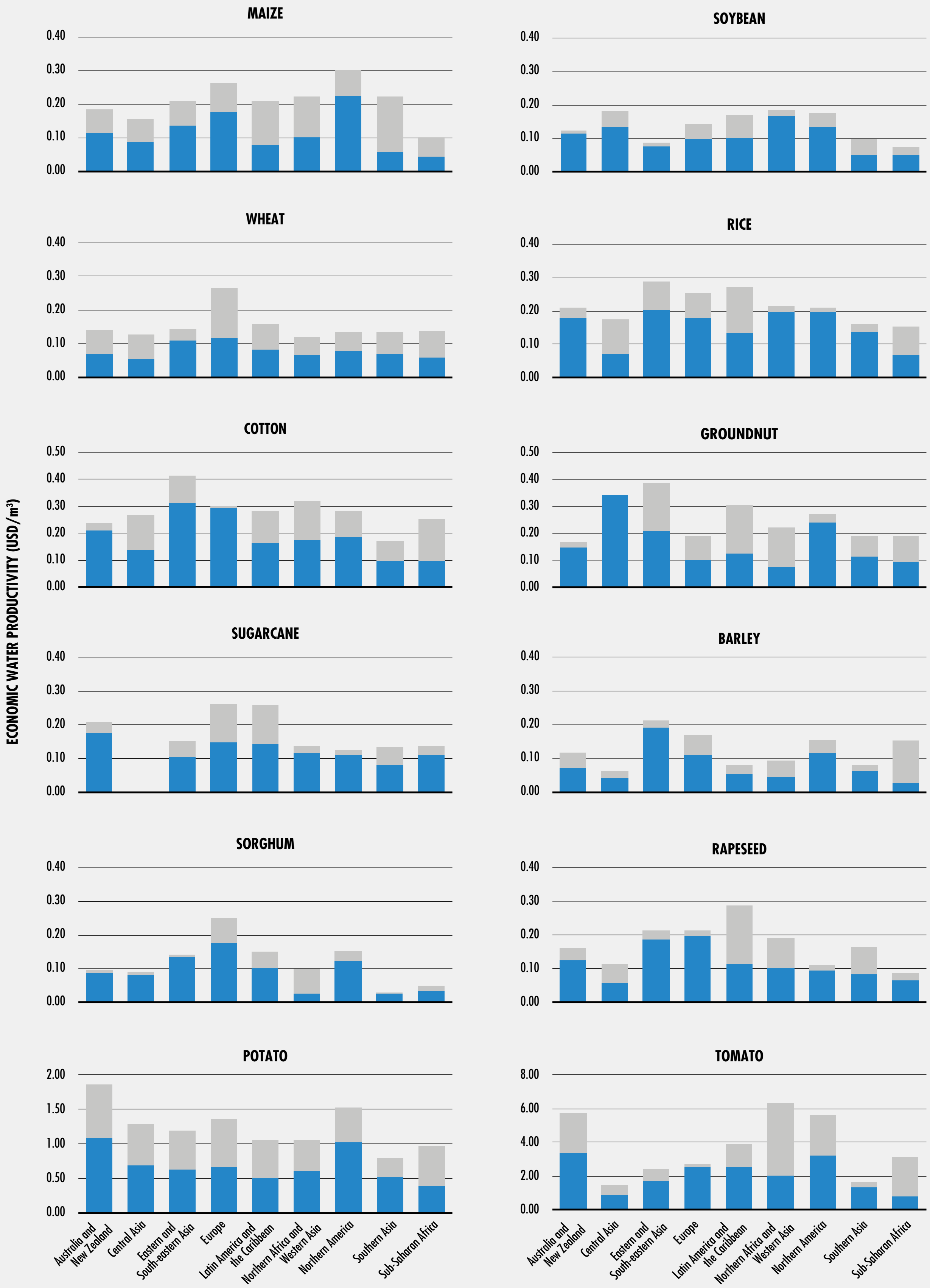
Despite considerable improvements in water productivity, gaps remain between actual and attainable yield per unit of water. Figure 18 shows actual water productivity (blue) and productivity gaps (grey), in economic terms, for irrigated crops by region. Australia and New Zealand, Europe, and Northern America have the smallest water productivity gaps, while Latin America and the Caribbean, Northern Africa, Western Asia, and sub-Saharan Africa have the largest water productivity gaps for most crops. While closing yield gaps can promote food security and nutrition in most countries, some may be more relevant than others.[51] Farmers and policymakers may prioritize those crops where economic gains are likely to be greatest.

For example, Europe has one of the largest water productivity gaps for sorghum and wheat, partly from climate change.[52] While wheat accounts for half of cereal production in terms of value, sorghum production is negligible.[17] Sub-Saharan Africa, on the other hand, exhibits the highest water productivity gaps for barley and wheat, while that for sorghum is smaller compared with other regions. Sorghum and wheat account for almost one-third of African cereal production in terms of value, while barley reaches 3 percent. These findings suggest closing water productivity gaps for wheat in Europe and sub-Saharan Africa might bring the greatest economic benefits and improve food security and nutrition, especially in the latter region. The costs of closing these gaps must be considered, especially for wheat in Europe, where water productivity is already very high compared with that of other regions.

Different irrigation for different contexts

No single irrigation system is best for all situations, and when deciding, farmers must bear in mind several factors: soil, water and climatic conditions; crop types; financing possibilities; energy prices and sources; labour; application efficiency; economies of scale; and the depth from which the water is pumped, etc.[53] The three main irrigation methods are surface irrigation, sprinkler irrigation and micro-irrigation (e.g. drip). In surface irrigation, water flows over the soil by gravity. Sprinkler irrigation applies sprinkles or sprays of water droplets. Micro-irrigation involves frequent small applications by dripping, bubbling or spraying, and usually only wets a portion of the soil.[54] A fourth method is subsurface irrigation, which applies water below the soil surface to raise the water table into or near the plant root zone.[54] Table 3 shows some advantages and disadvantages of various irrigation systems. »

FIGURE 18
ACTUAL ECONOMIC WATER PRODUCTIVITY AND WATER PRODUCTIVITY GAPS FOR SELECTED IRRIGATED CROPS, BY REGION



NOTES: The blue portion shows actual economic water productivity and the grey portion the water productivity gap. Productivity gaps were estimated, per crop and per region, as the difference between the water productivity benchmark set for non-water-stress conditions. The data are averaged over 1996–2005.
SOURCE: Mekonnen & Neale. 2020,[50] based on Mekonnen & Hoekstra. 2011.[45]

TABLE 3
TYPICAL STRENGTHS AND WEAKNESSES OF IRRIGATION SYSTEMS

System type	Summary description	Strengths	Weaknesses
Surface irrigation			
Furrow	Small channels carry water down the slope between the crop rows.[61]	Low capital and maintenance costs; water flows in small channels.	High labour; less water control; soil erosion; possible runoff and percolation losses.
Basin	Applies water to an almost level field and may include ponding for extended time.	Efficient with good design; less labour than furrow.	Ponded water; sloping fields must be levelled.
Border	Water flows between dykes dividing a sloping field into rectangular strips with free drainage at the end.	Less labour and less runoff than furrow; easier to manage infiltration depth.	Water flows over entire soil surface.
Sprinkler irrigation			
Solid set	Applies frequent, small amounts of water to meet plant needs.	Good water control; possible to automate and irrigate frequently; fits odd-shaped fields.	High capital cost; system may interfere with field operations.
Set-move	Applies water slowly during the irrigation set. Once completed, the system is moved to an adjacent area for the next set.	Lower capital cost than other sprinkler systems.	More labour than other sprinkler systems; poor uniformity in windy conditions; greater application depth.
Moving[i]	Applies water as the system slowly travels through the field.	High uniformity; low labour.	High capital and maintenance costs; not suitable for odd-shaped fields; potential wind and evaporation losses.
Micro-irrigation systems			
Surface drip irrigation	Water is conveyed under pressure through pipes into fields, dripping slowly onto the soil through drippers located close to plants.[62]	Excellent water control; frequent applications possible.	High capital cost; requires clean water or treatment and filtration.
Subsurface drip irrigation	Water is applied through buried drip tubes or tape located at or below plant roots.[63]	Highly efficient and uniform water application; reduced surface water evaporation and incidence of weeds and disease.[64]	Higher capital cost than furrow systems; requires regular checks and careful maintenance.

[i] Includes centre-pivot, linear-move and low-energy precision application systems.
SOURCE: FAO elaboration based on Bjorneberg. 2013.[54]

» Farmers' decisions on investments in irrigation depend on associated costs. Studies on those costs and benefits can be useful. In Texas, the United States of America, Amosson *et al.* (2011) studied five common irrigation systems,[53] discovering furrow irrigation requires less capital than other systems but is less efficient and more labour-intensive. Centre-pivot systems (referred to as moving sprinkler systems in Table 3) are more efficient and reduce field operations to offset additional costs. Low-energy, precision application is a type of centre-pivot irrigation that generates the greatest benefits. For most crops, owing to high investment and small efficiency gains, subsurface drip irrigation may be limited to land where pivots cannot be installed.

In sub-Saharan Africa, where large-scale irrigation projects often underperform in relation to investment, small-scale farmers develop and expand their own irrigated land.[55]

BOX 10
FARMER-LED IRRIGATION – EVIDENCE FROM SUB-SAHARAN AFRICA

In sub-Saharan Africa, only about 3 percent of cropland is irrigated (see Figure 11, p. 37), and small-scale farmer-led irrigation systems are rapidly expanding. Farmers invest their own resources and access water from shallow groundwater, rivers, lakes and reservoirs. These are an attractive option to small-scale farmers because they use simple affordable equipment, including buckets, watering cans, treadle pumps, drip systems and conservation agriculture technologies, such as terracing and *in situ* rainwater harvesting. More than 80 percent of farmers who use irrigation employ manual lifting and watering using buckets and cans, although demand for more mechanized options is growing.

In Burkina Faso, 170 000 farmers – mainly small-scale farmers – irrigate 10 000 hectares of vegetable crops using buckets, watering cans and small motorized pumps. This tripled vegetable production between 1996 and 2005, raising dry season incomes by USD 200–600. In Ghana, 185 000 hectares are under small-scale irrigation, primarily cultivating vegetables in the dry season, benefiting half a million small-scale farmers. This adds between USD 175 and USD 840 annually to household income. In the United Republic of Tanzania, more than 700 000 farmers lift water from rivers and wells using buckets and cans to irrigate vegetables on 150 000 hectares. Half of small-scale farmers' dry season cash comes from irrigated vegetables. In Zambia, 90 000 hectares are under private irrigation, and the 20 percent of small-scale farmers who grow dry season vegetables earn 35 percent more than those relying solely on rainfall.

SOURCE: Giordano *et al.* 2012.[36]

Small-scale farmer-led irrigation systems can have lower unit costs than those managed by government agencies[56, 57] and offer much higher internal rates of return (28 percent) than does large-scale, dam-based irrigation (7 percent).[58] They also improve yields and income, and reduce risks from climate variability (Box 10). Governments should support these initiatives by, *inter alia*, removing market barriers, and promoting affordable and appropriate credit facilities to enable small-scale farmers to embrace the initiative. Governments should also enact regulations to ensure these initiatives are environmentally sustainable.[55]

In Asia, large-scale state-funded surface irrigation schemes are in decline for a variety of reasons, including poor maintenance by governments. Many were not set up to properly cater to farmers' needs and have failed to provide sufficient water for crops.[59] Efforts to rehabilitate them are constrained by poor service provision and a lack of effective management. As a result, farmers are tapping directly into groundwater. While this has helped boost farmers' efficiency and productivity gains, it has also placed excessive pressure on groundwater.[60] Addressing these issues will require modernizing old irrigation schemes, as well as coherent, effective and feasible policies, investment and interventions.

An agronomic practice with positive influence on water productivity is deficit irrigation, which ensures optimal water use. Deficit (or regulated deficit) irrigation is a way of maximizing water productivity.[65] The crop is exposed to a level of water stress either during a period or throughout the whole growing season. Any yield reduction will be insignificant compared with the benefits through diverting saved water to other crops.[66] Studies reveal higher water savings for fruit trees compared with herbaceous crops, for which there is almost always some yield penalty. Among other field crops, cotton and grain sorghum are suitable for deficit irrigation.[66] Other advantages of deficit irrigation include fewer fungal diseases and less nutrient loss, controlled sowing dates and improved agricultural planning.[67] As crop responses to water stress vary considerably, deficit irrigation requires precise knowledge of soil-water and salt budgeting, as well as crop behaviour.[65–68]

Investing in sustainable irrigation for improved livelihoods and the environment

The traditional assumption has been that increasing irrigation efficiency through modern technologies, such as drip irrigation, leads to substantial water savings to be released for other uses.[66] While the farm-level benefit may be substantial, when properly accounted for at basin scale, total water consumption by irrigation tends to increase, reducing return flows to other users, including the environment. With increased irrigation efficiency, much of the water previously "wasted" by inefficient irrigation returns to the system via groundwater recharge, rivers and drainage networks, and is often reused for irrigation.[33] In addition, as modern irrigation incentivizes farmers to switch to higher-water-consuming crops, expand cropping areas or increase cropping intensity, this raises farmers' incomes but also water consumption.[69–73] Without a water allocation system, new irrigation often leads to higher water consumption at the basin level. This is documented, for example, in the Indus Basin in Pakistan,[74] and in Andalusia, southern Spain.[71]

None of this is to recommend inefficient irrigation, but rather promote measures such as limiting water use while improving rural livelihoods (see Chapter 4). One study estimated that integrated water management (the integration of rainwater management with irrigation upgrades) could increase global kilocalorie production by 10 percent, while still respecting environmental flow requirements.[75]

In addition, advanced irrigation technology brings important benefits that must be promoted as it (i) often saves labour; (ii) allows precise and economic application of fertilizers and chemicals; (iii) minimizes leaching of nitrates and other pollutants; (iv) reduces pumping costs and saves energy; and (v) allows the farmer to diversify into higher-value crops, increasing production value (Box 11).[66] If adoption remains low, this is mainly due to a lack of awareness of these benefits, among other economic and structural constraints. To be sustainable, investments in advanced irrigation technology must include robust water accounting; a cap on extractions; assessment of uncertainties; valuation of trade-offs; and better understanding of the incentives and behaviour of irrigators (see Chapter 4).[76] ■

INTEGRATED FARM-LEVEL APPROACHES TO IMPROVE WATER PRODUCTIVITY IN RAINFED AND IRRIGATED PRODUCTION

Water management is most effective when combined with optimal use of inputs and good crop management. The efficiency of a limited resource is at its best when all other inputs are at their optimum.[83] Improved water management should be combined with correct management of other inputs. Modern high-yielding crops are crucial in raising water productivity. During the green revolution, modern crop varieties, with increased irrigation and agrochemicals, played a major role in increasing yields of major crops. Soil nutrient status also has major effects on crop water productivity. Sadras (2004) demonstrated this for wheat crops in the Mallee region, Australia, where water and nitrogen accounted for a proportion of the gap between attainable and actual water productivity.[84]

Several integrated approaches allow farmers, particularly on small-scale rainfed farms, to improve productivity sustainably.[25] These combine best practices with improved soil and water management that intensifies production through integrated soil fertility management, greater water-use efficiency and crop diversity. Box 12 illustrates the importance of crop management for yield, evapotranspiration and water productivity.

BOX 11
THE BENEFITS OF MODERN IRRIGATION – EVIDENCE FROM CHINA, INDIA AND THE UNITED STATES OF AMERICA

In the Province of Hebei, China, subsurface drip irrigation has reduced evapotranspiration compared with flood and surface drip irrigation by 26 percent and 15 percent, respectively, increasing water productivity by 25 percent.[77] It has further increased grain yield and biomass formation through lower evaporation, and can therefore be used to address water scarcity.

In India, field trials in 2012 and 2013 in Coimbatore City showed drip irrigation increased grain yields by almost 30 percent, doubled water productivity and used 27 percent less water relative to conventional rice production.[78] There was also a 40 percent increase in the return on investment. Another field study in the Sirsa district of Haryana State illustrated the economic benefits of drip irrigation, showing it was more cost-effective than furrow irrigation in cotton production, reducing cultivation costs by 25 percent and generating water and electricity savings of 33 percent.[79] It also reduced weeding and soil erosion problems. However, a lack of subsidized equipment and farmers' know-how has restricted access to this technology.

According to a study in California, United States of America, subsurface drip irrigation increases crop yield and water productivity through better water management and improved fertilizer control.[80] Another study in San Joaquin Valley, California, showed the yield of tomatoes under drip irrigation was about 20 percent higher than that under sprinkler irrigation for similar amounts of water.[81] It also found that, depending on the difference in yield and interest rates, profits per hectare under drip irrigation were from USD 867 to USD 1 493 higher than under sprinkler irrigation. However, little, if any, water saving per hectare is possible by converting to drip irrigation. Luhach *et al.* (2004) encourage sprinklers in fruit production owing to their economic viability, reduced pressure on water resources, and lower operational and labour costs.[82]

Some critical primary crop and nutrient management factors include:

- timely crop planting and harvesting to match rainfall, multicropping when possible to utilize soil moisture and recover soil nutrients, and shifting the planting season to periods of low evaporation;[68, 85, 86]
- plant spacing and row orientation, involving optimum planting density (the amount of space between plants) and high stand uniformity;
- selecting crop varieties with high yield potential and/or that are resistant to drought and/or grow faster under canopy cover;[87–89]
- spatial allocation and zone crop management, identifying and excluding fields that deliver consistently lower yields to help improve average crop water productivity;[86]
- nutrient management, as soil nutrient status affects crop water productivity, weeding and pests.

Conservation agriculture

Conservation agriculture can improve water and nutrient efficiency by promoting minimum soil disturbance (i.e. no tillage), maintenance of permanent soil cover with crop residues and live mulches, and diversification of plant species.[m] Conservation agriculture has expanded rapidly, reaching about 180 million hectares across 79 countries.[93] The main reasons include higher factor and water productivity; lower production costs and higher profitability; and greater yield stability. In China, conservation agriculture has contributed to yield increases from 2 percent to 8 percent for wheat, maize and rice.[94] In India, it has substantially reduced production costs for farmers and increased irrigation water productivity.[95]

m For more on conservation agriculture, see FAO. 2020.[92]

BOX 12
EFFECT OF CROP MANAGEMENT ON EVAPOTRANSPIRATION, YIELD AND WATER PRODUCTIVITY – EVIDENCE FROM ARGENTINA AND INDIA

A study in Argentina analysed the response of maize yield, crop evapotranspiration and water productivity to reduced row spacing under different water and nitrogen regimes.[90] Grain yield response to narrow rows (35 cm versus 70 cm) ranged from 0 to 23 percent, higher for water limited rainfed crops and/or nitrogen-deficient crops (i.e. non-fertilized crops). Narrow rows increased crop evapotranspiration during initial stages of growth by 8 percent, while nitrogen fertilization did not influence it. Reduced row spacing further increased water productivity for grain by up to 17 percent. The effect was more pronounced when the crop was nitrogen-deficient and/or with water limitations, but negligible for fertilized and irrigated crops.

Van Dam *et al.* (2006) simulated crop growth at different sowing dates (between 10 November and 10 December) in Sirsa District, India.[91] Early sowing increased grain yield and, combined with a small increase in evapotranspiration during growing, raised water productivity by 20 percent.

Conservation tillage can improve soil-water storage, soil quality and crop yield, and reduce evaporation.[96–100] Livestock on improved pastures derived from crop–pasture rotations based on conservation agriculture produce more meat per unit of pasture and with less greenhouse gas (GHG) emissions.[101] The impacts on water productivity depend on context and effects on evapotranspiration and yields.[50, 102] Conservation agriculture may face challenges in sub-Saharan Africa and Southern Asia, where crop residues are used as livestock feed or household fuel.[103–105] Other challenges include increased weeds and additional labour when herbicides are not employed, affecting women in particular.[106] The success of conservation agriculture often depends on identifying agroecological regions and soil types where it can be readily adopted. Developing site-specific packages and educating the farming community and general public about benefits will also help.

Conservation agriculture can also contribute to making agricultural systems more resilient to climate change. In many cases, it has reduced farming systems' GHG emissions and enhanced their role as carbon sinks.[101, 107] Climate-smart irrigation agriculture is another important option for adaptation to climate change. It focuses on improving productivity and profitability of existing irrigation, enhancing farmers' resilience to climate change.[108] Box 13 estimates the potential benefits of implementing the improved management strategies described in this chapter. ■

WATER PRODUCTIVITY IN ANIMAL PRODUCTION

Animal products have lower water productivity compared with crops in terms of kilograms of product per cubic metre of water (see Table 4 relative to Table 2). Crop productivity ranges from 0.12 kg/m^3 for nuts to 5.49 kg/m^3 for sugar, while animal products range from 0.07 kg/m^3 for beef to 1.05 kg/m^3 for milk. After milk, the highest water productivity is reported for eggs and tilapia. Depending on the production system, the water productivity of tilapia can vary considerably. For instance, when cultured in fed aerated ponds, its water productivity is lower.[110] In fisheries and aquaculture, calculating water consumption is less straightforward than for cropland and livestock, as the former considers feed, energy, and level of circulation and discharge. For further discussion on water use by fisheries, see the In Focus: Aquaculture in the context of sustainable water use in food systems, p. 79. »

BOX 13
PUTTING IT ALL TOGETHER – THE POTENTIAL FOR ENHANCING RAINFED AND IRRIGATED CROP PRODUCTION

Based on the rainfed and irrigated production systems in Figures 5 (p. 28) and 7 (p. 30), it is possible to estimate the percentage of cropland that can benefit from increased yields from different types of irrigation and water management technologies and practices. (For a breakdown by country of the share of cropland under each production system with water constraints, see Table A2 in the Statistical Annex, p. 138). Projected yield improvements are based on investments to expand irrigated areas, irrigation rehabilitation, and the potential adoption of the following technologies and management practices: (i) drip irrigation; (ii) sprinkler irrigation; (iii) water harvesting; (iv) drought-tolerant varieties; (v) heat-tolerant varieties; (vi) conservation tillage; (vii) integrated soil fertility management (i.e. combining chemical fertilizers, crop residues and manure/compost); and (viii) precision agriculture (for a definition, see section Making innovation, communications and technology work for all, p. 75).

The analyses in the figures in this box indicates what could be attained by 2030 based on the percentage of cropland using that technology according to projections of IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT). A more detailed description of this modelling exercise and an overview of IMPACT are presented in the Technical Annex (p. 127).

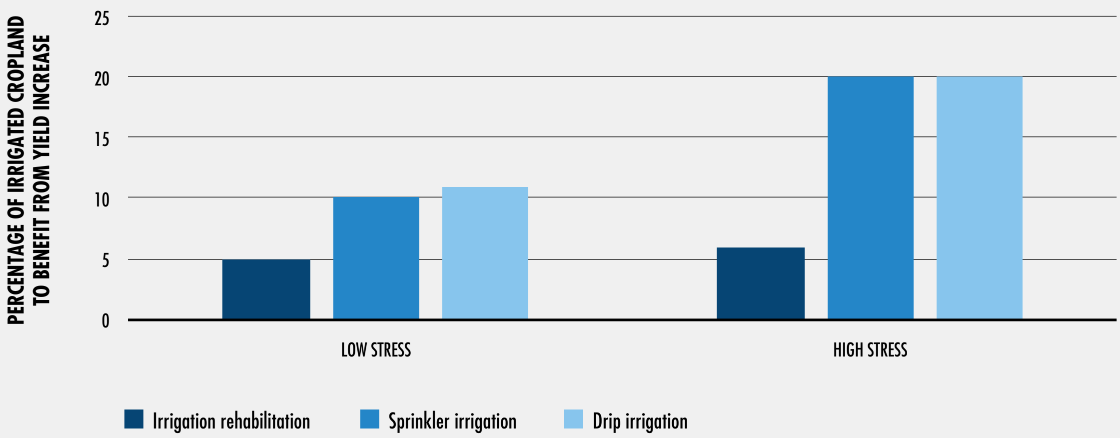
Under the projections, investment in irrigation rehabilitation and modernization is slightly greater with high water stress than with low water stress, as under high stress, investments can have higher returns. The expected investment in drip and sprinkler irrigation is also greater in irrigated settings with high water stress. Where water is plentiful, investments may not be profitable; where water is scarce, adoption offers farmers better control and application efficiencies to grow higher-value crops and achieve higher yields. To make sure investments translate into water savings for a watershed, they should be contingent on water accounting and allocations (see Chapter 4). Investments must also be accompanied by socio-economic analysis, considering local requirements and conditions.

Water harvesting and drought-tolerant varieties were modelled for rainfed production only. The projected adoption rate is higher in low-input rainfed production systems, indicating this could benefit small-scale farmers. As for drought-tolerant varieties, the projected percentage of areas is substantially higher in rainfed areas with high drought risk under both high- and low-input use.

Growing heat-tolerant varieties benefits all areas, rainfed or irrigated. Increased drought frequency is correlated with higher evaporation and temperatures, although the benefits may be greater in regions subject

PERCENTAGE OF CROPLAND AREA TO BENEFIT FROM INVESTMENT IN SELECTED TECHNOLOGIES AND MANAGEMENT PRACTICES BY 2030

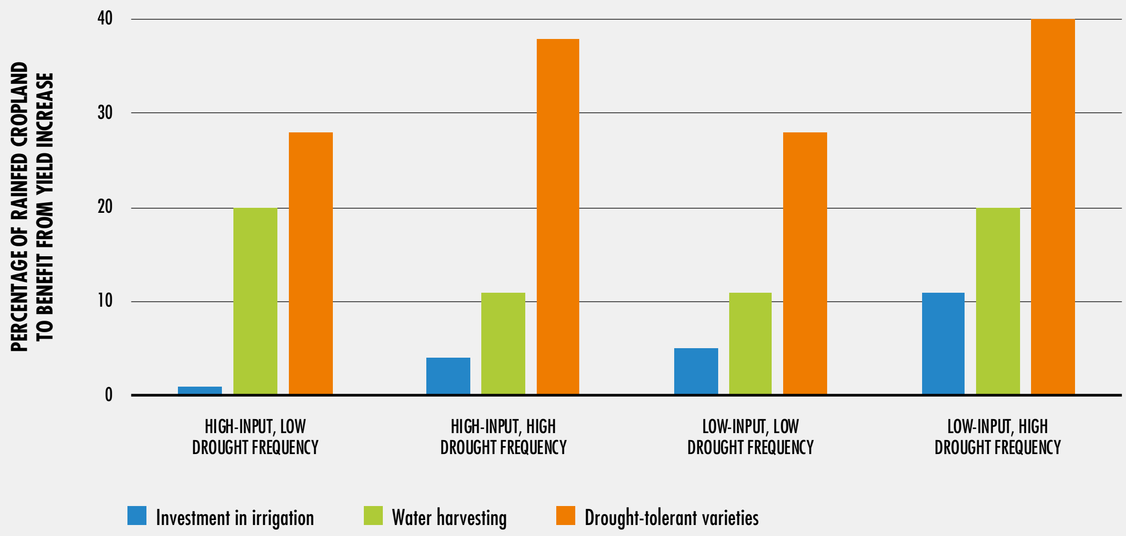
A. Options for currently irrigated areas



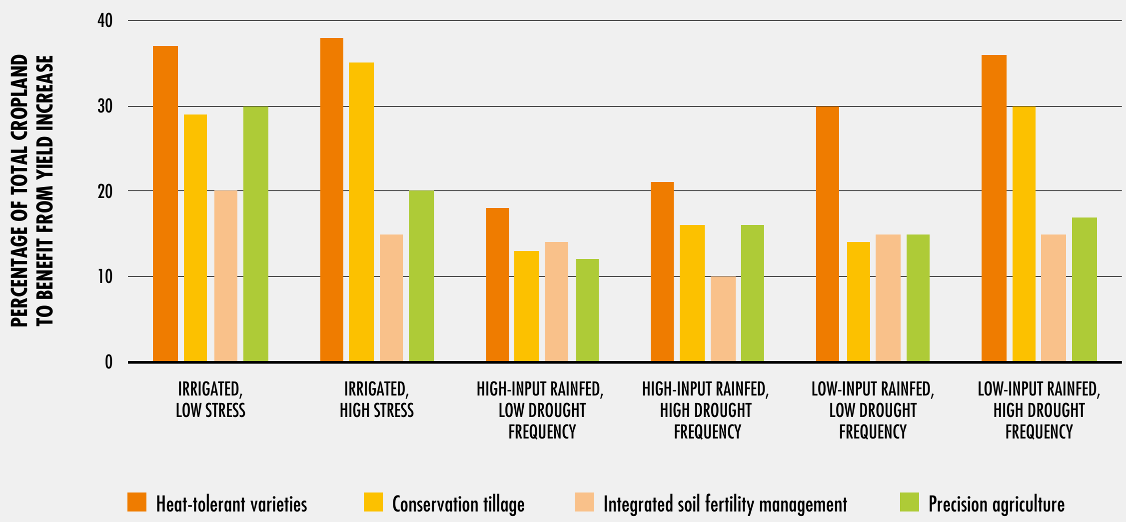
to frequent droughts and particularly relevant for low-input systems. Conservation tillage benefits irrigated and rainfed cropland and, for rainfed systems, has more scope in low-input systems facing droughts, indicating small-scale farmers could benefit. Integrated soil fertility management can benefit all areas, in particular, those with low water stress, but no clear pattern emerges across the different profiles. Under the projections, precision agriculture is the most profitable option and therefore the most adopted in irrigated systems with good control over water.

The investments, technologies and management practices assessed could provide benefits in all production systems with different water constraints. Although these will not resolve water shortages and scarcity on their own between 2020 and 2030, they can have a substantial impact for millions of farmers in irrigated and rainfed systems. Positive impacts vary significantly across countries, highlighting the importance of tailoring water management to irrigated and rainfed systems, to local capacities and conditions, and to water challenges.

B. Options for currently rainfed areas



C. Options that apply to both rainfed and irrigated areas



SOURCE: Rosegrant. 2020.[109]

TABLE 4
GLOBAL AVERAGE WATER PRODUCTIVITY OF SELECTED ANIMAL PRODUCTS

Food item	Water productivity			
	Mass (kg/m³)[i]	Calories (kcal/m³)[ii]	Protein (g/m³)[ii]	Economic value (USD/m³)[iii]
American catfish	0.16	216	24.8	–
Beef	0.07	101	9.2	0.166
Butter	0.19	1 491	0.0	0.828
Chicken meat	0.26	373	32.9	0.316
Eggs	0.35	502	39.1	0.310
Milk	1.05	591	34.8	0.309
Pig meat	0.19	519	19.6	0.263
Sheep meat	0.10	199	13.4	0.254
Tilapia (fresh weight)	0.30	288	60.3	–

[i] Values for livestock and fish products from Mekonnen & Hoekstra. 2012[111] and Lemoalle. 2008,[110] respectively.
[ii] Calculated from blue and green water productivity and nutritional content of livestock products.
[iii] Calculated from water productivity and producer price of livestock products. Nutritional content and producer price obtained from FAOSTAT.[112]
NOTE: For fish products, the conversions to energy and protein contents were computed according to the United States Department of Agriculture Nutrient Data Laboratory.[113]
SOURCES: Mekonnen & Neale. 2020[50] and Lemoalle. 2008.[110]

» In calorific terms, crops generally have higher water productivity than do animal products. From a protein perspective, tilapia reports the highest value in Table 4 and is more efficient than American catfish. Milk, eggs and chicken report relatively high values. Economic water productivity (in terms of US dollars per cubic metre of water) is often greater for animal products than for crops, with the exception of fruits, vegetables and starchy roots.

Global demand for livestock products is rising (as is also that for animal feed), potentially a burden on freshwater resources. There is a need for further improvements in water productivity for animal products.

Options for livestock production systems

Livestock production makes use of different systems with varied water-use patterns.

For feed, livestock may rely on grazing and/or feed from either rainfed or irrigated production. In mixed production, livestock consume crop residues and by-products, and produce manure to fertilize crops. More than one-third of the planet's ice-free land is used for pasture.[114] Livestock graze on about 2 billion hectares of pastures and meadows, two-thirds of which are not suitable for crops. In these areas, livestock production is the only way of transforming rainfall into food. Besides using a large share of agricultural land, livestock production also uses large amounts of water.[115] Unlike cropland, livestock are often not considered subject to agricultural water management, even with many opportunities to improve water productivity and environmental performance.

Livestock are also a strong asset for resilience as they buffer the impact of drought on agricultural outputs and farmers' livelihoods through, *inter alia*, animal mobility, disease control and animal health, feed and drink management, and stratification of production to reduce grazing pressure in arid areas.[116]

In many pastoral societies, mobility is a key strategy for accessing dispersed grazing and water over large areas, which is particularly important during severe droughts.[117]

In pasturelands, proper control of the grazing season, intensity, frequency and distribution can improve vegetation cover, reduce soil erosion and maintain or increase water quality and availability.[118] Animal management includes improving animal health and careful animal husbandry.[115, 119] Diets can also meet the dual challenge of increasing the sector's water productivity and conserving water through improved management and closing the yield gaps of feed crops. A study in Santa Catarina, Brazil, in 2001–2011 found that nutritional strategies could reduce the water footprint of swine by 18 percent, and increase water productivity – in nutritional terms – by more than 20 percent.[120] Another study in northern Germany found that increasing milk yield, combined with grass and maize silage-based feeding, substantially raised water productivity on dairy farms relative to pasture and concentrate feeding.[121] In mixed crop–livestock farming systems, choosing feed types carefully, improving feed quality and sourcing, increasing feed water productivity and grazing management can raise water productivity.[119, 122] These practices improve land- and water-use efficiency and significantly reduce GHG emissions.

The effective use of stored water in tanks and reservoirs, rainfall and marginal quality water for livestock is key, given that much water in livestock farming is for animals.[115] Reducing the amount by water-efficient drinking devices (e.g. water bowls and bite-type drinkers), and maintenance and repair of water troughs to eliminate leaks, are important conservation strategies. Beyond changes to animal diets and drinking systems, other options include shade on waiting yards or feed yards, and regulating the temperature in animal housing.[115] Managing cleaning, high-pressure washers or recycling can also reduce consumption and vulnerability to shortages, and water from alternative sources alleviates pressure on water-scarce sources. Attempts to improve agricultural water productivity must recognize differences among systems and optimize resource use by their components.[122] Taking institutions, policies and gender into consideration can lead to successful uptake of interventions.[119] ■

WATER MANAGEMENT APPROACHES AND IMPACT BEYOND THE FARM

Linking agricultural landscapes and ecosystem functions

Agricultural production systems are major drivers in a range of desirable and undesirable environmental changes. Rainfed cropland and pastureland can substantially affect biodiversity and water quality.[123] Some water strategies can have negative impacts. Decentralized measures, such as rainwater tanks and storm-water harvesting, even if small, can have a negative impact on a catchment's water balance when not combined with other solutions (e.g. restoration of upstream ecosystems). Large programmes of small-scale water harvesting, such as local basin management in the State of Andhra Pradesh and other parts of India, have substantial impacts on overall hydrology and availability of water downstream,[124] and can seriously affect the productivity of river fisheries. However, evidence is mixed, and there is a need for new modelling tools and field data collection.[125, 126]

Improved agricultural water management can also lead to desirable environmental changes. In the Kothapally watershed in southern India, for example, agricultural water interventions have reduced sediment loads to the rivers, with large positive impacts on in-stream river ecology and the lifespan of reservoirs.[125] Appropriate water management can also substantially reduce GHG emissions. For example, reducing or interrupting periods of flooding is one of the most promising techniques for reducing rice-related emissions, as it lowers bacterial methane production and thus methane emissions.[127, 128] Several approaches take account of the relationship between agricultural landscapes, resource use and ecosystem functions. Nature-based solutions are inspired and supported by nature, and use or mimic natural processes to contribute to improved water management. They can involve conserving or rehabilitating natural ecosystems and/or enhancing or creating natural processes in modified or artificial ecosystems.[129] They can

BOX 14
FORESTS AS NATURE-BASED SOLUTIONS

As key elements of the water cycle, forests and trees are central to nature-based water solutions. Their sustainable management can contribute to better water quality and quantity, and improved timing of water delivery, while reducing risks, such as flooding, soil and coastal erosion, and drought. Cloud forests, which occur in tropical and subtropical areas, contribute additional water inputs into the watershed, capturing fog and lowering evapotranspiration.[130]

Forests and trees also improve water quality through increased infiltration and reduction of water contamination from agriculture runoff as well as erosion and sedimentation, with significant effects on biodiversity. An example is the importance of riparian forests for aquatic productivity in the Pacific Northwest of Northern America, where strips of forest maintain water temperature, nutrients, channel morphology and substrata, which need to be within certain levels to maintain inland fisheries, such as salmon. Forest nature-based solutions can also increase the resilience of people and their crops to climate change and extreme weather. In coastal areas, forests could mitigate the impact of storm surges, coastal erosion and salt intrusion from sea-level rise, all of which impact agriculture. Mangrove ecosystems can protect coastal settlements against the effects of wind and wave erosion, as well as other coastal hazards.[131] Coastal vegetation, particularly mangrove forests, has great potential to treat wastewater, remove chemical contaminants and mitigate coastal pollution and soil erosion.[132, 133] Mangrove restoration can be coupled with aquaculture – planting ponds with mangrove seedlings is a cost-efficient and environmentally friendly option for treating aquaculture wastewater.[134]

have positive cascading effects for agriculture, biodiversity, food security and the environment. However, despite increasing recognition, their broad implementation still faces some challenges. There are calls for a paradigm shift to view forests, peatlands and other ecosystems as regulators of freshwater from site to continental scales with a landscape approach across many stakeholders (Box 14). Enabling conditions place nature-based solutions at the same level as other water management options. These may include redirection of investment, payment for ecosystem services, and sustainable agricultural practices and policies that support these solutions.[129]

Runoff management, and sediment and erosion control

An undervalued benefit of agricultural water management is the effect on surface water runoff retention and sediment control. Retention systems' capture of runoff and extreme rainfall not only reduces water shortages during drought, but also flooding, and they are useful for biomass production and nutrient retention.[135] Sediment control aims at alleviating erosion and sedimentation, such as loss of valuable topsoil – which reduces the productivity and the water-holding capacity of land – and infrastructure damage (e.g. to hydropower stations and wastewater treatment plants). Sedimentation may also degrade water quality through discharge into streams, lakes and coastal zones, reduce the water storage capacity of reservoirs, and aggravate flood damage.[136]

A study in Ethiopia showed that water harvesting and soil and water conservation, such as bunds and conservation agriculture, had significant benefits in terms of retained runoff and reduced sediment loss by 45–90 percent.[41] In Southern Africa, sediment and surface runoff were reduced by 80 percent and 60 percent, respectively.[40] A meta-analysis by Joshi *et al.* (2008) covering more than 600 microwatersheds in India reported an average runoff reduction of 45 percent, and 1.1 tonnes per hectare of retained topsoil.[137] The study also showed a positive relationship between participation and benefits from watershed development, highlighting the importance of stakeholder participation in preventing actions of one group of farmers from adversely affecting another group. The use of strips of grass, shrubs and trees is another soil and water conservation practice, a nature-based solution that, in addition to retaining moisture and preventing erosion on slopes,[25] can significantly reduce sediment loss.[138] Planting along waterways can greatly improve water quality for fish. In the Zarqa river basin, Jordan, sustainable rangeland management has resulted in increased edible biomass, carbon sequestration and/or sediment stabilization.[139]

These findings are not easily scaled up to watershed level and beyond.[140] There are large data gaps for tropical and subtropical agricultural regions, as well as micro- to meso-scale watersheds (from 0.01 km^2 to 100 km^2).[141] There is a lack of long-term landscape monitoring across all regions and production systems, something that would be especially valuable in low-income and least developed countries where agriculture is under rapid transformation.

Managing agricultural nutrient loadings

Agricultural production can interfere with natural cycles of nutrient elements – nitrogen and phosphorus – leading to concerns about water degradation from excess nutrient loadings and eutrophication. These problems are expected to intensify as a result of population growth and wealth generation. Growth is faster in low-income countries, with a projected increase of up to 118 percent for nitrogen and up to 47 percent for phosphorus.[142] These are the countries with most population growth, driving food demand and agricultural production. Ensuring food security and nutrition and environmental sustainability will require addressing agricultural pollution.

Water management, such as vegetation strips, infiltration ditches/basins and human-created wetlands, can contribute by retaining excess nutrients, especially nitrogen and phosphorus (the most common water pollutants), thus reducing non-point pollution load, also known as diffuse pollution.[138] While these technologies have varied efficiency, often dependent on design and local landscape, they are widely applied in agricultural production systems in Europe and Northern America.

The integration of aquaculture within agricultural systems can help retain excess nutrient loadings and improve water quality.[143] In some systems, the presence of fish aids rice–fish culture, nutrient cycling and circulation. These reduce pesticide use and related costs, suppress weed growth in rice fields, and improve soil fertility. However, this may add complexity to the management of these systems. For more information on water pollution from agriculture, see In Focus: Agriculture, water pollution and salinity, p. 44. ■

NON-CONVENTIONAL WATER SOURCES FOR ALLEVIATING SCARCITY

In the face of growing demand, the use of non-conventional water sources, such as treated wastewater and desalinated water, is gaining momentum. Most human water activities produce wastewater, potentially recoverable for secondary uses such as in agriculture. If all this water were recovered, it would substantially reduce pressures on freshwater and alleviate scarcity, provided accounting assessments ensured the return flow was not serving an environmental function.

Water reuse

Wastewater is predicted to increase considerably with population growth and urbanization. On average, high-income countries treat about 73 percent of their wastewater. The figure drops to 54 percent in upper-middle-income countries and to 28 percent in low-middle-income countries. Globally, about 80 percent of wastewater is released without adequate treatment.[144, 145] In 2019, 7.5 million m^3/day of new water reuse capacity was forecast. China dominates this total (3.7 million m^3/day), followed by the United States of America (880 000 m^3/day) and India (680 000 m^3/day).[146] Most is tertiary and/or advanced wastewater treatment. This is part of a broader trend towards advanced treatment driven by industrial demand for higher-quality water, and from agricultural users.

Although definitive numbers on water reuse in agriculture are hard to find, about 10 percent of the total global irrigated land area receives untreated or partially treated wastewater, more than 30 million hectares in 50 countries.[144, 147] For decades, the most significant benefit of water reuse in agriculture has been that of decreased pressure on freshwater sources.[148]

The circular economy has brought a different perspective on water reuse in agriculture, proposing a model where the value of products, materials and resources is sustained for as long as practical and waste reduced or even eliminated.[149] Treated wastewater is readily available for agriculture, including irrigation. Water reuse for irrigation brings more certainty that water will be available throughout the year, even during dry spells. Nutrients can be recovered from sewage sludge (biosolids) and reused as fertilizer, as widely practised in many countries.[150] In Europe, more than one-quarter of sewage sludge produced in 2017 was used in agriculture.[151] A final benefit is energy recovery, such as biogas production from waste treatment at the farm level.

When treated according to the end users' needs (fit for purpose), wastewater is a realistic option for non-conventional sources of water, nutrients and energy for agriculture. Reusing water in agriculture from fit-for-purpose treated wastewater is a "win-win" situation as it is based on improved sanitation (collection systems), treatment facilities, reuse of chemical elements (nitrogen and phosphorus) and making water available for higher-value uses. However, in some countries, using treated wastewater to irrigate food crops is still not culturally acceptable. With strong communication channels, government regulations and the involvement of stakeholders would help to change negative perspectives about the use of non-conventional waters for food production. Moreover, assessment of water quality criteria, potential environmental impacts and regulatory issues need to be resolved to foster best practices and implementation.

The current policies for using reclaimed water are highly fragmented, and in many countries incomplete, which tends to inhibit development.[152] There is a need to develop both policy and planning frameworks for governments, municipalities and water resources groups to develop recycled wastewater as a future supply for irrigated agriculture. Training and capacity-building programmes can promote technology uptake through local and international streams, taking into account local needs and conditions. Removing barriers and creating an enabling environment will require appropriate legislation and regulations to make finance available for their adoption.

Desalination

Desalination covers the removal of dissolved solids (predominantly inorganic salts) and other dissolved contaminants from several sources, including seawater, brackish water (surface water and groundwater), and irrigation drainage. Aristotle, in his famous *Meteorologica* (written in about 350 BCE), described distillation to remove salts and other compounds to produce freshwater. Since then, desalination has become a major option for urban water supply, especially in desert and drought-prone regions. Owing to almost unlimited seawater, desalination is an attractive solution to the age-old challenge of its abundance despite being undrinkable.[153] There are approximately 16 000 desalination plants, producing about 100 million m^3/day of drinking water for 5 percent of the world's population, of whom 48 percent are in the Near East and North Africa.[154, 155] Since 2018, more than 400 desalination projects have been contracted worldwide, with 4 million m^3/day in new capacity in the first half of 2019.[146]

The main way to produce freshwater has been distillation, where saline water is distilled into steam and then condensed into pure water. The 1950s brought the development of membrane processes, such as electrodialysis and reverse osmosis. In electrodialysis, an electric current separates salts in water. In reverse osmosis, pressure forces water through a semi-permeable membrane that extracts most of the salts.[156] Unlike distillation, modern membranes use very little energy to produce freshwater, although a major environmental problem has been disposal of salts removed from water.[157]

The main obstacle to desalination has always been the cost. Its application in agriculture has been limited to a small number of areas, for certain high-value crops, and needing government subsidies in capital costs.[156] Over the last decades, however, desalination has become much more efficient and cost-effective thanks to rising demand, technology improvements, reductions in costs and energy use, increase in plant size to large and mega capacity sizes, and more competitive project delivery.[158] A 2008 study showed a consistent reduction in desalination costs over nearly three decades, and estimates that large-scale desalination plants are capable of producing water in the range of USD 0.5–2.0/m^3, depending on plant size.[159] Similarly, a more recent study estimates that the cost of desalinated water varies between USD 0.5–1.5/m^3.[160] In terms of cost, brackish-water desalination is more suitable for agricultural production than is seawater. Membranes and renewable technologies such as solar power have made desalination more feasible, especially for high-value cash crops such as greenhouse vegetables. Farmers welcome it as the process removes salts (especially sodium and chloride) that damage soils, stunt plant growth and harm the environment.[161]

Several countries, such as Australia, China, Mexico, Morocco and Spain, are now using desalinated water profitably for agriculture. Dévora-Isiordia *et al.* (2018) calculated the cost of desalination (USD 0.338/m^3) and its economic use in agriculture in Sonora, Mexico.[162] They concluded that, in order to ensure its viability, farmers should choose high-yield crops with profitable cost–benefit ratios, such as vegetables (e.g. tomatoes and chillies), and apply drip irrigation. Integrated agri-aquaculture farms are testing the integration of saline water into farms using salt-tolerant crops.[152] Policies and regulations have a powerful role in boosting both through public projects, enabling the private sector and knowledge exchange.[152] Public–private partnerships also reduce investment risks.

Water desalination can have negative impacts on the environment (e.g. brine disposal of residues from desalination and GHG emissions). Although there are technology and management options to reduce such impacts, there is a need for standards and impact assessment studies (local and regional),[156] as well as for brine disposal research and continuous monitoring of effluents. ■

MAKING INNOVATION, COMMUNICATIONS AND TECHNOLOGY WORK FOR ALL

With agriculture increasingly becoming knowledge-intensive, and farmers having to make more complex decisions on land and water, on which crops to produce and how, and on where to buy their inputs and sell their outputs, information needs will only become greater. The localized nature of agriculture means information should be tailored to each context.[163] Information and communication technology (ICT) has great potential to increase agricultural productivity and preserve natural resources, including water.

The term ICT is an umbrella covering anything from radio to satellite imagery, mobile phones to exchange information via messaging services, and electronic money transfers.[163] In India, Nano Ganesh, an irrigation automation system, allows farmers to switch their water pump on and off remotely and obtain information on water and electricity usage. It also allows them to time irrigation to meet crop water requirements. About 20 000 farmers used this device in 2015, and the estimated benefit–cost ratio was 6:1.[163] Use of this system can bring additional income-generating opportunities, such as through installation, repair, training and demonstrations, with job opportunities for women.

Precision agriculture comprises other ICT tools, including Global Positioning System (GPS), satellites, sensors and aerial images, that provide farmers with site-specific information to make management decisions.[163, 164] Determining soil and crop conditions – while minimizing impacts on wildlife and the environment – is at the root of precision farming. Although concentrated in high-income countries, some precision tools have great potential in low-income countries. Many of these applications have been limited to large-scale farming, but there are opportunities for small-scale farmers. Wireless sensor networks – a group of small sensing devices, or nodes, that capture data – are a case in point. Not only is the technology fairly cheap (some units cost less than USD 100), but it can operate on batteries and alternative energy, crucial for low-income countries.[165] Wireless sensors can also be used in aquaculture to monitor oxygen, tidal currents, temperature, fish behaviour and water conditions. AKVA, a Norwegian firm specializing in commercial fish farming, uses sensors with a built-in camera to detect uneaten feed in fish cages.[166] With this information, sensor signals can stop the release of feed, allowing for more specific care and feed purchase. The sensors can also adapt to the accurate feeding rate of the fish over time.[163]

Satellite technology is another tool that can capture, manage and analyse data relating to crop productivity and field inputs. However, the initial costs and technical requirements are a problem for small-scale farmers. Efforts to be inclusive and effective must focus on the full range of capacities and resources required by small-scale producers. An example of satellite information is FAO's recently developed Water Productivity Open-access Portal (WaPOR), a publicly accessible database using satellite data (Box 15).[167]

Advances and the global spread of ICT tools, such as geospatial statistical methods, have made it possible to gather, analyse and share data more effectively, as well as visualize and understand what this information means for agriculture.[163] The array of sensors in smartphones has expanded to include barometers and thermometers that can collect hyperlocalized weather information. Small-scale farmers with mobile phones are beginning to benefit from improved tools. However, access to data remains a challenge.

Both the public and private sectors have important roles in helping to bridge these gaps. Integrating ICT into national programmes, creating an enabling environment, and designing digital systems that are compatible and easy to use can help improve access. One example is the Global Open Data for Agriculture and Nutrition initiative, launched in 2013, which advocates for open-data and open-access policies in the public and private sectors. Another example is Open Ag Data Alliance, launched in 2014, which aims to help farmers access and control their data.[163] Launched in 2008, Digital Green enables extension agents and peer farmers to upload videos online to share knowledge on improved agricultural practices. As of June 2020, the organization had reached 1.8 million small-scale farmers in India – 90 percent of them women – across 15 200 villages.[168] The FAO Dimitra Clubs seek to empower rural communities, especially women and young people, using mobile phones and radio stations to share information. There are age asymmetries in ICT access as young people tend to adopt more readily, which can be turned to advantage and used as a learning tool within communities. ■

CONCLUSIONS

Meeting future demand for food without further undermining the environment is possible but will require transformations in water management. This chapter has explored technological options and new water management practices to address water shortages and scarcity in irrigated and rainfed cropland, livestock, inland fisheries and aquaculture, and to improve agricultural production, food security and nutrition, and climate resilience in a sustainable way. Some key points emerge.

First, although rainfed agriculture predominates, substantial yield gaps in rainfed crop systems persist. Combined with agronomic practices, improved water management has major potential to increase yields, especially in sub-Saharan Africa, Eastern Europe and parts of Asia, where yield gaps are largest, taking into account local needs and conditions.

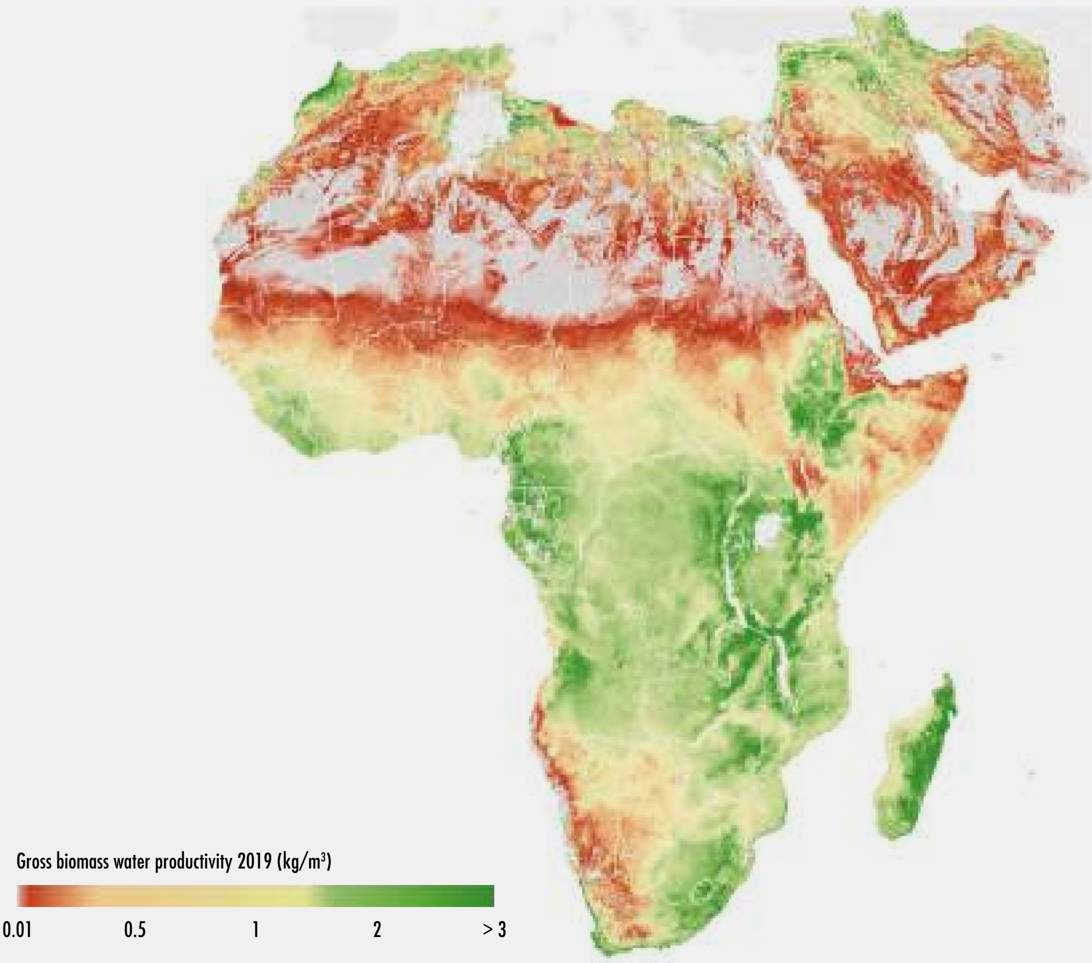
Second, while irrigated areas have higher and more stable yields compared with rainfed agriculture, substantial gaps remain in »

BOX 15
WATER PRODUCTIVITY OPEN-ACCESS PORTAL (WaPOR) – REMOTE SENSING FOR WATER PRODUCTIVITY

FAO's WaPOR platform offers operational and open access to a water productivity database and thousands of map layers. It allows for direct data queries, time series analyses, area statistics and data download of key variables associated with water and land productivity.[169] By providing near-real-time pixel information for all of Africa and the Near East, WaPOR opens the door for service providers to help farmers achieve more reliable yields and better livelihoods. At the same time, authorities have information to modernize irrigation schemes, while government agencies can enhance efficient use of natural resources.

The figure in this box shows the spatial variation of water productivity measured by WaPOR. The yellow-green patches have high water productivity, with low water consumption per crop produced and fields that yield at least 1 kg of product per cubic metre of water. The orange-red fields are underperforming, with low water productivity, possibly owing to poor agronomic practices. To improve red areas, green areas can be analysed and referenced for scaling up.

GROSS BIOMASS WATER PRODUCTIVITY, 2019



NOTES: Annual gross biomass water productivity expresses the quantity of output (total biomass production) in relation to the total volume of water consumed in the year (actual evapotranspiration). Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined.
SOURCE: FAO. 2019.[170]

» irrigated agriculture, suggesting major scope for improvement, particularly in sub-Saharan Africa, Northern Africa and Western Asia, and Latin America and the Caribbean. Investments are required in water accounting and allocation; efficient irrigation; high-yielding and resilient crop varieties; adequate fertilizer and pesticides; and improved soil and water management. Non-conventional sources can also ease pressure on freshwater resources.

Third, animal production uses significant amounts of water, especially for feed, and therefore holds great promise for increased water productivity. For livestock, options include better use of pasturelands; improved animal health and animal husbandry; effective provision of feed and drinking water; and the integration of crop, livestock and aquaculture systems.

There is also a need for integrated approaches to improve productivity in rainfed and irrigated areas and environmental sustainability, tailored to the capacities and resources of producers. These include conservation agriculture and nature-based solutions, such as agroforestry and soil and water management that intensifies production sustainably. Fourth, ICT has a role for farmers in making complex decisions on land and water resources.

Water management strategies mean strengthening intersectoral institutions and mechanisms that effectively involve users and stakeholders, with concern for affordability and the human right of access to water, particularly for the most vulnerable. Finally, water demand and supply strategies require finance for essential and responsible investment. These dimensions are discussed in more detail in the following two chapters. ■

IN FOCUS

AQUACULTURE IN THE CONTEXT OF SUSTAINABLE WATER USE IN FOOD SYSTEMS

Aquaculture and water use

Aquaculture, or farming in water, includes farming of both animals (including finfish, crustaceans and molluscs) and plants (including seaweeds and freshwater macrophytes). Whereas agriculture is predominantly based on freshwater, aquaculture occurs in freshwater, brackish-water and marine environments. Although all aquaculture requires water, and intensive fish culture (e.g. high-density catfish culture) consumes water, many other aquaculture technologies are either: (i) non-consumptive, meaning they do not remove water from the environment; or (ii) integrated with other agriculture production, meaning two or more products are produced with the same amount of water.

Aquaculture provides high-quality nutritious food,[171] and a wide range of aquaculture products have evolved within various agroecosystems and economic settings, reflecting cultural differences, market demands and consumer preferences. Aquaculture itself is diverse, practised in a wide variety of ways and around the world. It uses strikingly different production systems such as ponds, cages or raceways. More than 600 species are farmed, but most aquaculture, similar to agriculture, relies on a small number of "core" species such as tilapia, carp, shrimp, bivalves and seaweeds. The 20 most-produced species accounted for more than 80 percent of global production in 2018.[172]

To discuss sustainable water use in aquaculture, it is important to understand two major divisions. First, there is the division between fed and non-fed systems. Fed systems are generally more intensive, and differ in efficiency of input use, including water, compared with non-fed systems. Non-fed systems are particularly relevant for efficient water use as filter feeders and omnivorous species (e.g. carp and tilapia) utilize the natural productivity of waterbodies. The second major division is between freshwater and saltwater. World production of farmed food fish (i.e. fish destined for human consumption) relies predominantly on inland freshwater aquaculture. In 2018, inland aquaculture was the source of 51.3 million tonnes of farmed food fish, or 62.5 percent of the world's total farmed food fish production, as compared with 57.9 percent in 2000.[173]

There are also major divisions according to production systems. Cage culture and marine systems, where fish or other aquatic animals are raised within floating or fixed structures submerged »

IN FOCUS

AQUACULTURE IN THE CONTEXT OF SUSTAINABLE WATER USE IN FOOD SYSTEMS

EGYPT
Fresh plants and fish growing inside a greenhouse at an aquaponics farm that focuses on sustainability and clean energy.
©FAO/Khaled Desouki

» in water (in reservoirs, lakes and rivers), can also be considered non-consumptive farming, together with culture-based fisheries, where water use can be improved with good monitoring and correct management decisions. Earthen or excavated ponds are most commonly used for inland aquaculture production, although raceway tanks, above-ground tanks, pens and cages are also widely used where conditions allow. Recirculation aquaculture is one of the aquaculture practices that save most water. It uses tanks, pumps and filters to contain, circulate and clean water so that it can be recirculated, or recycled, and does not need to be changed. Depending on the technology and intensity, water usage can drop by a factor of 100 compared with flow-through systems.[174] Some recently developed, superintensive systems use as little as 300 litres of new water, and sometimes even less, per kilogram of fish produced. Traditional outdoor farms retrofitted and reconstructed as recirculation systems, report consumption of 3 m^3 of water per kilogram of fish. A traditional flow-through system for trout will typically use about 30 m^3 per kilogram of fish produced per year.[174] A downside of recirculation agriculture is its high technological complexity and higher costs, but the water savings are significant.

Integrated agriculture–aquaculture systems come in several forms, including livestock–fish, birds–fish or rice–fish production systems.[175] Aquaponics, linking fish production with soil-less plant production in recirculating systems, offers an additional approach. Outputs from one subsystem, which otherwise might be wasted, become an input to another subsystem, improving water productivity. The agricultural element tends to be the pre-eminent crop, with fish grown to provide a secondary crop, as well as providing wastewater rich in nutrients that can benefit the agricultural component.

This integration leads to greater efficiency in the use of land and water that are under a farmer's control. As the water is fertilized from fish waste, it becomes rich in organic nutrients, thereby increasing plant production and decreasing the need for additional fertilizers.[176] There are reports of integrated agriculture–aquaculture farming, including desert and arid lands, that have reduced water consumption by 80–90 percent compared with traditional aquaculture.[177]

One example – a large, almost entirely contained integrated agriculture–aquaculture farm – is in Egypt, where tilapia are grown in fish tanks connected to ponds growing a special floating water fern called *Azolla* that is used as feed.[178, 179] *Azolla* is a cosmopolitan aquatic plant that absorbs nutrients from water while fixing atmospheric nitrogen, literally creating fertilizer from the air. This water is used to irrigate grapes, olive trees, oranges and mangoes.[180]

Integrated agriculture–aquaculture systems can be particularly important in mountainous and remote areas, depending on temperature, where poverty and malnutrition are prevalent. For example, the integration and diversification of aquaculture allows production of rice and fish in a single terraced paddy field, and non-fed aquatic species enrich the nutrition level of local people as well as develop the rural economy.[181]

An important point in terms of sustainable water use is that, in specific cases, aquaculture can be carried out where land or water is otherwise unsuitable for agriculture. In some countries (e.g. China and Egypt), aquaculture with saline water is carried out in areas where soil conditions and the chemical properties of available water are unsuitable for other types of food, such as food grain crops or animal fodder.[182, 183] Commonly, tilapia or shrimp are used in these cases. In seasonal floodplains or coastal inundation zones, aquaculture can provide an agricultural strategy to make these marginal lands productive.

Use of saline–alkaline water resources for food and livelihood

In many places around the world, soils are becoming unusable for crop farming, and one major cause is salinization – the increase in salt concentration in soil.[184] This often occurs where irrigation water contains dissolved salts, increasing the pH of the soil (alkaline), further reducing its ability to produce crops. There are about 950 million hectares of saline–alkaline land area in the world, one-third of total land area.[182, 183] There are several options to manage salinized lands, and an interesting one is conversion to aquaculture. There are many success stories on developing aquaculture in alkaline land areas. Adopting aquaculture improves land productivity and, thereby, the rural economy by increasing overall production.[185]

Another option is production of *Artemia*, an aquatic animal that grows in saline water and is used as feed in aquaculture. *Artemia* grows around the world and is widely used as live food for the larvae of marine and freshwater crustaceans and for finfish. It is considered critical to successful aquaculture production. The collection and utilization of *Artemia* cysts (dormant eggs) have become an important livelihood and income source for people living around salt-alkaline coastal, lake and related waterbodies, and the system shows great potential for livelihood development, without freshwater.[186]

Aquaponics for integrated fish and vegetable production

Aquaponics connects aquaculture with hydroponics in one soil-less production system, such that the fish provide the nutrients for the plants, and the plants clean the water for the fish. By connecting these two separate production systems, all the water is recycled. None is lost to runoff, saturation or weeds, and evaporation is reduced to a minimum. Vegetables produced from aquaponics use about 90 percent less water than do field-grown crops, delivering a second product in addition.[179] Further water conservation is seen in that there is no effluent discharge from an aquaponic system, neither from the fish nor from crop runoff. This has positive impacts on the watershed, and averts nutrient and chemical pollution.

Although aquaponics is an effective water-saving practice, it is not suitable for all locations, nor for all crops and producers. It is most appropriate for freshwater fish and high-quality, high-value vegetables and herbs, but less appropriate for pulses and grains.[179] A disincentive has been the higher costs associated with scaling up large aquaponic businesses. However, it has been proved economically feasible in many locations around the world, especially where land and water are scarce.[179] Successful examples are in Barbados, Indonesia, Saudi Arabia and the United States of America, demonstrating the adaptability and effectiveness of this integrated farming system.[187]

Rice–fish farming for improved livelihoods and nutrition

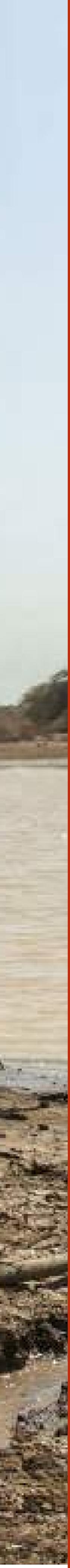
The integration of aquaculture and agriculture is not a recent innovation. With increasing pressure on natural resources, land and water, aggravated by climate change, such integration offers opportunities to build more sustainable food systems through new and improved practices that produce more, while generating socio-economic and environmental benefits.[188] Rice–fish farming continues to expand, especially in China, Lao People's Democratic Republic and Madagascar, where local stakeholders and indigenous communities have jointly made improvements. In China, rice is increasingly integrated with new, high-value fed species such as mitten crab and crayfish. In Guinea, rice–fish integration has been adapted to develop technologies for increased fish production.[188] With their efficient resource use and significant benefits,[189] there is much potential for further expansion of these integrated systems, especially in Africa.[190] There have been encouraging results from rice–fish farming in Burkina Faso, Guinea-Bissau, Mali and Uganda.

In general, rice–fish farming is fish farming conducted at the same time as rice cultivation, although rotational systems also exist. Trenches dug within the paddy serve as fish refuges, and the fish are able to navigate the rows of rice, eating insects and snails, aerating the soil and oxygenating the water, thereby increasing rice yields in the paddy. One of the benefits of rice–fish farming of relevance to water use is that it requires less use of fertilizers and pesticides, by about 30–50 percent, with direct implications for the health of the watershed by reducing pollution.[191] Two separate products, fish and rice, are produced with the same water consumption. When implemented with an agroecological approach, rice–fish farming, as other types of integrated agriculture–aquaculture, helps alleviate poverty and hunger, while at the same time providing positive social and ecological benefits.[192] Some systems are internationally recognized for their cultural, agricultural and environmental benefits, and have been designated Globally Important Agriculture Heritage Systems.[193]

In summary, aquaculture can provide many advantages in sustainable water use, such as:

- integrated crop–aquaculture systems can reuse aquaculture water to cultivate crops and produce additional food with the same amount of water (if recycled).
- aquaculture can be adopted in areas where freshwater crops cannot be grown, for example, in saltwater inundation areas, or where the water is alkaline.
- new and improved technologies, such as recirculating aquaculture, increase water savings through careful management and reuse of water resources.
- non-fed aquaculture reduces the carbon footprint by producing food at lower trophic levels, but it takes longer for fish to gain weight.[194]
- some aquaculture is non-consumptive, meaning it does not remove water from the agroecosystem (e.g. cage culture).

ETHIOPIA
A farmer pumping water from the pond to water fodder seedlings.



CHAPTER 4
IMPROVED GOVERNANCE FOR MANAGING WATER IN AGRICULTURE

Key messages

- As demand for water grows and tensions among users intensify, governance becomes increasingly important to ensure sustainable, efficient and equitable water use.

- Water accounting and auditing – understanding the status, trends and broader societal context of water resources – should be the starting point for any effective management and governance strategy.

- Regulations that promote coordination across entities and actors – within and outside agriculture – will be key in managing competing demands for water, equitable access and ecosystem services.

- Secure water and land tenure – with carefully designed water trading and pricing systems – can establish incentives for efficient and sustainable water use in irrigated and rainfed areas.

- Transfer of water management to community associations can be beneficial by adapting to local conditions for stakeholders, particularly women, who remain under-represented and disadvantaged.

CHAPTER 4

IMPROVED GOVERNANCE FOR MANAGING WATER IN AGRICULTURE

Chapter 3 presented water management options for reducing water risks and improving productivity in rainfed and irrigated cropland, livestock systems, and inland fisheries and aquaculture, while ensuring environmental sustainability. Their relative potential will depend on a series of factors, including local agroclimatic conditions, water shortages and scarcity, agricultural production systems and the benefits of different strategies. It will also depend on external factors, including global trade and climate change, as well as governance, institutional frameworks and the policy environment.

This chapter focuses on the need for effective governance and strong institutions to guarantee sustainable and effective use of water and equitable distribution of benefits. It provides an overview of the opportunities, challenges and impacts of existing tools and measures to manage water scarcity, including water pricing to control demand and recover costs, as well as allocation tools, such as water rights and quotas, to protect the resource and its quality, and to ensure equitable access. The chapter goes beyond irrigated systems, and reviews options for water governance of rainfed crops, livestock, inland fisheries and aquaculture, and the impact of excess water in agriculture. The overall policy framework is presented in Chapter 5. ■

THE ROLE OF GOVERNANCE IN MANAGING WATER CONSTRAINTS

Figure 13 (p. 43) shows that reducing water shortages and scarcity will require major transformations involving technological change and management innovations, influenced by the overall political, institutional and legal framework. Water issues typically involve multiple stakeholders (e.g. watersheds across multiple administrative regions or even country borders) and institutions, and there are often political economy considerations and conflict over the roles of public and private actors.

Safeguarding the contribution of water to food security and nutrition will involve significant governance challenges from local to broader levels (Box 16).[1] Institutions at various levels will need to address the continued degradation of soils in irrigated areas, the deterioration of freshwater ecosystems and sustainable water use. Strong political will, discussion and cross-sectoral collaboration will be needed to negotiate increasing competition for freshwater resources, including between agriculture and cities. Policymakers and regulatory agencies should be informed on the needs, operational capacity and importance of different sectors, especially regarding those groups of people who lack sufficient political leverage (e.g. fishers).[2, 3] In collaboration with FAO, Jordan is improving national, regional and local capacity to cope with water scarcity, especially that of farmers and livestock breeders, as a result of an improved knowledge of water use in agriculture and capacity needs to develop water harvesting and irrigation technologies.[4]

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BOX 16
WATER GOVERNANCE FOR AGRICULTURE AND FOOD SECURITY

Water management has dominated the discussion, efforts and proposed solutions to water problems, but without considering governance. At the turn of the century, water governance emerged as a prominent issue for the international community, with implications for food security and nutrition, and for economic development. Governance refers to formal and informal rules, organizations and processes through which public and private actors articulate their interests and make decisions. Water governance refers to the processes, actors and institutions in decision-making on water resources and delivery of water services, encompassing political, administrative, social and economic domains along with formal and informal systems and mechanisms.[5]

At FAO, the Committee on World Food Security recognized the importance of governance by asking the High Level Panel of Experts on Food Security and Nutrition to prepare a report on water and food security for its forty-second session in 2015.[1] The report recognized governance as one of the main components for improved food security and nutrition.

Efforts to support national and international governance in the water sector have intensified, with several initiatives, such as:

- FAO has implemented the Groundwater Governance Project, supported by the Global Environment Facility, the Intergovernmental Hydrological Programme of the United Nations Educational, Scientific and Cultural Organization, the International Association of Hydrogeologists and the World Bank. The goal is to put on decision makers' agenda the need for governance to sustain the socio-economic benefits of groundwater and avert an impending water crisis. Operational since 2011, the project has developed the Global Framework for Action, a set of policy and institutional guidelines, recommendations and best practices to improve groundwater management and governance at all levels.[6]
- The 2005 Water Governance Facility, a joint initiative of the United Nations Development Programme and the Stockholm International Water Institute, aims to provide policy support and advice to countries, and to build knowledge and capacities for improved water governance within governments and civil society as well as among United Nations agencies.[7]
- The Organisation for Economic Co-operation and Development has launched the Initiative on Water Governance, an international multi-stakeholder network of members from various sectors (public, private and not-for-profit) to share good practices of better governance in the water sector.[8]
- Alongside the existing river basin partnerships (such as the Nile Basin Initiative), SDG Indicator 6.5.2 tracks cooperation across country borders for rivers, lake basins and transboundary aquifers to assess coverage of operational arrangements across transborder basins.

These initiatives help advance knowledge and effective water governance. However, they do not sufficiently integrate the critical links between water, agriculture and food security,[5] making water governance particularly complex. Water allocations are dependent on the wider political economy, such as energy prices. Countries should consider incorporating water governance for food security, adequate nutrition and sustainable agriculture in policies and frameworks as well as in collaboration with FAO and other partners.

- Devolution to provincial or district government further exacerbates the complexity of water governance, resulting in the need for horizontal and vertical decisions across water, agriculture and land institutions.[1] Improved coordination and integration should be achieved vertically from the sectoral and river-basin level through irrigation systems and households, and horizontally across sectors (agriculture, households and industries). Furthermore, some of the world's dry areas are becoming even drier, and precipitation more variable and extreme, calling for robust and flexible water management as well as innovative technologies and finance to develop new water resources.

Fragmentation and conflict remain part of water governance systems. Control over land and water is important when establishing political allegiance, with implications for less powerful groups. Water tenure is particularly insecure for small-scale farmers and other vulnerable groups, such as women, youth, migrants and indigenous populations. Appropriate water management strategies, governance, innovations and policies can go a long way towards ensuring that water usage is inclusive, equitable and sustainable. Recognizing that water accounting and auditing should be central to any programme to address the challenge of water shortages and scarcity, the following section highlights their role in water resources management and improved governance.

The subsequent sections review tools and strategies to improve governance and manage water constraints and competition in agriculture. Acknowledging that managing scarcities and competing demands encompasses allocating and managing freshwater withdrawals, governance options are first assessed for irrigated agriculture. The chapter then focuses on water governance in rainfed crop production, livestock systems, aquaculture and inland fisheries. ■

TRANSPARENT WATER ACCOUNTING AND AUDITING

Effective water risk management must be based on sound water accounting – the systematic study of the hydrological cycle and the status and future trends in water supply, demand, accessibility and use.[9] Water accounting is vital as a resource baseline for any policies and interventions aimed at tackling water scarcity, especially in agriculture.[10] Without understanding water endowments, societies risk excessively optimistic estimates of water and subsequent over-allocation of water rights, causing serious shortages during drought. Future climate change is likely to further invalidate the hydrological assumptions on which water rights have been based.[9]

However, water accounting will only make a difference if it forms part of a broader process of improving governance. Auditing goes one step further than water accounting by placing trends in water supply, demand, accessibility and use in the broader context of governance, institutions, public and private expenditure, legislation and the wider political economy.[11] Combining accounting with auditing can provide the basis for more realistic, sustainable, effective and equitable water management.

Despite information being critical, government departments – such as agriculture, sanitation and the environment – rarely share a common information base.[9] Incorrect understanding of water volumes and distribution often underestimates pressure on resources and decreasing water availability. Water accounting and auditing are necessary for policy coherence and a common information base acceptable to stakeholders' planning or decisions. Eight countries in the Near East and North Africa region use water accounting and auditing to consume less water and use it more productively.[12] In Iran (Islamic Republic of), water accounting and auditing have highlighted issues of water-use efficiency on farms in conveyance, groundwater depletion, and the disparity between availability and government recommendations. In Jordan, water accounting has highlighted issues related to water quality, and suggested the benefits of adding small amounts of irrigation through water harvesting.

Water accounting and auditing are not free of challenges. First, the dynamic nature and uncertainty of both the physical processes of water and societal responses – including water stocks, depletion and replenishment rates, the condition of infrastructure, and user demand – make the long-term measurement of water resources particularly challenging. Therefore, water management plans need to be problem-focused and dynamic.[9] Second, in low-income countries, where infrastructure and institutions are weaker, and large irrigation systems service many small-scale farmers, measuring water use can be costly and a major constraint to water management. Third, the need to allocate water for environmental flows requires more detailed understanding of hydrological and ecosystem needs, often beyond the capacity of irrigation engineers and water managers, and cost–benefit models. Water accounting is an iterative process, with continual improvements needed in order to increase comprehensiveness and accuracy.

Compared with water accounting, water auditing requires societal information – qualitative and quantitative – and ensuring that well-motivated personnel have the necessary training.[11] The managing and collecting of water information requires resources, skill and patience, as it is often fragmented, sourced from different organizations and of variable quality. The overall cost of water accounting and auditing programmes varies enormously with, for example, the scale and ambition of the programme, the cost of contracting an implementation team, and the need to collect primary and secondary information. Advances in cyber technologies (e.g. remote sensing, drones, online information bases, and GPS-enabled smartphones) reduce costs and provide information even in remote areas without biophysical and societal monitoring networks or programmes. They are also strengthening global and regional databases with free information, involving more scientists.[11]

Because water accounting and auditing depend on context, there are different approaches and no standard methodology. In 2017, FAO published a sourcebook that is a good starting point for any organization to: use water accounting and auditing for the first time; combine water accounting with auditing; or review, and possibly refine, water accounting or auditing already in place.[11] ■

TOOLS FOR MANAGING WATER SCARCITY IN IRRIGATED AGRICULTURE

Water should be treated as an economic good with a value and a price. Insecure water rights, inequalities, inappropriate subsidies and poor cost recovery undermine water infrastructure and investments in water projects. These can lead to unproductive water use and excess irrigation.[13] Coupled with agricultural support – i.e. policy transfers linked to production, such as price support for high-water-using crops (e.g. rice) or subsidies for irrigation technology or fuel – they can also lead to overuse and misallocation. In India, price supports for rice and input subsidies have caused excess water use and environmental degradation.[14]

Many mechanisms and tools manage scarcities and competing demands. They include allocation tools and incentives, including water rights and quotas; tradable permits; licences; reform of social protection systems; and other measures, including water quality and protection regulations.[1] The choice of tools and social and legal systems (both formal and informal) can affect water availability and quality for agriculture, food security and nutrition, and access to water for poor, vulnerable and marginalized populations. Regulations with high compliance costs increase the risk of degradation and illegal groundwater pumping.[15]

Water allocation ranges from identifying national priorities and allocation between countries in shared river basins, to individual basin-level users (Box 17).[1] Badly adapted tools can disrupt existing systems. In times of severe drought

BOX 17
EVOLUTION OF WATER GOVERNANCE IN MOROCCO – CARROT PRODUCTION IN BERRECHID PROVINCE

Morocco is addressing governance of the water–energy–food nexus at the national and subnational levels. At the subnational level, co-management of aquifers is a new governance mode via a contract that encourages stakeholders to take responsibility for regulating and improving groundwater management. This is included in broader regional development plans and river basin management for consistency between objectives and actions taken.

In Berrechid Province in Morocco, the Water Basin Agency negotiates aquifer contracts, managing the actions and interests of agriculture and energy stakeholders. At the centre of the discussion is unequal access to water, whereby users in carrot production are perceived as relatively better-off. It is estimated that carrots use between 5 000 m³ and 15 000 m³ of freshwater per hectare, and cover a large extent of cropland. Despite using drip irrigation, water demand has led to over-exploitation of the aquifer.

FAO is supporting the Water Basin Agency to modify the aquifer contract into a new alliance between all stakeholders, exchanging information and strengthening trust and collaboration. The objective is for stakeholders to improve crop water productivity, through economic incentives (e.g. agricultural diversification) or engaging farmers associations in water accounting. This indicates the potential to bring together different actors – such as those involved in the water–energy–food nexus – to identify key aquifer challenges, and the best way forward, including investment and finance.

SOURCES: Bojic & Vallée. 2019,[18] and IAV Hassan II. 2019.[19]

and water stress, market tools may prioritize sectors offering the highest economic value (such as cities and industries), restricting water for agriculture.[1, 16] The challenge is to prioritize water for food production as well as the basic needs of poor and vulnerable populations.

Where river health deteriorates owing to flow disturbances, it is important to restore flows to meet environmental needs and maintain species abundance and diversity, supporting other river ecosystem services.[3] Although politically challenging, most high-income countries, and some low-income ones, now have environmental flow regulations.[3, 17]

The role of water tenure, land tenure and water rights

Discussion about allocation, reallocation and equitable delivery of water services takes place around water rights, associated with land rights. A water right is a legal right to extract and use water from a natural source, such as a river, stream or aquifer.[20] There are distinct types of water rights, just like relationships under the heading of water tenure, including annual licences (to use water based on command and control), supply contracts, and agency control (legal power for an irrigation agency to use water).[10] Because of their connection to property, water rights are today a cause of controversies between countries of all income levels. In this report, water tenure (Box 18) is a broader, supplementary concept to water rights. Neither term should be confused with the human right to water emerging from international human rights law.

In a world of increasing demand, water and land tenure can be a strong building block for efficient use and secure, equitable and sustainable access to water. It allows adjustments through the market, while the price mechanism – reflecting the true value of water – incentivizes users to monitor and use water more efficiently and productively.[21] By requiring user consent to any reallocation and compensating for any

BOX 18
EXPLORING WATER TENURE

Before considering water tenure, it is useful to examine tenure itself in more detail. Tenure determines access and use of different natural resources, and how they relate to one another through formal and informal rules and agreements.[10] The term most commonly concerns land. Although there are many definitions of land tenure, a succinct definition from FAO is "the relationship, whether legally or customarily defined, between people, as individuals or groups, with respect to land."[24] This report proposes the following definition of water tenure: "the relationship, whether legally or customarily defined, between people, as individuals or groups, with respect to water resources."[10]

For agricultural water use, most types of tenure are relevant. Farmers in high-income countries may rely on traditional formal water rights (those deriving from land tenure rights), modern water rights (permit-based long-term rights, of 12–30 years or more) or bulk water supply contracts, such as commonhold tenure through water users associations. In low-income countries, farmers may be less likely to hold modern formal water rights, but may rely on customary or informal rights (e.g. India),[10] particularly for groundwater. These can be flexible, socially negotiable and highly adaptable depending on local, social and environmental circumstances. Local water allocation can also be robust and play an important role in conflict resolution, as access to water is through an intricate set of social and reciprocal relations (e.g. chiefs, elders and local authorities).

Compared with the water rights approach, which tends to be top-down and state-led, water tenure is a bottom-up, user-focused approach, more appropriate for the complexity of water, involving a holistic approach to relationships with water and sustainable and inclusive use. Water tenure also considers countries where local law dominates water management and use, in addition to statutory arrangements such as permits, water supply contracts and concessions.

Water tenure focuses on access and use, whereas governance embraces the wider social and economic processes and forces that determine the status of water. Tenure influences water governance and is simultaneously influenced by it. Until there is clear understanding of water tenure, attempts at governance reform will likely fail.

transfers, tenure empowers users and increases the economic value of water, provided that state institutions and enforcement mechanisms operate properly. This incentivizes farmers to invest in, *inter alia*, irrigation, land and soil management, more advanced technologies and reducing resource degradation.[22, 23] Secure water rights can also help develop ICT, such as real-time management of irrigation systems, and water mapping through satellite technology, artificial intelligence and blockchain tools.

Traditional formal water rights (Box 18) are still relevant.[10] Tied to land tenure rights, a formal mechanism and associated bureaucracy are not necessary, as a person with a land tenure right also has a water right. Landholders should assert their water rights against third parties, without enforcement by water administration. Often, traditional formal water rights are inadequate for enforcing access. Although a system of water tenure exists in most settings where water is scarce, those systems not formally recognized or grounded in law are more vulnerable to encroachments and expropriation.[25] Establishing rights should be transparent and secure in order to protect small-scale users, enabling them to negotiate benefits or compensation. Community-based water tenure can support indigenous peoples, local communities and women – who are often unaware or unable to assert water rights.

FAO developed the Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National

Food Security to address the land–water interface.[26] This includes improvement of policy and legal frameworks, with the overarching goal of food security for all and realizing the right to adequate food. Young (2015) lays out a blueprint for water rights and trading (buying and selling water rights), based on the Murray–Darling River Basin in Australia.[27] It highlights the importance of allocating water in a transparent process, accounting for evaporative losses and environmental outcomes, including water quality and flows to the sea. This provides transparency in response to changes in the water available to each irrigator. As water tenure is context- and location-specific, the situation in Australia can be very different from that in other countries, particularly low-income countries. Small-scale users are often reluctant to register water use for fear of invoking fees. This may risk access to water as water rights regimes are rolled out in many countries.[1, 28]

Adding to the difficulty of reform, water is often treated as a free good and generally subsidized, which impedes secure water rights. Entrenched interests benefit from existing subsidies and water allocations.[29] Access and tenure are often linked to political dynamics, different groups, interests and influence. Within the agriculture sector, priority may go to the most productive and largest users over small-scale producers, especially women, threatening their livelihoods and food security. This can be remedied through a user approach with equal priority on a territorial basis, considering intended use (e.g. food security and nutrition) and water productivity. This aligns with agreed principles, including the human right to water and food.[30, 31]

Water tenure can promote policy coherence across sectors. The land–water interface is an obvious example, with the use of one resource influencing and being influenced by the other.[10] Well-defined water tenure can improve irrigation technology for conveyance, diversion and metering, and the institutional frameworks of water management, especially in low-income countries. This requires a water accounting and an allocation system *before* investing in new irrigation. Without secure water rights, new technologies can actually increase water consumption. There can be economic gains by allocating more water to higher-value uses, such as fruits and vegetables. However, there is the risk of increasing water consumption with negative effects on small producers and women. It is also possible to improve water quality by reducing withdrawals, managing groundwater levels and sustaining baseflow in rivers (i.e. the portion of streamflow maintained by groundwater discharge).

Economic instruments – redirecting farmer incentives

Economic instruments can encourage producers to change their behaviour to achieve the desired hydrological outcome.[15] Such schemes may produce revenue for the regulator (via taxes), be costly to the regulator (subsidies), or involve payments only between farmers (trading). In the absence of binding and enforced water tenure, incentive-based instruments may be difficult to implement and their outcome hard to quantify; hence, they are often used with underlying regulatory approaches for monitoring and enforcement, rather than independently.

Water market opportunities and challenges

In areas where freshwater allocations are in place, it may be possible for producers to transfer entitlements among themselves. Mechanisms include leasing and selling water rights, auctions, water banks, block pricing and water quality trading. These treat water as a good to transfer among users according to market price.[21] Under certain circumstances and in some country contexts, markets may allocate water effectively, being economically efficient and responsive to change. When users can decide to buy or sell, those who sell, do so voluntarily, which is often not the case when a central authority reallocates or expropriates water. The market mechanism can thus reduce conflict although there is a very small number of functioning water markets with sufficient experience.[32]

Exceptions include the Camp de Tarragona, Spain, where market mechanisms have led to the proper allocation of resources and flexibility in competition among different uses with high economic efficiency. Collaboration between beneficiaries and the managing institutions provided the basis for the market.[32] Analysis of the period 1954–2012 of the Rio Grande water market in Texas, the United States of America, shows that it facilitated a shift towards higher-value, more productive crops. This was largest during droughts and accounted for about 30 percent of revenue in water market counties.[33] In the United States of America, the average annual value of water trading across 12 western states between 1987 and 2008 is estimated at USD 406 million.[34] Annually, the value of water transactions has varied from less than USD 1 million in Montana and Wyoming, to almost USD 40 million in Arizona, Colorado, Nevada and Texas, and more than USD 223 million in California. In Australia, the size of the market is substantial, with the total value of water markets estimated at about USD 1.7 billion[n] in 2017–2018.[35]

However, there are significant preconditions to a successful water market and equitable distribution. For example, in Chile, (new) water rights are auctioned to the highest bidder, with the expectation this will result in equitable water allocation, based on the premise that anybody can join the market.[36] This often hurts subsistence farmers, whose benefits are difficult to calculate in economic terms. How market rules are designed and monitored matters. In Chile, speculators hoard water-use rights, with limited registering or tracking of those rights.[37] One study for the Limarí river valley in Chile found that eliminating trade restrictions on water markets between districts would result in welfare gains of 8–32 percent of agriculture's contribution to regional GDP.[38]

In Australia, water markets in the Murray–Darling basin reduced overall benefits and imposed environmental costs owing to the over-allocation of rights. To increase efficiency and free up water for environmental flows, heavy public investments were directed into irrigation.[39] Analyses show it would be much less expensive and more effective to buy back excess entitlements. The cost of infrastructure subsidies is almost 2.5 times more than the cost of acquiring water.[40] Similarly, the cost of increasing environmental flows from subsidies is more than six times greater than that of direct purchases.[40] The Murray–Darling basin illustrates the benefits from water markets, and the importance of a correct sequence of reform and of the definition and quantity of water rights.

The principles of groundwater management are more complex than those governing surface systems owing to information constraints. With caps on water withdrawal in the aquifer, these markets can improve accessibility to groundwater irrigation, particularly for marginal and small-scale farmers. Negative aspects include monopoly power by local water sellers and combining water markets with electricity subsidies without usage regulations, leading to over-exploitation of groundwater (Box 19). The costs of depleting groundwater reserves can be disproportionately borne by small-scale and marginal farmers. In extreme cases, over-extraction can lead to abandonment of irrigation in many coastal areas (e.g. in Morocco and Tunisia).[41]

Policies to manage over-extraction usually require state funding, and regulatory and incentive-based tools. These include limits on new wells or irrigated acreage, pumping rights and permits, certification of irrigated acreage and well metering. Lower-cost metering can be achieved through proxy measurements and advanced information technology, such as remote sensing, especially in dry areas. Controlling expansion in the number of wells requires strong political will and field staff, in addition to the imposition of gradual sanctions on violators. The number of wells can be reduced by buying them back. Incentive-based tools include taxes, fees, land retirement, trading groundwater permits and cost sharing to incentivize water management. See Box 20 for two cases of general groundwater management in the United States of America.

In an in-depth analysis of groundwater management reform, Molle and Closas (2017) find that co-management by users and the state offers greater potential for success where implemented with a combination of the following factors: (i) the threat of sanctions in accordance with the law, often linked to environmental safeguards or water-sharing agreements/treaties;

n Converted at the 2019 exchange rate of USD 1 = AUD 1.44.

BOX 19
IMPACT OF GROUNDWATER MARKETS ON EQUITY AND WATER-USE EFFICIENCY – THE CASES OF CHINA AND INDIA

In India, agricultural water markets are limited almost totally to groundwater. These are informal and localized, but the estimated area served is between 8.4 million and 13 million hectares, about 14–22 percent of total area irrigated with groundwater. The annual value of water selling in Indian irrigation is about USD 1.7 billion, with another USD 2.6 billion per year from hired irrigation services.[42] The impact varies, but groundwater markets can improve accessibility to groundwater irrigation, particularly for marginal and small-scale farmers, mitigating water vulnerabilities.[43] They also allow farmers to raise their productivity. Water buyers have been shown to be more efficient in water use, while sellers are more efficient than a control group of pump owners who do not sell water.[44] Despite these benefits, in the context of subsidized electricity, groundwater markets may still have negative implications through over-exploitation that reduces groundwater for future agricultural use.[43] Improving groundwater productivity can reduce consumption and over-extraction, but clear accounting is needed.

In northern China, groundwater markets have also grown rapidly. A survey showed that 18 percent of tubewells were selling water in 2004, and that 77 percent of water pumped from private wells was sold in the groundwater market the same year.[45] The analysis indicates that farmers who buy water from groundwater markets use less than those who have their own tubewells. The yields of water buyers were not negatively affected, suggesting water buyers try to improve water efficiency. Groundwater markets in northern China are not monopolistic, offering poor rural households affordable irrigation water. Another analysis found that groundwater markets in China have brought sellers moderate profits, while providing irrigation to buyers at a reasonable price, especially to the poor.[46]

(ii) a severe drought or environmental crisis that makes state intervention more legitimate and acceptable; (iii) lower transactions costs; (iv) limited number of users and relative social homogeneity; (v) sufficient resources to offer incentives beyond regulations and sanctions; (vi) possibility of disaggregation of management of the aquifer into smaller parts, provided that effective regulations and incentives ensure water-use efficiency; (vii) reliable and transparent information on water resources; and (viii) establishment of agreed accountability and transparency about the rationale behind the measures, and distribution of costs and benefits.[41]

Overall, many surface water and groundwater market-based mechanisms are still fairly new, and water market approaches will improve based on such experiences. More firms are investing in or supporting water markets, a sign of a developing marketplace.[21] The implementation of water market mechanisms, whether a water auction, water bank, or other forms of transferring water utilizing price, is complicated and requires specialized expertise for each location, including on socio-economic, political, legal, hydrological and environmental circumstances, or on the heterogeneity of water tenure. Given that pressures on water will continue and that the traditional approaches of developing resources are nearing their limit, experimentation and innovation in different water market approaches is likely to continue.

Water pricing – opportunities and challenges

Water pricing, charging for a water (use) right in monetary terms, can serve to recover direct (water supply and infrastructure) and indirect (environmental, social and opportunity) costs.[48] It may also help conserve water and promote more sustainable use, address scarcity problems and foster investments into alternative, less water-intensive crops or water-saving technologies. In agriculture, water pricing is difficult to implement for political, cultural and

BOX 20
GROUNDWATER MANAGEMENT IN THE UNITED STATES OF AMERICA

In the United States of America, the Upper Republican Natural Resources District in Nebraska uses multiple tools to reduce groundwater declines and satisfy an interstate compact with Colorado and Kansas on surface water flows. The tools include a moratorium on drilling new wells, a well permit system, "land occupation" taxes, a cap on groundwater pumping for formal and informal water markets, and stream augmentation projects. The cost of soil moisture probes is subsidized to incentivize better management practices. Strong community involvement and support for monitoring and enforcement have been key to success. The district has respected the interstate compact while minimizing the impact on water users. However, the long-term issue of declining groundwater level remains and, although the groundwater decline is lesser today than predicted, the district has so far been unable to stabilize levels. Excessive initial allocations have been a problem, as many users have banked large amounts of water for future use, reducing the incentive to conserve water. The district has attempted to address this by restrictions on carry-over accounting.[47] Hydrologically correct initial allocations and flexibility in correcting over-allocation are essential for success in water reforms.

The Edwards Aquifer Authority in Texas, United States of America, manages groundwater levels and spring flows needed for the survival of several endangered species. Caps on groundwater pumping and tradable permits limit withdrawal. Water trading has established specific caps in state law, minimizing transaction costs, developing an online trading platform and fostering flexibility on how users divide their allocations. Making water-use data publicly available has increased transparency, built trust and helped ensure buy-in from programme participants. The Edwards Aquifer Authority has succeeded in maintaining minimum spring flows, even during drought.[47]

equity reasons. In many countries, there is no national price for water, as it can vary greatly within the country and for different irrigation systems. Some countries do not price water at all, despite the need for investment in infrastructure and technologies, which requires massive private and public financing.[49]

In certain local and regional agricultural circumstances (e.g. a low share of water costs in proportion to overall production costs), price elasticity of water demand can be low, especially in the short term. In these cases, a higher water price may not lead to significant use reductions.[48] Incentive-based tariffs are more prominent as they deal with the way water users pay and whether the right price signals are transmitted, instead of just focusing on cost recovery. These trends reflect the devolution of water management from central governments to regional or local authorities, the increasing private-sector investment in water services and the financing of large water investments through public–private partnerships. These emphasize the importance of water pricing, but also call for strong regulation to guarantee protection of the public interest.[49]

It can be very difficult to raise cost recovery from users. In most cases, even operation and maintenance costs are not recovered.[50] Robust allocation can help shift water from cereal crops towards higher-value uses, with flexibility to adjust to changing conditions.[51] Encouraging payment for water management and services also requires consistent quality of water services and a clear explanation of how revenue is used to benefit users, in addition to regulations and sanctions. For a pricing scheme to deliver optimal cost recovery and sustainable use, design options such as the tariff structure and price level are crucial. Table 5 presents a summary of the main pricing methods.

TABLE 5
WATER PRICING METHODS

Pricing method	Summary	Strengths	Weaknesses
Market-based water pricing	Prices determined indirectly via a decentralized pricing mechanism (such as a market) and by supply and demand.	Potential for signalling scarcity and opportunity costs. Can be highly effective at maintaining the gross value of irrigated agriculture during droughts and reallocating water from users with lower water productivity to those with higher productivity.	Requires appropriate market-support mechanisms, including transparency about prices and trading, as well as timely and accurate information on supplies, which can be costly.
Non-volumetric water pricing	Price based on output, input, area irrigated or land values.	Fairly easy and low-cost procedure to implement and manage.[52] Reduced monitoring and enforcement costs.	Little or no direct incentive to conserve water.
Volumetric water pricing	Price based on water extracted or consumed.	Creates incentives to improve water conservation and change agricultural practices towards more efficient water use.	Requires the water authority to set the price, monitor extraction and collect fees.

SOURCE: FAO elaboration based on Rosegrant. 2020.[53]

A number of countries have included water prices in their responses to water scarcity. In Australia, accurate price signals and effective water markets are seen as essential in improving water-use efficiency and encouraging users to adjust to climate change.[9] In Israel, the Water Commission sets the price of water using a three-tier system according to consumption (i.e. volumetric pricing, see Table 5) in order to encourage water savings. For a given allotment, farmers pay differential prices for potable water. According to one FAO report, the first 60 percent of the water allocation costs USD 0.20/m^3, 60–80 percent costs USD 0.25/m^3, and 80–100 percent costs USD 0.30/m^3.[54] In irrigation, there is no fundamental difference between an agency setting prices, with farms then choosing how much water to use, and having the agency assign (tradable) water rights or quotas, with the farm revealing marginal costs through water-use decisions. The choice of control mode depends on its relative effectiveness. If there is any advantage to choosing price or quantity control, it is owing to inadequate or asymmetric information, uncertainty about transaction costs, or unequal sharing of risk among water users.[55–58]

Several factors make volumetric pricing of irrigation water difficult to implement. First, in irrigation systems, the value of water rights has already been capitalized into the value of irrigated land. Holders see pricing as expropriation of those rights, leading to capital losses on farms.[23] Attempts to establish prices are often strongly opposed by irrigators, making it difficult to maintain an efficient price system.[23] Second, measurement and monitoring costs may be prohibitive, especially in low-income countries. Last, water scarcity is often dealt with through quota definition, with prices mainly used to regulate use at the margin, beyond the quota, rather than rationing scarce water.[59] This is particularly true for surface water, as its application to groundwater may be challenging.

Reasons for the predominance of quotas include transparency and ensuring equity when supply is inadequate.[60] Quotas can also bring use directly into line with varying resources, aligning them with information from water accounting, and leading to smaller income losses relative to price-based regulations. For example, in Greece, an increase in water prices led to serious income decreases.[61] In China, a study found the price of water had to be raised substantially to generate water savings; however, the increase resulted in substantial income losses for small-scale farmers.[62] In high-income countries, farmers can respond by reducing water on a given crop, adopting water-conserving irrigation technology, shifting to more water-efficient crops, and changing the mix to higher-value crops. In low-income countries, these options may be unavailable or too costly. Prices set high enough to induce significant allocation changes (or recover capital costs) can severely affect farmers' incomes.[62–65]

For this reason, raising water prices should occur over several years in order to give farmers time to adapt, with integrated management involving communities to make sure no one is left behind. To avoid negative effects and deliver ecosystem services, payments for them could be considered a complement to incentive pricing (see Chapter 5).[48]

Quantity and price allocation can be combined. While yet to be applied, a potential allocation is water brokerage or passive market. This introduces incentives for efficient water allocation while protecting farm incomes, provided the water agency has accurate information on aggregate water demand and supply.[66] Instead of imposing volumetric water prices on farmers, this pays farmers to use less water based on the charge–subsidy approach for pollution control. If demand exceeds the base water right, users pay an efficiency price, based on the value of water in alternative uses. If they use less, the same efficiency price is paid to users instead. Base water rights establish a cap on total water use in the basin or system, allowing amounts to be maintained or reduced.[67] The passive market is distinguished from formal water markets because the buyer or seller does not have to pursue a matching seller or buyer. Instead, each farmer simply determines water use at the price set by management without reliance on a unique water market.

Collective management – bringing farmers together for irrigation management

Management of water resources also goes through local organization of water users, such as watershed management organizations, farmers and fishers associations, and water users groups, also known as water users associations. These can play an important role in managing resources, especially at the local and community level. The work of Ostrom (1990)[o] has shown that collective action is crucial to governing common resources.[69] There is often a divide between stakeholders (farmers, fisherfolk, etc.) with different objectives.[1] Governance has to arbitrate between diverging interests and establish transparency, accountability, and equitable and inclusive participation.

Managing water requires local-level analysis, planning and action, for which local groups play a central role. The important contribution of water users associations to water management and governance is their ability to bring together farmers (particularly small-scale farmers) to manage a shared irrigation system. Through synergies, members can pool their financial, technical, physical and human resources to operate irrigation schemes, including other local water systems, such as a river or water basin. Through water users associations, it is easier to access credit for investment in irrigation in order to improve water management. Association members, particularly small-scale farmers, can increase their bargaining power in negotiations with large water users and regulators. However, those relying on non-consumptive water use (e.g. fisherfolk), still have little say over how resources are managed and how the costs and benefits are shared.

Case study evidence suggests water users associations have led to yield improvements,[70, 71] more efficient use of water, increased production in a dry year[72] and improved conflict resolution.[73] In Punjab Province, Pakistan, watercourse-level users associations

o For a review of Ostrom's well-known and time-tested eight principles, see Box 1 in FAO. 2017.[68]

BOX 21

WATER USERS ASSOCIATIONS BRING BENEFITS, BUT ATTENTION TO GOVERNANCE IS REQUIRED – EVIDENCE FROM ASIA

Transferring irrigation management to water users associations and other farmers organizations can contribute to more equitable access and conservation of water. It can also take into account the needs of users and the state of the resource.[1] However, positive outcomes are not always certain as they depend on broader water governance.

Evidence from the Philippines shows that decentralized irrigation associations are more likely to solve problems such as free-riding, conflict resolution and rule enforcement than are associations controlled by central authorities.[79] Those associations that could make rules and impose sanctions (e.g. the authority to withhold water or fix water charges) were more likely to have greater farmer participation in group work, resolve conflicts without external assistance, implement irrigation operation and maintenance, and enforce rules.

Other case studies of water users associations are more pessimistic about the prospects for success. A review of 108 cases in 20 Asian countries found that only 43 irrigation management transfers were successful along a continuum of impact scores.[80] The study concluded that successful cases occurred under a set of specific factors, which were either impossible to replicate elsewhere, or very costly, and therefore impractical. The search for a "magic" formula of successful water users associations yields no results, as these cannot be socially engineered.

In many cases, reforms through management transfer are not transparent. Policies and programmes may not be translated into local languages, resulting in information asymmetries between rich and poor farmers. As a result, local elites have an unfair advantage in taking leadership positions. Shah *et al.* (2002) argue that transferring irrigation management to users associations is unlikely to work for small-scale farmers in low-income countries, even when preconditions for success are met, including a supportive legal–policy framework, secure property rights, local management, capacity building and management transfer.[81, 82] They argue that success is more likely to occur in large-scale and high-value crop farming than in small-scale agriculture involving thousands of poor farmers.

have increased crop yields by 10 percent for farms at the tail of a watercourse, and by 8 percent for those relying on groundwater.[74] Devolution of sub-basin water management to community-based water users associations, farmers groups or other private-sector actors can also be beneficial, but the evidence is mixed (Box 21). Improvements are conditional on representing the interests of stakeholders in water users associations. For example, the exclusion of fisheries from decision-making lowers fish yields.

Some tendencies can help determine the conditions for successful water users associations. Top-down implementation has not generally worked well, as it can undermine genuine association leadership and equitable, inclusive member participation.[75] According to a review of associations in sub-Saharan Africa, they are more likely to be effective when their design and implementation involve prospective members and emphasize improved water delivery services, such that farmers' engagement goes beyond paying fees.[75] Improved services through infrastructure and technology, and the benefits of improved inclusiveness, accountability, capacity and conflict management, all give users an incentive to pay and participate. Participation in the design can help users, irrigation managers and officials find affordable infrastructure and management solutions that include technological innovations and mechanization. Irrigation management turnovers are more likely to be successful when boards are farmer-elected, management consists of professional cadres and legal systems handle increasing complexity (Box 21).[76] It is equally important to establish clear roles and responsibilities through agreements between the irrigation agency and the water users association. The potential for conserving water is enhanced when water tenure and service objectives are clear and secure, water is priced as an economic good, and consumption is monitored at the farm and basin level with water-conserving technologies.

Given their highly variable experience illustrated in Box 21, the creation of water users associations needs to be carefully promoted to develop decentralized, community-based and inclusive organizations. Enabling conditions include social and economic context; equity dynamics; local control and enforcement of water rights, services and fees; monitoring capability; and clear legal authority. Effective associations also depend on members' ownership, and the attitude of relevant government agencies and their accountability to water users associations as service providers.

It is essential to increase women's engagement in water users associations and farmers organizations, where they remain under-represented and disadvantaged. The use of fixed gender quotas is one approach, as well as capacity development of skills such as communication and negotiation to encourage participation and leadership.[77, 78] It is essential to target men to raise their awareness of gender roles that disadvantage women and, in challenging them, show how this can benefit both women and men.

Women-only groups can give women a new voice and bring many benefits. Where such groups exist alongside water users associations, they must be involved in decision-making. In Tajikistan, women have started to teach younger people about irrigation. In some instances, their role has become informally institutionalized, the community accepts them and some receive a salary.[77] ■

THINKING BEYOND IRRIGATION – WATER GOVERNANCE IN RAINFED AND INTEGRATED SYSTEMS

Policy and governance on water resources management for agriculture remain focused on irrigation, while the framework at watershed and basin scales concentrates primarily on allocation and management of freshwater in rivers, groundwater and lakes.[83] Water resources management is normally under ministries for water affairs and focuses on large-scale irrigation, drinking water and hydropower. This has resulted in limited investments and innovations in governance, policy, institutions, practices and technologies to support small-scale farmers in rainfed areas and non-consumptive uses such as inland fisheries and aquaculture.

Institutions for managing water in rainfed crop production

Rainfed agriculture is facing growing challenges in terms of irregular, insufficient or inadequate rainfall. Increased climate variability is expected to further increase the frequency and severity of droughts, extreme rainfall, weather events and flooding, radically disrupting markets and increasing production risks. (For a discussion on the impact of flooding in agriculture, see In Focus: Too much water? Flooding waterlogging and agriculture, p. 104.) Precipitation anomalies on grazing lands are also a threat to livestock production. Low-income countries are particularly vulnerable to water risks owing to weak institutional mechanisms and their high dependence on low-input rainfed agriculture,[84] which remains the livelihood of the majority of the rural poor.

What is needed is effective integration to promote investment in water management from rainfed to irrigated agriculture. Focusing on river-basin water planning does not emphasize sufficiently water management in rainfed areas.

This usually occurs below the river basin scale, on farms of less than five hectares, with small catchments. An equally strong focus is thus needed to manage water at the watershed and basin scales.[83]

The potential gains from water investments in agriculture are greatest when combined with other production practices, such as improved or high-yielding crop varieties, no tillage and restoration of soil organic matter. Improvements can be achieved through synergies, but ensuring the full benefits from water management also requires attention to land tenure, water ownership and market access.[83] As water shortages and land degradation in rainfed areas cannot be tackled through farm-level interventions alone, community-based watershed management is preferable.[85] This extends to forest conservation and restoration at the watershed level, particularly in large basins, and calls for new investment to plan and manage water for rainfed agriculture. Improved water management in rainfed agriculture also requires public investment in infrastructure and access to roads to link farmers to markets. For this to occur, farmers organizations, financial policies and other institutional arrangements need to go hand in hand with policy advances (see Chapter 5).

The management of rainwater and other investments to upgrade rainfed agriculture is receiving increased priority. In 2005, the National Commission on Farmers in India adopted an integrated watershed management approach with a focus on harvesting rainwater and improving soil health for drought-prone rainfed areas.[83] The following year, the National Rainfed Area Authority was established – a central agency that supports strategic plans for watershed development projects and the country's rainfed agriculture. The agency facilitates convergence of different government projects and, therefore, acts as coordinator between all bodies, organizations, agencies and ministries involved in watershed programmes.[85, 86] There is growing evidence of the importance of redirection of water governance and management towards upgrading rainfed agriculture, including livestock production, as explained in the following section.

Livestock management during droughts

Livestock are a key livelihood asset for pastoralist and other communities. During emergencies such as drought, livestock conditions and production can worsen dramatically owing to lack of feed and water. Livestock mortality can be high, and rebuilding herds extremely difficult. Without preventive support, longer-term impacts are possible.[87] In view of concerns that emergency interventions often fail to support pastoralists and other livestock keepers, preparedness and contingency planning as well as emergency response are paramount. National policies, regulations and institutions can influence the ability to use livestock assets in any emergency, such as drought. Veterinary services and policies on taxation, marketing and exports all have an impact on livestock-based livelihoods. However, the measures for implementing the most appropriate intervention are often lacking. A wide range of governance strategies can improve water management of livestock production, particularly during times of drought. Some of these are discussed below.

Involving community representatives and local institutions – Effective identification, design and implementation of livestock interventions requires local community involvement, particularly of marginalized or vulnerable groups who keep livestock or might benefit from access to livestock or livestock products. Community participation in targeting is an effective means to ensure fair distribution of benefits.[87] Customary or indigenous institutions can play a key role in emergency interventions and in managing natural resources, including grazing land and water. Their participation is necessary to sustain activities and contribute to livelihoods. In the United Republic of Tanzania, the Engaresero Maasai pastoralist site has established a community-based organization to manage natural resources and livestock sustainably, promote tourism, and preserve and develop the indigenous knowledge and customary law of the local community.[88]

Identifying and mapping water sources, and early warning systems – In drought-prone areas, spatial data and geographical information systems for mapping water points (including groundwater) are an important step towards forming a knowledge base for mitigation and water emergency report planning.[89] A case in point is the extreme drought in Kenya in 2000, which led to the loss of up to 50 percent of cattle in certain districts. Owing to a lack of information on the location of alternative local water sources in the worst-affected areas, relief agencies remained helpless.[89] Early warning systems can anticipate emergencies and allow time for preparation and mitigation of disasters. They can also help inform emergency response.[87]

Secure and flexible access to land and resources – As pastoralists use land and other resources collectively, a narrow sense of ownership (i.e. the right to control a resource completely and exclusively) does not fit with their traditions and livelihoods.[90] Pastoral property rights are understood as overlapping, often nested within a different set of rights over another resource, operating with different authorities and functions. Access to resources must be flexible enough for negotiations to accommodate different rights that often overlap. Women's participation should also be improved in land tenure and decisions. A five-year joint programme by FAO, the International Fund for Agricultural Development (IFAD), UN Women and the World Food Programme (WFP) is advancing women's land rights in Ethiopia, Guatemala, Kyrgyzstan, Liberia, Nepal, Niger and Rwanda through advocacy work, awareness-raising campaigns and training.[91]

Developing national guidelines and standards for livestock responses to water risks – In some countries, such guidelines already exist and can assist livestock projects, including policymakers and decision makers. To complement existing guidelines or develop new ones, the Livestock Emergency Guidelines and Standards (LEGS) project was created in 2005. The project is managed by a steering group, comprising FAO, the African Union, the Feinstein International Center, the International Committee of the Red Cross, and Vétérinaires Sans Frontières Europa.[92] A global network of more than 1 500 organizations and individuals consults with a range of stakeholders. The project aims to provide rapid assistance to protect and rebuild the livestock of crisis-affected communities, and to improve the quality and livelihoods impact of livestock projects in humanitarian situations. The project has generated two main products: a handbook and a training programme. The handbook sets out standards, guidelines and tools to design, implement and evaluate livestock interventions in rapid- and slow-onset emergencies, such as flooding and drought. It covers assessment, response identification and technical areas including destocking, veterinary services, water, feed, shelter and restocking.[92] The training programme focuses on a series of regional three-day training courses across Africa, Asia and Latin America.

Governance for integrating inland fisheries, aquaculture and irrigated systems

The impacts of irrigation on inland fisheries and aquaculture can be profound in positive or negative ways. Irrigation changes geomorphology, hydrology and land use, aquatic habitats and nutrient contents, which, in turn, affect inland fisheries. In most cases, productivity has declined because of a lack of awareness or a lack of priority being given to the impacts of irrigation on inland fisheries, and the way these systems are designed and operated.[2, 93] Environmental impact assessments of irrigation schemes rarely recognize the existence of inland fisheries.[94] However, despite these constraints, irrigation can create opportunities for inland fisheries and livelihoods, changing the economic environment and institutional arrangements that affect how, by whom and to what extent fisheries resources can be utilized.[95]

In an irrigated area of northwestern Bangladesh, rice farmers have largely replaced the Aus rice crop (produced between April and July) with fingerlings, while continuing to produce Aman (August–November) and Boro rice (December–March). There are three advantages to this: (i) fingerlings are produced at the start of the fish culture season, when demand from pond owners is high; (ii) one cycle of fish production breaks the rice production cycle, reducing pest survival (with fewer pest problems in subsequent crops); and (iii) fingerling production is far more productive than Aus rice.[2]

TABLE 6

IMPACT OF IRRIGATION-RELATED GOVERNANCE ASPECTS ON INLAND FISHERIES AND AQUACULTURE

Governance aspect	Limited integration of irrigation with inland fisheries and aquaculture	Irrigation supports inland fisheries and aquaculture
Use of storage reservoir area	Reserved for water storage only	▶ Habitat created to enhance fisheries ▶ Stocked for enhanced fisheries ▶ Designated areas for cage aquaculture ▶ Managed for recreational fisheries
Water abstraction	Draining reservoir or dewatering rivers/waterbodies is only focused on meeting irrigation demands	▶ Minimum water levels in reservoir maintained to sustain fish population and aquatic ecosystem ▶ Minimum flows in rivers to sustain fish and aquatic ecosystem function ▶ Creation of refuge areas and wetlands
Irrigation water use	Use permitted for field crops only	▶ Water permitted for use in diversified production systems, including aquaculture ▶ Rice–fish production permitted
Irrigated land conversion	Deviation from primary crop production not permitted	▶ Modification to enable secondary crop (e.g. rice–fish channels) production permitted ▶ Conversion to fish ponds permitted
Design of water control structures	Lowest cost design and construction, with focus only on water delivery	▶ Designs adapted or required to enable upstream and downstream passage of fish ▶ Additional measures (construction of fishways) required to ensure connectivity
Operation of water control structures	Priority for operation to maximize water delivery for irrigation, irrespective of other ecosystem services	▶ Minimum flows retained in watercourses to sustain aquatic ecology ▶ Sluices opened during critical upstream fish migration periods ▶ Sluices operated in a way that is least harmful to upstream migrating fish

Source: Funge-Smith & Baumgartner. 2018.[2]

National and regional laws and policies can have a large impact on governance structures to manage water resources, and on the extent to which inland fisheries and aquaculture can be integrated within irrigation systems (Table 6). Some countries and regions encourage integration of natural resources governance, while others treat them separately. For example, in Cambodia and Sri Lanka, integrated rice–fish practices are encouraged, and community fish refuges – a fish conservation measure to improve the productivity of rice-field fisheries – have become a national policy thrust.[96] Other countries do not allow rice-field areas to be used for fisheries nor rice fields to be converted for fish culture,[97] or they specifically ban fisheries-related activities, such as that of placing fish cages in irrigation canals.[98] ■

CONCLUSIONS

Despite the clear linkages between its multiple functions, water at all levels is still managed today in a fragmented manner. Water-related responsibilities are dispersed across several sectors, and effective coordination is the exception rather than the norm at decision-making level, among implementing entities and across national boundaries. The behaviour of different actors in relation to water management is the result of political and policy choices by various sectors that often remain disconnected.

This chapter has recognized the need for a stronger focus on inclusive water governance as water management alone is less effective at solving problems, and different sectors (involving water, food and energy) are clearly interlinked such that no sector can operate in isolation. Solutions to water problems most often lie outside the water domain. Therefore, this chapter has examined ways to improve water governance and how such governance relates to efficiency and equity, ensuring the human right to water and sanitation, as well as to food. The different mechanisms and tools, such as water rights, market-based instruments, water tenure and water users associations, can improve access to irrigation and rainwater, particularly for marginal and small-scale farmers, while mitigating water constraints. When water is not allocated properly, when usage regulations are lacking and when prices do not reflect the true cost of water, these mechanisms can contribute to over-exploitation of surface water and groundwater resources. Often, most of the benefits accrue to larger farmers who use more water, fertilizer and energy, further exacerbating inequalities.

The chapter has highlighted the need for sound transparent water accounting and governance analysis in order to establish accountability mechanisms and transparency about the rationale behind the measures, and the distribution of costs and benefits. It is also important to promote a human rights approach to water management, with particular attention to vulnerable groups, such as small-scale producers, women and indigenous peoples. The water tenure concept can provide a holistic approach to understanding people's relationships with water, and serve as a strong building block for equitable and efficient water use. These measures need to be combined with realistic water market instruments and the credible threat of sanctions in accordance with the law, often linked to environmental safeguards and water-sharing agreements or treaties. ■

IN FOCUS

TOO MUCH WATER? FLOODING, WATERLOGGING AND AGRICULTURE

Timing of water-related events and consequences of flooding

Water plays a vital role in agriculture, and an equally vital role in ecosystems; however, these roles may not always be compatible. One example is that of floods, which can support the health of wetland areas, carrying and depositing nutrient-rich sediments crucial for animal and plant life. However, floods can cause long-term economic hardship for various food system actors owing to loss of livestock and crop production, and damage to food storage facilities, industries or commercial enterprises.[99, 100] However, not all flooding is bad for agriculture, as shown by flood-based farming systems in sub-Saharan Africa and Asia, which rely on flooding to improve soil health when river sediments recharge nutrients in topsoil, making lands more fertile. In sub-Saharan Africa, it is estimated that 25 million hectares are irrigated by flooding.[101] Moreover, flooding can also replenish and recharge groundwater and underground aquifers, in addition to benefiting inland fisheries and creating wildlife habitats.[102]

Nevertheless, floods are a major concern to societies because the damage caused is occurring more often. Although the word flood has different definitions, it is generally understood as a temporary covering of land by water.[103] By considering the size of the affected area and the duration of the triggering precipitation, a distinction can be made between long-lasting floods and local sudden floods.[104] The spatial and temporal dimension of flood events largely determines their impacts, whether beneficial or damaging.

The agriculture sector is particularly vulnerable to natural hazards, and the increase in the frequency of extreme weather-related events – such as floods – over recent decades poses a significant challenge to agricultural systems. Post-flood, stagnant waters often render cropland useless and make it difficult to maintain livestock, which, without proper shelter, veterinary care or adequate feed, easily fall prey to disease or starvation. Floods are frequently associated with water contamination and accelerated soil degradation, and can erode topsoil from prime growing areas, resulting in irreversible habitat damage. They are particularly disastrous for the world's poor, the majority of whom live in rural areas and rely on agriculture for their food and income. Many struggle to replace what has been lost or damaged, such as seeds, tools, livestock, animal feed, fish from ponds, or fishing gear.

Notwithstanding the many efforts at the national and international levels, there is limited information on the impact of disasters, including floods, on agriculture and its subsectors – crops, livestock, fisheries (inland and marine), aquaculture and forestry. A review of 74 post-disaster needs assessments conducted in 53 developing countries over the decade 2006–2016 shows that agriculture and its subsectors absorbed 23 percent of all damage and loss caused by medium-to-large-scale climate-related disasters (floods, drought and tropical storms).[105] Damage can be expressed as replacement and/or repair costs of physical assets, while loss refers to the changes in economic flows occurring as a result of a disaster, such as a decline in crop production (including loss of fish from flooded fish ponds). Damage to agricultural assets accounts for 16 percent of damage in all sectors while almost one-third of all disaster loss is accrued in the agriculture subsectors.

The relative economic importance of drought and floods vis-à-vis other hazards depends on how agriculture subsectors are affected (Figure A). For livestock from 2006 to 2016, drought was by far the major cause of losses and damage (86 percent). However, for crops and fisheries, floods cause proportionately greater damage relative to other hazards, contributing to almost two-thirds of all damage and loss to crop producers and 44 percent for fisheries and aquaculture. In absolute terms, the most harmful disaster for crops was the 2010 flood in Pakistan (USD 4.5 billion), followed by the 2008–2011 drought in Kenya (USD 1.5 billion). In recent years, global crop production has been severely affected by events such as the 2015 floods in Myanmar (USD 572 million), and the 2014 floods in Bosnia and Herzegovina (USD 255 million). In both cases, the cost occurred as a result of reduced yields and late planting owing to limited access to arable land.

Between 2005 and 2015, about USD 96 billion was lost as a result of declines in crop and livestock production in developing countries after natural disasters. Twenty percent of this loss was caused by floods, amounting to about USD 19.5 billion (Figure B).[105] The extent of production loss from floods is higher in Asia than in Africa or Latin America and the Caribbean.

There is increasing attention on natural flood management measures to face these challenges in a sustainable way and as a way of alleviating downstream flood risks.[106] The basic principle is to affect river flows by intervening at the catchment-scale. Interventions upstream would reduce flood inundation downstream rather than protecting local floodplains from inundation.[107] Natural flood management is one form of catchment-based flood management consisting of measures such as (i) reduced runoff generation on hillslopes; (ii) water

FIGURE A
DAMAGE AND LOSS TO AGRICULTURE SUBSECTORS BY TYPE OF HAZARD, 2006–2016

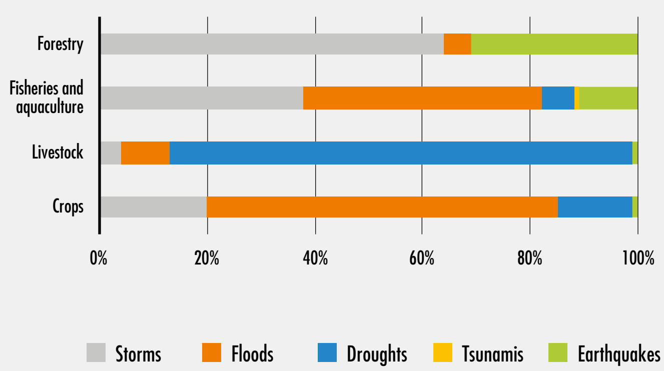
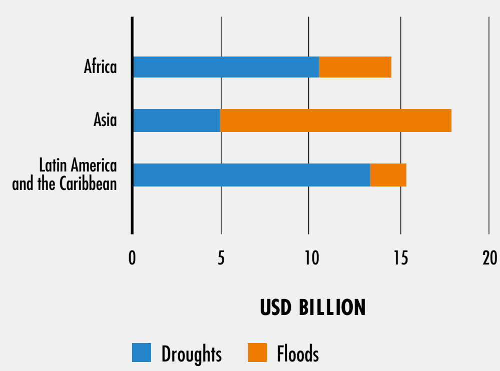


FIGURE B
PRODUCTION LOSS FROM DROUGHTS AND FLOODS BY REGION, 2005–2015



NOTE: Fisheries includes both inland and marine.
SOURCE: FAO. 2018.[105]

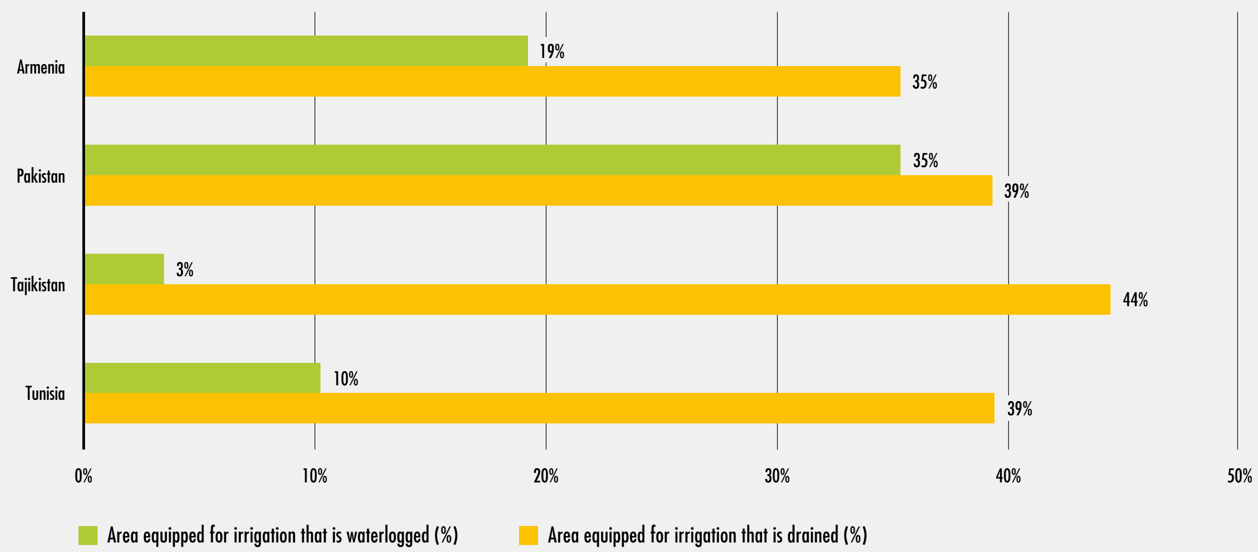
storage during high river flows; and (iii) limiting the connection between runoff sources and potential flood zones. However, it is uncertain whether natural flood management is effective for larger river catchments.[107] When applying this strategy, it is important to consider the potential negative consequences for aquatic ecosystems and inland fisheries. These rely on the connection of flood pulses and habitat at the right time and for the right duration, and consequently on these ecosystems delivering food and nutrients.

Water-related production losses not associated with extreme events – waterlogging

Although difficult to quantify, variable precipitation and the drainage capacity of soils can influence agriculture in ways that are comparable with droughts and floods, without the extreme conditions. For example, waterlogging can reduce agricultural productivity when there is too much water close to plant roots, restricting their access to oxygen.[108] Australia has recorded crop yield reductions of as high as 80 percent, while another study in India has shown an increase in yields of rice, wheat, cotton, sugar cane and wheat from subsurface drainage, concluding that yields in drained fields were significantly higher than those in non-drained fields.[109, 110] The phenomenon is considered as being among the major obstacles to sustainable agriculture because it limits plant growth and reduces yields. The impact of waterlogging is worsened by salinity, as salt uptake increases greatly, as does salt concentration in shoots, reducing plant growth or killing plants altogether.[111–113]

Despite the relevance of waterlogging, no comprehensive data exist on the extent of the problem across countries. For the few countries where information is available, waterlogging affects a sizeable proportion of irrigated areas; for example, up to 35 percent in Pakistan (Figure C). This highlights the importance of proper drainage in irrigation projects. Waterlogging is not limited to irrigated areas, and estimating its incidence in agricultural areas and using remote-sensing data

FIGURE C
WATERLOGGING AND DRAINAGE IN SELECTED COUNTRIES



NOTE: Data are for the most recent years: Armenia (2006), Pakistan (2006–2008), Tajikistan (2009), Tunisia (2000).
SOURCES: FAO. 2020,[115] and ICID. 2018.[116]

SERBIA
Flood-damaged crops near Jamena and Sremska Raca, northwest Serbia.
©FAO/Igor Salinger

can provide guidance to policymakers on the severity of the problem and possible corrective actions.[114]

To sustain and improve the productivity of irrigated agriculture, integrated irrigation and drainage are essential because irrigation management and drainage problems are closely interlinked through (i) excessive or inefficient irrigation as a cause of waterlogging and (ii) the relationship between irrigation management and effluent disposal.[117] Minimizing drainage effluent by improving irrigation efficiency and reuse of drainage water at the farm level while maintaining the health of the soil is a realistic option. An in-depth discussion of the many drainage options is beyond the scope of this report but can be found in Smedema, Vlotman and Rycroft (2004).[118] In the North China Plain, drainage is the basis for comprehensive control of drought, waterlogging, salinity and saline groundwater.[119] However, if waterlogging persists or drainage is not viable, as may be the case in rainfed areas subject to waterlogging, it is also possible to adapt crop or pasture management to the waterlogged conditions. For example, plant breeding techniques and conventional or genetic engineering may help to grow crops in waterlogged conditions in an effective and economic way.[108]

UZBEKISTAN
Farmer cares for his family's apple orchard using modern drip irrigation technologies.
©FAO/Rustam Shagaev

CHAPTER 5
A COMPREHENSIVE PICTURE OF AGRICULTURE AND WATER: POLICIES AND PRIORITIES

Key messages

➔ Managing water resources requires coordination and policy coherence across sectors, subsectors in agriculture, and locations, as well as effective governance to manage interdependence and trade-offs between them.

➔ Agriculture plays a central role through the landscapes it manages and the water it uses. More coherent strategies are needed across rainfed and irrigated cropland, livestock production systems, forests, and inland fisheries and aquaculture.

➔ Incentives are important: any subsidies should incentivize investment in greater water productivity while also meeting environmental flow requirements for sustainability; payments for environmental services – particularly within watersheds – can play a role in sustaining ecosystem functions.

➔ Water policy priorities will depend on the water risk faced – whether water stress, drought, flood, or water quality issues – as well as on a country's agricultural production systems, level of development and political structures.

➔ Producers working on 128 million hectares (or 11 percent) of rainfed cropland affected by recurring drought can greatly benefit from water-harvesting and water-conservation techniques.

➔ For herders working on 656 million hectares (or 14 percent) of drought-affected pastureland, a variety of farming measures can buffer the impact of drought and improve water productivity, such as improved animal health. A key policy area for both rainfed cropland and pastures is drought preparedness.

➔ For 171 million hectares (or 62 percent) of irrigated cropland under high or very high water stress, priority should be given to improving governance and establishing effective and equitable water allocation, followed by the rehabilitation and upgrading of irrigation infrastructure, and adoption of innovative technologies. In sub-Saharan Africa, irrigated areas are expected to more than double by 2050, benefiting millions of small-scale farmers.

CHAPTER 5

A COMPREHENSIVE PICTURE OF AGRICULTURE AND WATER: POLICIES AND PRIORITIES

The previous chapters have demonstrated how, in many parts of the world, growing water shortages and scarcity are urgent and major challenges for agricultural systems and the environment. Demographic pressure, urbanization, dietary change and climate change are expected to amplify the issues. However, despite increasing competition in the demand for water, agriculture will remain by far the largest water user, as its withdrawals of water – currently 70 percent of total withdrawals – continue to increase. The agriculture sector (crop and animal production, and forestry) manages the greater part of the landscape in water basins. Addressing water shortages and scarcity must rely on a combination of sound water accounting and auditing, suitable water technologies and water management in which the agriculture sector must play a major role. Chapter 3 has shown that there is a wide range of technical options and management strategies to align water-use patterns with different users' needs, while also accounting for environmental flow requirements. However, the adoption of integrated technical solutions does not happen in a vacuum. Adoption and implementation are dependent on appropriate institutions and the political economy surrounding water, as illustrated in Chapter 4, and on aligning incentives for efficient and sustainable water use. This chapter considers the broadest dimension presented in Figure 13 (p. 43) by focusing on policy coherence and setting policy priorities.

Over the last 25 years, water governance paradigms have been shifting towards coordination, and towards decentralized, participatory and integrated approaches. The SDGs and the 2030 Agenda have given renewed impetus to the debate on the interconnectedness of multiple sectors, and refocused attention on the need for greater cross-sectoral coordination and policy coherence. In particular, SDG Target 6.4 on water use and scarcity has a strong link to SDG Target 2.4: "By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality."

Although it is clear that water is an increasingly scarce and finite resource, and that water shortages are a growing problem for rainfed agriculture and livestock, the integration of these concerns into policy frameworks is still slow, even within the agriculture sector. Globally, water is seriously undervalued owing to its unique properties (presented in Chapter 1). In many countries, water is not charged for at all. As prices do not reflect its true cost, water is misallocated, and there is little investment in new infrastructure and water scarcity management. Recognizing that scarcity will also generate tensions among users, this chapter starts by asserting the need to harmonize water-use policies across different sectors, subsectors within agriculture and locations. The chapter reviews policies and practices for better water resources management in agriculture, and for aligning private incentives for farmers with the overriding purpose of optimizing water use.

Having covered policy coherence and more efficient and sustainable water-use incentives, the chapter then examines opportunities for actions and investment in agricultural water management, based on the analysis and discussion of preceding chapters. Building on the challenges in Chapter 2 concerning drought risk in rainfed crop and pastureland systems, and water stress in irrigated areas, this chapter outlines policy strategies tailored to specific situations. It takes an "all of agriculture" perspective, highlighting the important role of nature-based solutions, and how the interests of inland fisheries and aquaculture are well aligned with environmental flow requirements. ■

ENSURING POLICY ALIGNMENT FOR WATER, AGRICULTURE, AND FOOD SECURITY AND NUTRITION

Need for policy coherence across sectors

The behaviour of different actors is the result of political and policy choices in various, often disconnected, sectors. Adding to the challenge of reducing water scarcity is the need to improve coherence through coordination across various policies, legislation and fiscal measures that influence water management. Many policies can have a major impact on water supply and demand, through measures such as energy taxes, trade agreements, agricultural subsidies and poverty reduction strategies.[1] While these may have major implications for water use, they are often not taken into account (Box 22). There is a need to integrate decision-making, as different departments take decisions on irrigation and on industrial or municipal use of water with little consideration for the cumulative impacts on water demand and quality. Without this integration, water-related ecosystems are under increasing pressure from growing water demands from cities, industry and agriculture, seriously affecting their ability to deliver services essential to meeting the SDGs.

Integrating horizontally across sectors will help reduce possible negative cross-sectoral effects of policies within each sector, thereby saving resources and reducing trade-offs.[2] The water–energy–food nexus is part and parcel of the need for policy coherence. Agriculture policies directly influence water and energy, when, for example, they encourage overplanting of water-intensive crops (e.g. rice) leading to excessive water and energy use to pump groundwater.[3] Higher energy prices may reduce water withdrawal from aquifers with less pumping, thus reducing over-exploitation of groundwater.[4] Affordable solar-powered pumps could significantly change this relationship by expanding groundwater extraction. Agriculture may then use even more freshwater. To avoid greater water scarcity, integrated agriculture and irrigation information systems, across other major water-using sectors, can help make effective decisions under uncertain conditions. Data services and knowledge management for the water–energy–food nexus can promote transparent and robust decisions and take into account hydrological constraints and environmental flow requirements.

Subsidies are often justified to provide public goods, as an incentive to adopt new technologies, to promote food security, to deliver income support to small-scale farmers and as a counterbalance to poor infrastructure.[27] As shown in Box 22, agricultural input subsidies can help raise production and profitability, but they can also promote inefficiency, and over-exploitation and unproductive use of water, with important economic and social consequences. Governments often maintain large subsidies for private goods such as energy, »

BOX 22
INCENTIVES, WATER SCARCITY AND PRODUCTIVITY IN THE NEAR EAST AND NORTH AFRICA REGION

In the Near East and North Africa (NENA) region, per capita renewable freshwater is less than 10 percent of the world average.[5] High water and energy subsidies, coupled with weak monitoring and enforcement, undermine incentives for efficient water use across the region. They encourage over-exploitation and, in many countries, perpetuate a pattern of low-value uses and low water productivity.[6, 7]

As a consequence of underpricing fuels in groundwater extraction and undervaluation of water, water extraction in most NENA countries exceeds renewable resources, resulting in depleted aquifers.[5, 8] In agriculture, water charges do not reflect either the scarcity value of water or the delivery cost.[9] Farmers have little incentive to save water, and tend to grow water-intensive crops if they are profitable, delaying adoption of water-saving irrigation technologies.[10]

Governments in the NENA region have prioritized national self-sufficiency in food staples, mainly by subsidizing cereal production through a combination of producer price-support and input subsidies as well as import controls and public procurement. Self-sufficiency in cereals to reduce import dependence has been central to agricultural policies in several NENA countries, including Algeria,[11] Egypt,[12, 13] Iran (Islamic Republic of),[14] the Syrian Arab Republic[15] and Tunisia.[16]

In the absence of incentives to use water efficiently and increase productivity, and given the high irrigation requirements of these crop yields, water overuse has been the norm. This has resulted in serious depletion of aquifers, with important consequences particularly for small-scale producers.[5, 17]

The dominance of cereal production (wheat in particular), promoted by expensive subsidy systems, entails major GDP losses compared with policies that encourage production in line with comparative advantages.[17]

With the region having the lowest water tariffs in the world, water-use patterns result in very low economic water productivity. Although physical water productivity levels are high compared with global trends, agriculture produces the lowest economic returns from water while accounting for almost 80 percent of the region's water use, higher than the world average of about 70 percent.[7, 17]

A study done by FAO has revealed that the most remunerative crops per cubic metre of water are fruits and vegetables, with economic water productivity in the range of from USD 1.07/m^3 to USD 6.18/m^3. Cereals, namely wheat and rice, have the lowest economic productivity, with values of about USD 0.35/m^3. To date, the low cost of water, coupled with cereal production support, has decoupled water use from its economic productivity.[17]

An earlier study compared the economic water productivity of major crops in Egypt, Jordan and Lebanon with quantities of water used.[18] The results demonstrated that Egypt's staple irrigated food crops (including wheat, maize, sugar beet and rice), consuming most water, had the lowest economic water productivity. On the other hand, vegetables had the highest productivity, while consuming a very small share of agricultural water (see figure in this box). The study showed similar results from Karak Governorate, Jordan, where four irrigated crops – barley, wheat, olives and tomatoes – occupied 85 percent of cropland and consumed 95 percent of freshwater, but had the lowest economic water productivity, while other vegetables were more productive and consumed less than 5 percent of irrigation water.

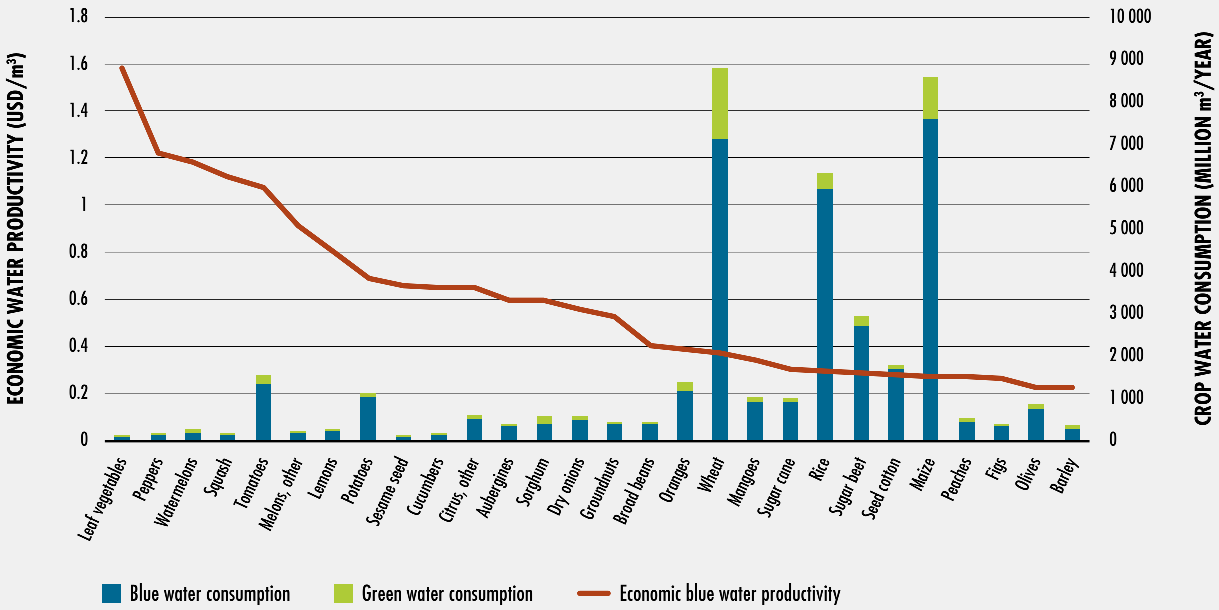
Low water tariffs and high energy subsidies, coupled with inadequate or absent metering and monitoring, have disincentivized farmers from adopting more efficient irrigation. Data from FAO reveal that conversion to modern irrigation such as sprinklers or a localized scheme has been slow, especially in low-income or highly water-scarce countries. In Egypt, Morocco and the Syrian Arab Republic, more than 70 percent of irrigated land uses surface irrigation, while more efficient schemes are almost absent in Yemen.[21] Farmers in the NENA region are mostly small-scale farmers and lack financial incentives to invest in technology. Incentives are further weakened by land fragmentation.[22]

In some cases, self-sufficiency policies for staple crops have resulted in extreme depletion of water and mass population displacement. This was the case in the Syrian Arab Republic, where policies, mostly targeted to wheat self-sufficiency, played an important role in degrading natural resources. Several studies have highlighted how government policies favouring irrigation-intensive crops (wheat and cotton) collapsed groundwater levels.[15, 23] This limited the coping capacity of Syrian farmers when severe drought struck

BOX 22
(CONTINUED)

the Near East in 2007–2009. Conditions were further worsened in 2008 when the government lifted diesel subsidies (the main fuel used in irrigation), triggering an overnight price jump of 300 percent.[15, 24] While the same drought had negligible impacts on other countries in the region,[24, 25] in 2009 it displaced about 300 000 people in the Syrian Arab Republic from rural areas towards cities, leaving 60–70 percent of villages deserted in the regions of Hassakeh and Deir ez-Zor.[26]

ECONOMIC WATER PRODUCTIVITY AND WATER CONSUMPTION OF MAIN CROPS IN EGYPT, AVERAGE 2007–2011



SOURCES: Adopted from Elbehri & Sadiddin. 2016,[18] whose calculations were based on data from FAOSTAT,[19] and Mekonnen & Hoekstra. 2011.[20]

» fertilizer and credit, displacing important public goods (e.g. investment in research, roads and education), offering incentives that promote inefficiency as well as unsustainable use of natural resources, including water. This also applies to private water use, where cheap or free irrigation water to farmers continues to distort incentives, leading to overuse and polluted water resources.[28] This can promote the planting of crops that need a lot of water. Subsidies on electricity and water have caused over-extraction of groundwater, causing land subsidence, salinization, and degradation of land and water. In India, where groundwater subsidies are estimated to exceed the education budget, subsidies contribute to unsustainable groundwater extraction.[29] When subsidies are broadly based or poorly targeted, most benefits go to larger farmers who use more water, fertilizer and energy.[27] Water subsidies are a considerable cost for society. In Andhra Pradesh State, India, a conservative estimate by the Global Subsidies Initiative revealed annual irrigation subsidies between 2004 and 2008 of about USD 300 million on average.[30] (See Box 22 for a discussion of the implications of public policies on water use in the NENA region.)

Proper incentives are a crucial component of policy coherence for sustainable water use. Managing the many water-related challenges in agriculture and in the broader economy will require a rethinking of the incentives that drive water-use decisions. It will entail taking into account the role water plays beyond agricultural production, for ecosystems more broadly and society more generally, while bearing in mind that policies that transcend water use can shape incentives.

The need for coherence is also strong across agricultural subsectors

Better integration is needed also across subsectors in agriculture. As it uses most water, agriculture is the largest beneficiary of water subsidies and policies. The impact across agricultural subsectors is very uneven, as these policies often benefit irrigated farming to the detriment of other systems such as inland fisheries and rainfed production. One example of trade-offs that illustrates the need for coordination is the relationship between irrigation and inland fisheries. Although the expansion of irrigated lands across the globe since the green revolution has brought major food-security benefits to low-income countries, these may have been partly offset by losses in inland fisheries. The 2030 Agenda can be a starting point for the multidisciplinary and inclusive dialogue needed to negotiate trade-offs and balanced solutions based on common and trusted data.[31]

Within the agriculture sector, the bulk of managed water use is in irrigated systems. Rainfed agriculture does affect the share of rainfall left after evapotranspiration that percolates as groundwater or surface water runoff. However, irrigation has a more direct impact through groundwater withdrawals that affect surface water flows and ecosystems through dams and diversions. As mentioned in the beginning of this report, around 41 percent of current global irrigation water use occurs at the expense of environmental flows requirements.[32] Irrigation – where present in a water basin – thus plays a central role in water accounting, which in turn should guide sustainable water allocations. In regard to environmental flows and ecosystem services, there is a window of opportunity to implement actions to rectify earlier mistakes in the design and operation of irrigation systems, and so improve productivity and the nutritional benefits of irrigated agriculture. Actions span technical and policy interventions for more effective integration of fisheries and aquaculture in irrigated areas, covering (i) modified design and operation of delivery and storage infrastructure to improve water connectivity and flows; (ii) construction or improvement of habitat and refuge areas – i.e. constructed or enhanced natural depressions – within and around irrigated systems; and (iii) revised policies, regulation and management of irrigation systems to enable these modifications.

Integrating fish into irrigation systems can benefit from the availability of fingerlings for aquaculture. Globally, the production and distribution of huge numbers of quality fingerlings have boosted aquaculture. Fingerlings from hatcheries are now so inexpensive they can be used in great numbers to stock waterbodies, such as reservoirs, in what have become known as culture-based fisheries. Across Asia, irrigation dams are now routinely stocked with fingerlings to enhance fish production.[33–35] Mexico systematically stocks its reservoirs with fingerlings, and has established seed production centres solely for this purpose.[36] Recognizing a vast untapped potential, there are now international guidelines to support responsible stocking of reservoirs and other open waterbodies.[37]

Broader coordination in agricultural strategies, beyond irrigation, will also play a role in rethinking water use. The proportion of cropland requiring irrigation may be reduced by introducing innovations that improve rainfed agriculture productivity. Similarly, forest conservation and management upstream will affect water resources downstream. This highlights the broader issue at the subsectoral level of aligning the many sectors and stakeholders that influence water management, service delivery and demand. An example that is particularly relevant for water in an agricultural context is that of non-consumptive water use and how water can be reused.

Coherence needed across locations – integrated approaches

Realigning private incentives with true costs by adjusting subsidies and prices to make water use more sustainable is important. However, it is unlikely to address the full scale of the problem, as impacts of water use by one stakeholder may affect availability to others downstream in a water basin. For this reason, this report emphasizes environmental flow requirements and water allocation systems based on water accounting as an important precondition for more sustainable water management. In turn, these allow a more integrated approach, taking into consideration different water users in a watershed, including non-consumptive use and water needed for ecosystem services.

One example of an integrated approach is irrigation scheme management that maintains food production levels as well as other environmental and ecosystem services.[38, 39] These range from regulating functions (i.e. groundwater recharge and flood control) to provisioning services (watering small gardens and livestock, inland fisheries and aquaculture). The development of inland fisheries (whether capture fisheries or culture-based) and aquaculture in irrigation schemes is a particularly attractive option as it can offer additional production at little or no additional water service cost. Examples of positive irrigation impacts on inland fisheries are found in Sri Lanka,[40] in large reservoirs of Lao People's Democratic Republic and Thailand for indigenous Thai river sprat,[41] and in the Lake Kariba reservoir, shared between Zambia and Zimbabwe, with the introduction of the non-indigenous Lake Tanganyika sardine.[42] Evaluating these interventions must also take into account the loss of riverine and floodplain fisheries caused by the damming of watercourses to create the reservoir.

Watershed management aims for sustainable use of resources through an integrated ecosystems approach centred on understanding the overall interactions between biotic (including humans) and abiotic factors. It is best to address inequalities among communities at the watershed level regarding socio-economic status and access to water, resources and services as a consequence of their location. Watershed management provides a framework for understanding and reconciling interconnections among various land-use systems, and for collaborative action and decision-making in the face of competing claims on resources, especially water. Based on a sound analysis of conditions and dynamic processes in the watershed, a medium-to-long-term vision will allow for the design and implementation of measures to preserve ecosystems and biodiversity, optimize resource productivity, and improve human livelihoods and well-being. Watershed management is very context-specific but also highly flexible and adaptive to different fields of application and implementation scales.[43]

Mechanisms and tools for improved policy coherence

Rather than general subsidies on private goods, targeted subsidies on environmental services can incentivize specific goals such as new irrigation technology and environmental services by, for example, subsidizing structures to mitigate the impacts of irrigation development and dam construction. Such structures include fish-friendly irrigation and fish passages, constructed wetlands, and refuges for fish and aquatic biodiversity. As general subsidies for private goods are phased out in favour of more-targeted ones, there is the possibility of loss of income for small-scale farmers and other vulnerable populations who may not qualify for the targeted subsidy. They can be compensated for losses by using some of the funding saved, for example, with smart cards or smartphones for efficient funds transfer to small-scale farmers.[27] Other options are targeted loans or subsidized equipment prices for small-scale farmers to invest in practices such as drip irrigation, or to cover labour and installation costs of water harvesting structures.

BOX 23

SOLAR-POWERED IRRIGATION PUMPS FOR SMALL-SCALE FARMERS – EVIDENCE FROM BANGLADESH AND INDIA

Recent pilot programmes suggest that properly targeted subsidies can promote development and adoption of technology for groundwater use. Groundwater is abundant in Bangladesh and in Bihar State, India, but it is costly for small-scale farmers to access the water with diesel-powered pumps.[45, 46] Pilot programmes have promoted affordable groundwater irrigation for the poor in these two regions.[47] In Bangladesh, the Infrastructure Development Company piloted a pro-poor, irrigation-service, market approach, offering private companies or investors a 50 percent government subsidy and a 35 percent loan to purchase solar-powered irrigation pumps to sell irrigation services to small-scale farmers for an affordable fee. As a result, 300 such pumps were in operation there in 2016.

A similar pilot in Bihar State, eastern India, by the International Water Management Institute (IWMI) has organized farmers to create a pro-poor water market. In both Bangladesh and Bihar State, there is evidence of a 40–60 percent fall in water prices compared with those charged by diesel-pump owners, promoting efficient water use by the poor and the rapid expansion of solar pumps in pro-poor irrigated agriculture.[47] Another pilot by the IWMI in Dhundi, a village in water-scarce Gujarat State, India, has promoted co-usage of solar-powered irrigation pumps. In one village, well owners have given up grid power in exchange for subsidized solar-powered irrigation pumps of equivalent capacity. The small irrigation pumps form a microgrid managed by an owners cooperative, and the utility company buys surplus solar power from the cooperative at a single metered point. The pilot has sought to promote lower GHG-emitting irrigation, reduce the farm power subsidy, cut technical and commercial losses in serving grid power, give farmers an additional source of risk-free income, and incentivize them to economize on energy and groundwater.[47] Before the sale of solar power began in May 2016, farmers used their pumps solely for irrigating their own and their neighbours' fields. However, since then, they have sold as much power as possible and used only 35 percent of the solar power for pumping groundwater.[48]

Temporary subsidies during early input and technology adoption may help meet fixed costs of new technology and encourage farmer experimentation and learning during rapid technological change. Such subsidies should be temporary and phased out with adoption and appropriate use of technologies. Once in place and once they have political support, removing subsidies becomes difficult; thus, implementation requires care.[27, 44] Promoting linkages with other programmes may be effective; for example, linking social protection programmes such as public works or cash transfers with mechanisms and/or programmes for better water use. Box 23 reveals how targeted subsidies have increased the use of solar-powered irrigation pumps in Bangladesh and India. This type of intervention may be inappropriate in areas facing water stress, as affordable solar-powered pumps may increase the risk of over-extraction of groundwater. This highlights the importance of water allocation systems based on water accounting to avoid unintended effects, whereby even water-saving technologies can lead to greater water consumption.

In the context of integrated approaches and watershed management, payments for environmental services are another targeted policy instrument with environmental and economic benefits. They consist of payments to farmers or landowners who agree to manage their land or watersheds for environmental protection, to protect water resources, reduce GHGs, or improve soil quality and nutrient status. Most existing schemes focus on reducing deforestation or improving the watershed, adopting a nature-based management perspective. These incentives are extremely important when markets fail to take into account the scarcity of natural resources and the social value of well-functioning ecosystems. Examples are found in both higher- and lower-income countries, and their success and cost-effectiveness depends on their design.[49, 50] Evaluating these programmes to see which approaches work best can be challenging. The main challenge is that evaluations – to be rigorous – need to compare areas with payments for environmental services to other areas without payments, which can be costly.

Payments for environmental services will help sustain ecosystems where, even with an integrated approach, barriers to practices and property rights may make it difficult to address all environmental issues. There are significant positive impacts on environmental outcomes, primarily for local or subnational payments for environmental services. One example is the Rio Rural Programme in Brazil, which encourages sustainable farming systems, integrating income generation and environmental conservation in 72 municipalities of Rio de Janeiro State. The programme strengthens organization and community mobilization in 366 watersheds, developing skills and encouraging best practices.[51]

In general, smaller-scale programmes that are at least in part user-financed, with effective targeting criteria and strong conditionality rules, have performed better. Other factors in the success of these payments are low opportunity costs on other land uses – or payments high enough to cover these opportunity costs – limited production mobility and well-established property rights. Appropriate monitoring and sanctions, with social safeguards, also increase the probability of success. Payments are most likely to succeed where there is a clear demand for environmental services with economic value to one or more stakeholders; there are effective brokers or intermediaries; land and water rights are clear, and contracts enforceable; and outcomes can be independently monitored and evaluated.

However, improving policy coherence will need strong governance, tools and processes to manage and coordinate policy, and develop budgets and regulation. It will also require strong political commitment and leadership, cultural changes, monitoring, and learning from international experience and evidence.[52] Specific steps can include capacity strengthening for public institutions; coordination across water, agriculture and energy ministries; improved planning and monitoring tools; and upgrading and networking department databases to synthesize data and analytical capabilities. Putting in place effective regulatory and incentive policies is an important step towards policy coherence, eliminating general subsidies so that the water, agriculture and energy sectors face the same opportunity costs when assessing the viability of policies, programmes and projects. Another frequently debated dimension is the role of international trade and how it affects water use in countries (Box 24).

The institutional and policy reforms of water management require a complex blend of public-sector, market, and civil-society action (Box 25). This is particularly relevant because of the link between agriculture and food security and nutrition, both intimately linked to water. Food security and nutrition are affected by access to clean water (see In Focus: Improving access to safe drinking water in rural areas, p. 20). However, food security and nutrition are also linked to water through the many small-scale farmers and rural poor who depend on agriculture. This report shows how many people live in areas where water risks affect agricultural producers. Macroeconomic and commodity price policies that create a level playing field across sectors and commodities can enable small-scale farmers to make more-informed and less-risky water decisions, such as on water harvesting or on irrigation investment. Improving irrigation investments to include or link with other interventions that address gender, youth, health and nutrition outcomes could also transform irrigation programmes from solely increased food production towards being an integral component of poverty reduction strategies and improved food security and nutrition.[63]

BOX 24
THE ROLE OF VIRTUAL WATER AND TRADE IN ENSURING OPTIMAL USE OF WATER RESOURCES

Trade and development policy can also have important implications for water, including scarcity and quality. Food imports and their embodied virtual water have impacts on the water sector, and can reduce water constraints and improve food security and nutrition.[53] While producing some food domestically, many water-constrained countries will continue to rely on imported food crops as a significant portion of their food supply. Thus, virtual water may play a role in national policies that aim to increase food security and nutrition in water-constrained countries. The optimal combination of imports and domestic production varies among countries according to land and water endowments, and given other productive uses. At the regional and country level, the largest net exporters of virtual water are Northern and Southern America (Argentina, Brazil, Canada and the United States of America), Southern and South-eastern Asia (India, Indonesia, Pakistan and Thailand) and Australia. The largest net virtual water importers are Europe, Japan, Mexico, the Near East and North Africa, and the Republic of Korea.[54]

International trade is driven by economic and political forces rather than by water scarcity. Trade protection and domestic support for agriculture (e.g. tariffs, duties, commodity price support and subsidies) influence the movement of virtual water.[55] Empirical studies of the relationship between international trade and national water endowments confirm other factors are more important than water in determining agricultural and virtual water trade patterns. An analysis of country data on renewable freshwater availability and the net virtual water trade of 146 countries shows that scarcity does not determine a country's virtual water trade, but that access to arable land does.[56] Another international study shows that the amount of arable land per person is a better indicator of agricultural exports than are a country's renewable water resources, expressed either per person or per hectare.[57]

Evidence shows small to substantial increases in global virtual water flows owing to trade liberalization.[55, 58] Trade liberalization tends to reduce use in water-scarce regions but increases it and exports of virtual water in relatively abundant regions such as the United States of America and Southern America, while increasing virtual imports in water-scarce regions.[58] The potential for implicit infrastructure sharing is shown by countries with low dam-storage capacity obtaining a higher proportion of their agricultural water from virtual imports.[59]

Not all trade patterns lead to more productive water use. If water-scarce countries import from other scarce-water regions, this only shifts the burden of agriculture-induced water scarcity. Aligning trade and sustainable water use (e.g. through a water label) is essential in order to improve global water governance.[60] This is especially true in that the price of freshwater for agriculture does not reflect its economic value or the environmental impacts of its use.[61, 62] Virtual water is a helpful concept for encouraging public officials and citizens to focus on water scarcity. However, the virtual water perspective cannot be the primary criterion for shaping optimal agricultural trade or production policies.[57]

Agricultural extension, cooperatives and water users associations can include nutrition and diet in their messaging.[64] This could also be tailored for producers in rainfed areas and the water-related challenges they face. There should be greater targeting of water interventions towards women, to improve dietary quality and nutritional outcomes.[65–67] Identifying interventions that reduce women's time burden and support their control over production could accelerate nutritional gains and increase benefits.[64] ■

BOX 25
THE CHALLENGE OF POLICY COORDINATION – EXPERIENCES FROM BOLIVIA (PLURINATIONAL STATE OF) AND CHILE

In Bolivia (Plurinational State of), the Ministry of Environment and Water has, within its 2017–2020 water management programme addressing climate change, made governance fundamental to achieving water security.[68] It has made significant investments in irrigation works and technologies, inventories of water sources and water balances, and inventories of water rights. The programme recognizes ancestral irrigation organizations and water planning in strategic basins, linked to sustainable production. An inter-institutional platform for the strategic basin of the Guadalquivir River, in Tarija Department in the south of the country, promotes coordination between sectors, levels of government, academia and non-governmental organizations. FAO, in partnership with the German Agency for International Cooperation and the European Union, is promoting multi-stakeholder, multisector and multilevel dialogue, for better water governance and management integration in this semi-arid river basin that is vulnerable to climate change.

In Chile, FAO, together with the national irrigation authority (Comisión Nacional de Riego) in the Ministry of Agriculture, recently conducted a water governance case study in the Tinguiririca sub-basin of the Rapel River.[69] This basin faces severe drought, with demand for water exceeding supply, and is representative of the central region of Chile, which has been suffering from an extended drought for some 10–13 years. The 2019 rapid participatory study in the Tinguiririca sub-basin identified five main water governance challenges and needs.

- Strengthen trust between actors (related to drinking water, irrigation and hydroelectricity), ensure effective coordination between them, and prevent/resolve conflicts from the water crisis.
- Strengthen the efficiency and capacities of public and private institutions, from the Dirección General de Agua and the Ministry of Agriculture to extension agents; develop coordination between support entities; and improve the composition of groundwater communities.
- Improve territorial planning and effective regulation, protect the soil from non-conservation agricultural use, and regulate the expansion of irrigation based on water availability, taking climate change into account.
- Regulate water use and promote irrigation systems with efficient drip and sprinkler equipment, high-value crops needing less water and safe reuse of wastewater.
- Generate new and better information, share and integrate it, and modernize information management for informed decision-making.

The participatory review identified a range of actions to address gaps in infrastructure, policy and planning, administration, knowledge and information. In addition to strengthening institutions, it identified three priority interventions: (i) improve water efficiency to reduce vulnerability to climate change; (ii) regulate expanded water demand in agriculture/irrigation according to availability projections; and (iii) ensure water availability for production and consumption.

FAO continues to support these Andean countries, and those in the Dry Corridor in Mesoamerica, to address needs for improved governance and water management. A renewed focus on watershed management and integrated management of surface water and groundwater will be instrumental in enabling the sectors and actors to address land degradation and the scarcity and/or depletion of water resources, and to support sustainable and resilient agricultural systems.

SETTING POLICY PRIORITIES TO REDUCE WATER CONSTRAINTS IN AGRICULTURE

Although every country and region experiences some water risk – whether water stress, drought, flood or water quality issues – each faces different risks of varied magnitude. (For a brief overview of issues related to flooding, see In Focus: Too much water? Flooding, waterlogging and agriculture, p. 104.) Choosing the most suitable water management policies will depend on the production system: irrigated, rainfed (high- or low-input production), livestock, or inland fisheries and aquaculture. Also relevant are the risks faced and the endowment, in terms of both natural resources and finance, as well as each country's governance and capabilities. Deciding on concrete actions, interventions or policies means prioritizing objectives to direct limited resources to where they are most needed and can be most effective. Building on the spatial analysis in Chapter 2 for rainfed, irrigated and livestock production, Table 7 presents possible policies and intervention areas to reduce water shortages and scarcity in crop and livestock systems, as well as interventions and strategies for inland fisheries and aquaculture. These are elements of a portfolio of interventions for an "all of agriculture" water management strategy in parallel with intersectoral efforts to make water use more sustainable. The importance of water accounting, as a premise for sustainable water management, is a cross-cutting theme affecting all types of water users.

Improved water management in rainfed cropland

Globally, this profile is relevant for all 1.2 billion hectares of rainfed cropland, but especially for the 77 million hectares and 51 million hectares of low- and high-input rainfed production systems with high to very high drought frequency, respectively. In these areas, conserving water and the balance between irrigated and rainfed agriculture receive most attention, as relying solely on rainfed agriculture involves considerable risk of drought. Water harvesting techniques (e.g. to support supplemental irrigation) can bridge short dry spells, and thus decrease risk in rainfed agriculture.[70] Although water harvesting has great potential for enabling water management strategies to be most effective, such strategies also need best agronomic practices, including improved varieties, proper crop planting and harvesting periods, and nutrient management. Where drought risk and a lack of resources constrain farmers' investment in higher-risk and higher-return activities – making it harder to break the vicious cycle of low-input production – public interventions that invest in modern inputs will play a central role. Governments can help attenuate the effects of drought by investing in roads and market infrastructure to link farmers to their markets, and subsidize water capture and conservation, while at the same time contributing to overall agricultural development. Mobile phone apps, a cost-effective solution, can help farmers access market, financial and weather information. Where drought risk is severe, databases and information systems with drought monitoring and early warning systems will be key preventive measures. Governments can also eliminate barriers to investment through credit and extension services, or by introducing crop insurance and safety nets with alternative income sources for small-scale farmers.

Expanding water harvesting can affect the sustainability of inland fisheries and other water-related ecosystems and, consequently, the food security and nutrition status of those who depend on them. Any decision about investing in water harvesting should be based on detailed water accounting. Water harvesting that integrates agriculture systems with raising fish and other aquatic animals can be important for offsetting environmental and economic costs, adding nutritional benefits at the household and farm level, and increasing water productivity.

Realizing maximum benefits from interventions in rainfed agriculture also depends on involving farmers in developing the technology within their local community and possibly at the water-basin level.[71] A new water policy framework for integrated water resources management is required in order to plan and allocate rainwater at the watershed scale, given »

TABLE 7
POLICY PRIORITIES FOR IMPROVED WATER MANAGEMENT IN AGRICULTURE

Strategies/ actions	Rainfed areas		Irrigated areas	Inland fisheries and aquaculture
	Cropland High to very high drought frequency on **77 million hectares** (low-input) and **51 million hectares** (high-input)	**Pastureland** High to very high drought frequency on **656 million hectares**	High to very high water stress on **171 million hectares**	
Water accounting and auditing	Sound and transparent water accounting	Monitoring systems; water and feed assessments in drylands; using water as main input instead of land in environmental assessments	Sound and transparent water accounting	Incorporate proper valuations of water-related ecosystems and environmental flows in water accounting
Good agricultural practices	Best agronomic practices (e.g. improved seed varieties, nutrient and pesticide management, restoring soil organic matter and mulch)	Nutritional strategies; use of shade on yards; regulating ambient temperature; improved seeds and cropping systems of forage/feed crops; improve animal health and reproduction; strategic construction of forage and boreholes	Best agronomic practices (e.g. improved seed varieties, nutrient and pesticide management, restoring soil organic matter and mulch)	Responsible stocking and enhancement strategies for capture fisheries in man-made waterbodies through appropriate genetic material and use of non-indigenous species; improved aquaculture efficiency through water productivity and reuse, integration, and best aquaculture practices
Policy instruments	Extension services; financial services; crop insurance; targeted subsidies; improved market access (e.g. through roads)	National guidelines and standards for livestock responses to water risks; targeted subsidies (e.g. to restore pasturelands and to encourage using crop residues as animal feed)	Extension services; financial services; crop insurance; targeted subsidies	Adjust incentives and policies that impact negatively fisheries and aquaculture
Information and communication technology	Early warning systems; phone apps to deliver information on markets, weather; precision agriculture	Early warning systems; technologies for extensive grazing management (e.g. spatial information systems for mapping water points)	Early warning systems; phone apps to deliver information on markets, weather; precision agriculture	Wireless sensors to monitor water conditions and fish behavior
Water conservation	Soil and water conservation strategies, such as through terracing, contour cultivation and conservation agriculture	Water-efficient drinking devices; maintenance and repair of water troughs; integrated approach of hydraulic improvements	Conservation agriculture; water-use-efficient irrigation systems	Consider trade-offs between crop and fish production; form refuge areas in rice systems
Water harvesting and irrigation	Water harvesting	Use of tanks and reservoirs for livestock watering; preserve harvesting, conservation and irrigation systems; integrated solutions (e.g. rainwater harvesting that releases water for livestock watering)	Irrigation rehabilitation and modernization	Integrated solutions (e.g. rainwater harvesting that releases water for raising fish; small ponds)
Water governance	Community participation; integrated watershed management approaches	Community participation; customary or indigenous institutions; pastoralist organizations	Allocation and market-based tools; water users associations	Fishing/aquaculture associations; aquaculture allocation; regulations for retaining environmental flows; incorporate nutrition outcomes into policies/planning
Trade	Virtual water trade	Virtual water trade	Virtual water trade	Virtual water trade
Non-conventional water resources	–	Using water from alternative sources for feed production and animal drinking/watering	Water reuse and desalination; integrated systems (e.g. rice–fish and aquaponics)	Integrated systems (e.g. rice–fish and aquaponics) that allow reusing water
Nature-based solutions	Nature-based solutions	Nature-based solutions	Nature-based solutions	Nature-based solutions to enhance environmental and biodiversity services

NOTE: Table A2 in the Statistical Annex (p. 138) shows the country breakdown of the number of hectares under each agricultural and livestock production system experiencing severe water scarcity.
SOURCE: FAO.

» that water policies and regulations are usually designed to allocate irrigation water and not collect rainfall.[71] For the 14 million hectares of rainfed agriculture suffering very high drought frequency, governments could also remove agricultural distortions to facilitate trade in water-intensive goods in order to compensate for water deficiencies and provide food security and nutrition.

A key policy area for rainfed areas, both cropland and pastures, is drought preparedness. Drought policies should not simply be a response to disaster but a permanent concern for governments and society. Drought policies should be in place during non-drought years, when there is more time to plan and address challenges. During drought years, efforts will logically be directed towards drought response programmes. Each country policy will have its own characteristics based on local conditions; however, there are some elements common to all policies. A drought policy should have three pillars: (i) drought monitoring, forecasting and early warning systems; (ii) vulnerability and impact assessment; and (iii) drought preparedness, mitigation and response. These three pillars should be supported by cross-cutting policies involving, at a minimum, the following elements: coordination and institutional development; capacity building; finance; knowledge management, science, technology and research, and awareness; regional and international cooperation; stakeholder participation and inclusiveness; and evaluation.[72]

Improved water management in livestock production systems

Of the total of 4.6 billion hectares of pastureland, almost 15 percent (656 million hectares) experience high to very high severe drought frequency. The livestock sector is already a major user of natural resources such as land (although often marginal lands where crop production is not viable) and water through feed and rainfed pasture. Livestock water usage should be an integral part of agricultural water-resources management, taking into account the production system (e.g. grassland-based, mixed crop–livestock or landless) and scale (intensive or extensive), the species and breeds of livestock, and the social and cultural aspects of livestock farming in different countries.[73] To improve insight into the demand for freshwater in a specific region and enhance the performance of individual farms and the whole supply chain, stakeholders must undertake sound, transparent water accounting, taking into account climate, agricultural practices and feed utilization. To this end, in 2012, FAO established LEAP to improve the environmental sustainability of livestock, including optimal use of water, and to identify opportunities to improve water productivity for livestock (see Chapter 4).[73] Monitoring systems can conduct dryland water and feed assessments to improve early warning systems and inform development strategies.

As much livestock water consumption is feed-related, higher crop water productivity is pivotal to improving the water-related environmental performance of livestock production.[73] The water management for rainfed and irrigated agriculture mentioned in the previous and following sections is very important. Other critical options include improved seed varieties and cropping systems for forage and feed crops, and targeted subsidies to encourage the use of crop residues and by-products as animal feed. Other important subsidies are for the restoration, sustainable management and preservation of pastureland ecosystems. Apart from feed production, most water in livestock farming is for drinking. Chapter 3 presents several water management practices for reducing the amount of animal drinking water required. Improved animal health is one important way to increase overall production, and thereby water productivity, as the animals use fodder and other water resources more efficiently.[73] When access to water is lacking, improvements to infrastructure (e.g. boreholes) and the preservation of traditional water harvesting, water conservation and irrigation systems (e.g. canals, terraces and wells) should be promoted. Developing innovative technologies for extensive grazing management (e.g. mobile pumps and reservoirs) will complement this strategy.

There have recently been practical innovations in integrated production systems that harness synergies between crops, livestock and agroforestry, and ensure economic and ecological sustainability, while providing ecosystem services.[74] There are multiple ways to achieve this integration. The integration can be on-farm as well as on an area-wide basis involving some specialization. This will need political will, and policy and institutional support to adopt innovations and practices linked to promising crop–livestock systems for food security and nutrition. Governments should also promote input and output market linkage for such systems, with input and output supply chains and public–private service providers for different production systems and markets.

Successful scaling up also depends on strong farmers organizations, community empowerment, and multi-stakeholder and inter-institutional approaches. This requires knowledge exchange, capacity development, and adaptive and relevant interdisciplinary research.[74] Examples include farmer field schools and farmers clubs.

Improved water management in irrigated areas

As in rainfed systems, there are many options to alleviate water scarcity in irrigated agriculture. Globally, more than 275 million hectares of irrigated cropland would benefit from improved water management. Action is particularly urgent for the 171 million hectares under high to very high water stress. The starting point for any efficient, effective and sustainable strategy on water stress and improving water resources management in irrigated agriculture should be a detailed accounting of water supply and demand. Once stakeholders have a thorough understanding of the water balance – including the hydrological and ecosystem needs for water quantity and quality throughout the year – the challenge is to introduce clear, transparent allocation systems. These will need to balance water for food production, for the basic needs of the poor and vulnerable populations, and for environmental flows. Establishing secure water rights and access to ecosystem services within river basins and aquifers will also help create security for users, promote efficient water use, and open opportunities for water markets. To encourage effective management, the totality of water rights should amount to less than current usage in the basin or aquifer. Only under such conditions is it possible to design effective water conservation measures.

Although any expansion of irrigation must be done cautiously and as part of an integrated water resources management strategy, it is clear that the rural poor can benefit substantially from irrigation. In India, irrigation had the highest impact in reducing rural poverty from 1970 to 1993, compared with adopting high-yield varieties, fertilizer application, and improving rural literacy and rural road density across 14 states.[75] Other studies in Malawi and Pakistan have shown that – if well managed – irrigation can reduce the risk of stunting among children and promote diverse household diets.[76, 77] There is great potential to expand irrigation in some regions of the world. Between 2010 and 2050, the harvested irrigated area is projected to increase by 12 percent in Eastern Asia and the Pacific, by 35 percent in Latin America and the Caribbean, by 22 percent in the Near East and North Africa, by 30 percent in Southern Asia, and by more than 100 percent in sub-Saharan Africa.[78] The potential is even higher with appropriate policies in place. One study estimates that there is potential for at least 16 million hectares of profitable large-scale irrigation and 7 million hectares of small-scale irrigation in Africa, with a higher internal rate of return for individual and farm-community managed systems.[79] Another study has revealed an even larger potential for profitable small-scale irrigation expansion in sub-Saharan Africa, with potential of up to 30 million hectares for motor-driven pumps. This expansion could benefit more than 350 million rural people.[80] Given that many countries depend on inland fisheries for food security and nutrition and are threatened by such intensification, it is important to adopt a more holistic approach in order to offset or mitigate some of these negative impacts.

Beyond expansion, priorities for irrigation investment include rehabilitating ageing and obsolete systems and modernizing existing ones for improved water control and water-use productivity. This might involve investments in advanced irrigation technology to raise crop water productivity or reduce consumptive use of water by minimizing evapotranspiration. Other options involve producing higher-value crops from irrigation or limiting the cropped area under irrigation. However, implementation of the latter is usually more difficult and less popular.[1] Where financially viable, investing in precision agriculture allows farmers to enhance irrigation efficiency while minimizing impacts on wildlife and the environment. Another type of infrastructure worth prioritizing concerns integrated data and information systems to monitor water resources and rights. These help inform efficient water allocation systems to ensure water consumption is sustainable in the long run. Measures to enhance supply from non-conventional resources – namely, desalination and wastewater reuse – will also become more important but will need sizeable investment.

Where capital is required, particularly in the case of irrigation development, new funding mechanisms can increase investment in water resources management. Options such as green and blue bonds are a source of funding worth considering. Another funding option is a mix of grants, loans guaranteed by government, and contributions by beneficiaries. Blended finance, which strategically uses development finance or public funding to mobilize private investments (e.g. the Global Water Fund), is a promising approach to scale up private-sector finance in low-income countries.[81] There, investment has been limited mainly to groundwater and, to a lesser extent, smaller commercial surface-water systems. Several factors have inhibited private-sector investment in irrigation, including relatively low or uncertain rates of return; political interference during project management that sets water fees below sustainable levels for private investors or banking sectors; and government concern that the private sector might sell water to industries at higher rates than to agricultural users or domestic water suppliers.[82] Even where the government continues to provide the bulk of financing, bringing in the private sector through public–private partnerships can generate economic benefits.[p] Contracts need to be specifically designed to protect small-scale farmers. Payments for ecosystem services can be an additional source for water-related interventions. However, to date, none of these sources has provided significant funding specifically for irrigation development.[27]

Beyond investing in irrigation systems, to make the best use of scarce irrigation water, more active crop and nutrient selection is needed in all irrigated areas – particularly highly water-stressed areas – including crop diversification to higher-value and less-water-using crops (e.g. drought-tolerant varieties). Among integrated crop management options, conservation agriculture is one of the most important for enhancing efficient water and nutrient use. Other integrated management systems should also take into account the potential of aquaculture and inland fisheries, and environmental flow requirements.

As demand for water increases, much stronger institutions are needed to guarantee equitable distribution of benefits and maintain environmental services. Water governance reforms can help resolve water-related issues of equity and efficiency, especially in highly water-stressed areas. Depending on the context, key governance reforms include coordination of policies between government agencies across the food–water–energy nexus; integration of agricultural and urban water policies where there is direct competition for water; water users associations with strong capabilities (including control of local water rights, services and charges); enforcement of measuring and monitoring; and the promotion of clear legal authority. To avoid overuse of water, strategies should also consider phasing out payments coupled to production (e.g. price support), especially for crops that require a lot of water, and begin to phase out general subsidies for water, energy and fertilizers. Policymakers should also remove agricultural trade distortions in order to facilitate trade in agricultural commodities where subsidized water gives the sector a comparative advantage.

p For a description of the most commonly used contractual forms of public–private partnerships in the irrigation sector, see World Bank. 2017.[83]

Improved water management in inland fisheries and aquaculture

Inland fisheries and aquaculture are a valuable component of food systems and have a useful role in many development initiatives. Water use by the inland fisheries sector is inextricably linked to protecting and maintaining aquatic ecosystems. Any water development project should first consider the needs of inland fisheries and aquaculture in terms of water quantity and quality. While other sectors can use water resources such as groundwater and rainwater, inland fisheries are constrained by the availability of surface waters. Therefore, assessing how much water is available is often not enough. Equally critical features include the location of the water resources, their flow dynamics, availability, water quality and salinity, and the impacts of drivers of change and anthropogenic pressures.[84] There is a need to establish environmental flows to sustain aquatic ecosystems and incorporate valuations of water-related ecosystems into water management. Most high-income countries and some low-income ones now have strict regulations on environmental flows and water quality criteria,[85] helpful in sustaining fisheries and aquaculture. Other policy tools at the disposal of river-basin agencies include costings to allocate water for aquaculture and review incentives and policies on water-saving technologies to identify outcomes that impact inland fisheries and aquaculture, as well as nutritional outcomes. Expanding stakeholder consultation on water management to include inland fisheries and aquaculture can ensure a more balanced decision-making process for water schemes. Examples include involving aquatic experts in rehabilitating old irrigation schemes or developing new ones.

Disputes over water for irrigation and water for inland fisheries and aquaculture are often difficult to resolve owing to the different water needs for fish and crops.[85] Nonetheless, proper planning and a holistic approach to development, farming and fisheries can mitigate them. First, it is important to consider trade-offs between water use for field crops and for inland fisheries and aquaculture, and to explore potential integrated solutions that maximize outcomes, especially with nutritional benefits for poorer or marginalized stakeholders. Rice systems that integrate aquaculture into existing irrigated crop production or co-located waterbodies are excellent examples of how the two activities can coexist. There are many cases that demonstrate fish have a positive impact on rice crops, with less need for pesticides and fertilizers.

In rainfed systems, integration of aquaculture and fisheries can also create win-win situations. Integrated approaches include (i) encouraging water harvesting technologies (e.g. small ponds) that enable farm diversification and supplementary crops, such as fish, horticulture and livestock; (ii) establishing refuge areas within rainfed rice systems to sustain and encourage aquatic biodiversity; (iii) establishing and promoting community-based social systems to conserve water-related ecosystems; and (iv) looking holistically at floodplains to reconnect systems by reducing obstructions, such as those created by all-weather roads (e.g. culverts) or small weirs.

Policymakers should also look at nature-based solutions as a way to protect natural resources and improve the state and quality of water-related ecosystems. Options include restoring water channels through barriers and bottlenecks created by water management structures; managing flows and opening structures to allow fish to pass during breeding seasons and to disperse within systems; creating refuge wetlands as part of broad-scale water engineering solutions for large irrigation schemes; and enhancing integration of aquaculture into existing irrigated crop production. Environmental services need to be fully costed in food production systems, and subsidies must change to reflect this. Only then will policymakers consider changing policies and governance to promote an agroecological approach.[86] ■

CONCLUSIONS

Water resources management in agriculture will be key to attaining multiple Sustainable Development Goals linked to resource-use efficiency, the environment, and sustainable food production. This edition of *The State of Food and Agriculture* has focused on the extent to which agriculture contributes to, and is affected by, water constraints, specifically investigating the extent of the area and the number of people suffering severe drought frequency and water stress. The objectives have been to identify different constraints that producers might face vis-à-vis water resources management, and to provide guidance on governance, policy and prioritizing the interventions presented in this chapter, keeping in mind the heterogeneity of water users within agriculture (large farms, small-scale producers, women, men, indigenous peoples and traditional communities). The report has also highlighted the fact that competition for water resources is intensifying with population growth, economic development, changing consumption patterns, water quality degradation and climate change. As a result, the issue of managing trade-offs between economic, environmental and social objectives, and balancing the interests of all water stakeholders is moving up the policy agenda. Growing pressures on water resources will favour allocation regimes that perform well across a range of conditions and can adapt to changing conditions at the lowest cost.[87] The effectiveness of any water management policy will be influenced by fragmentation and rivalry between organizations; plurality of land and water tenure regimes; power relationships underlying existing institutions; conflict of interests; and access to and use of data and information.

Alongside the main theme of the report, there are water-related topics that are extremely important but could not be covered in depth. These were either touched upon in Chapter 1 – such as water use by the food processing sector – or covered by the In Focus briefs at the end of each chapter. The topics include the importance of rural wastewater, sanitation and hygiene (WASH), water pollution and salinity as they relate to agriculture, and also floods and drainage and how these impact agriculture. Each of these topics would warrant a separate chapter.

Water shortages and scarcity need to be addressed intersectorally and at the basin level, although agriculture is the largest user globally, with almost three-quarters of all water withdrawals, thus, holding the key to addressing these issues. More than ever, it is crucial to adopt an integrated approach, taking account of the water available throughout a watershed as a function of how different stakeholders use it, and to guarantee ecosystem functions. Better integration is needed across all subsectors in agriculture – including irrigated and rainfed areas, forests, inland fisheries and aquaculture – whereby the 2030 Agenda is a starting point for the multidisciplinary and inclusive dialogue needed to manage water resources in an efficient, equitable and sustainable manner.

One of the main findings of *The State of Food and Agriculture 2020* is that 1.2 billion people live in extremely water-scarce irrigated areas or rainfed areas affected by severe water shortages, and, of these, 520 million live in rural areas. About one out of six people on the planet are affected by severe water-related challenges – about 15 percent of the world's rural population. The confluence of increasing demand for water and of precipitation variability caused by climate change provides a sense of urgency to act according to the priorities laid out in this report. Policies should incentivize investment in increasing water productivity, combined with water allocation that better balances productivity both with equitable and inclusive access to water and with environmental flow requirements. This will entail the reforming of support policies, including other relevant sectors, that have led to inefficient water use. In many cases, water allocation will need reform, which can be politically challenging. Another possibility is to rely on alternative water sources, such as desalination and water reuse, or manage water demand more carefully through a combination of interventions. Additional efforts should be invested in developing tools and technological innovations to improve information and data on water resources and agriculture, as well as interactions and trade-offs, providing models to explore future pathways and optimal policy responses that balance economic, environmental and social objectives. Governance innovations should complement these efforts in leading a major transformation of the present food system and water paradigms to accelerate progress towards sustainable development that leaves no one behind. ■

TECHNICAL ANNEX

DISCLAIMERS ON MAP BOUNDARIES

For Figure A in Chapter 1, Figures 5–7 in Chapter 2, Figure 17 in Chapter 3, as well as Figures A1–A3 of the Statistical Annex, the following disclaimers on map boundaries apply:

The final boundary between the Republic of Sudan and the Republic of South Sudan has not been yet determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Malvinas). The boundaries shown on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers and boundaries. Dashed lines on maps represent approximate border lines for which there may not yet be full agreement.

METHODOLOGY USED IN BOX 13

The modelling framework used in Box 13 (p. 68) is based on Rosegrant (2020).[1] The share of cropland area to benefit from increased yield owing to adoption of technologies and management practices was estimated using an extension of the analysis in Rosegrant *et al.* (2014).[2] Specifically, the Decision Support System for Agrotechnology Transfer (DSSAT) crop model was used to simulate changes in yields for maize, rice and wheat in rainfed and irrigated systems, respectively, compared with a "business as usual" baseline. The DSSAT results were then fed into a series of globally gridded datasets, including the International Food Policy Research Institute's (IFPRI) Spatial Production Allocation Model (SPAM; see Box 7 on p. 36 for a description), that mapped global crop distribution and yield, as well as global climate scenarios and soils data. Crop yield improvements were then aggregated on an area-weighted basis to countries and regions. Modelling was done for the A1B climate change scenario from the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPPC),[3] using the model developed by the Commonwealth Scientific and Industrial Research Organisation.

Regarding irrigation expansion and investment, projected increases in irrigation area to 2030 were generated in currently rainfed areas, and based on the analyses by Rosegrant *et al.* (2017)[4] – using the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) (see below) – and Palazzo *et al.* (2019), using the moderate public support scenario of the Global Biosphere Management Model (GLOBIOM).[5] For the latter, the 2030 results were interpolated from the 2050 results. Data on rates of investment to rehabilitate and modernize irrigation systems were based on Rosegrant *et al.* (2017).[4] Global cropland adoption ceilings were based on Table 3.3 of Rosegrant *et al.* (2014), while regional yield increases by production system were based on Figures 4.7–4.11.[2] For more details on the modelling results, see Rosegrant (2020).[1]

IMPACT

IMPACT was developed at IFPRI in the early 1990s. It has been used to study the effects of alternative scenarios of investment in agricultural research and development, food policies, population, and income growth on long-term food supply and demand.[2] IMPACT uses a system of linear and non-linear equations to approximate the underlying production and demand relationships of world agriculture. The world's food production and consumption are disaggregated into 115 countries and regional groupings, and 126 hydrological basins. For this study, projected irrigation increases were based on recent trends in irrigated areas and investment, and on the potential for expansion based on water availability in different river basins, with feedback effects over time from changes in food prices that affect profitability. For a more thorough description of the latest version of the model, see Robinson *et al.* (2015).[6]

METHODOLOGY USED TO CALCULATE GEOSPATIAL AND TABLE DATA

To map water shortages and scarcity in different world areas and production systems, and quantify the number of hectares and people living in water-constrained agricultural areas, this report relied on six different datasets: (i) Global Agro-Ecological Zones (GAEZ);[7] (ii) SPAM;[8] (iii) Historic Drought Frequency of the Agricultural Stress Index System (ASIS);[9] (iv) Sustainable Development Goal (SDG) Indicator 6.4.2 on the level of water stress;[10] (v) the contribution of the agriculture sector to the level of water stress;[11] and (vi) the Global Human Settlements Layer population grid by Schiavina *et al.* (2019).[12] FAO's Hand in Hand Geospatial Platform – a digital public good to create interactive data maps, analyse trends and identify real-time gaps and opportunities – provides open-access to various datasets mentioned above.[13]

Mapping rainfed and irrigated cropland, and pastureland

From the GAEZ, three fractional layers were used as reference data to investigate the level of water shortages and scarcity in different world areas and agricultural production systems: (i) the layer for rainfed cropland; and (ii) the layer for grassland and woodland – which includes grassland, shrub-covered area and herbaceous vegetation – to investigate the frequency of drought in rainfed cropland and pastureland, respectively; and (iii) the layer for irrigated cropland to investigate the level of water stress in irrigated areas. Rainfed cropland was further differentiated between high- and low-input production based on the proportions by SPAM. The latter differentiates rainfed cropland between high-input, low-input and subsistence production;[14] however, for the purposes of this report, the class of subsistence cropland was merged with that of low-input production.

Mapping and quantifying drought frequency in rainfed areas

The Historic Drought Frequency indicator was used to map water shortages in rainfed cropland and pastureland (Figures 5 and 6, pp. 28–29), and to quantify the number of hectares and the number of people subject to drought (Tables A1 and A2 in the Statistical Annex, pp. 132–144). Figures A1 and A2 in the Statistical Annex further differentiate between high- and low-input rainfed cropland. This global drought indicator includes two crop-growing seasons, which have been combined by selecting the highest value of Historic Drought Frequency between the two. When there was only one season, that single value was used instead. Pixels with no season, and therefore no drought frequency assigned, are considered as "no data" in the statistical tables, and as "no seasons" in Figures 5, 6, A1 and A2. In Figures 5 and 6 "no data" accounts for pixels for which no level of drought was available but where cropland and pastureland was present, respectively, according to the GAEZ.

The indicator was further harmonized in terms of extent and spatial resolution to GAEZ fractional layers and reclassified as follows: low when the probability of severe drought affecting cropland/pastureland is less than or equal to 10 percent; medium when it ranges between 10 and 20 percent; high for between 20 and 30 percent; and very high for when it surpasses 30 percent.

Mapping and quantifying water stress in irrigated areas

SDG Indicator 6.4.2 on water stress at basin level was used to map water scarcity in irrigated areas (Figure 7, p. 30), and to quantify the number of hectares and the number of people subject to water stress (Tables A1 and A2). Figures 8 (p. 31), and A3 and A4 (p. 146) further map the contribution of the agriculture sector to water stress, and the levels of water stress at the country and basin level, respectively. Data for SDG Indicator 6.4.2 were also harmonized to GAEZ fractional layers and reclassified as follows: no water stress when the share of water withdrawal by all sectors is less than or equal to 25 percent; medium when it ranges between 25 and 50 percent; high for between 50 and 100 percent; and very high for when it surpasses 100 percent. Similarly, for the contribution of the agriculture sector, data were harmonized as follows: no water stress when the proportion of agricultural water withdrawal is less than or equal to 12.5 percent; medium when it ranges between 12.5 and 25 percent; high for between 25 and 50 percent; and very high for when it surpasses 50 percent.

Population living in water-constrained areas

The population layer by Schiavina *et al.* (2019)[12] was resampled and adjusted by excluding settlements of more than 20 000 inhabitants. The following decision tree was used to determine the number of people living in water-constrained agricultural areas: (i) people living in rainfed areas subject to very high drought frequency ***and*** people living in irrigated areas subject to very high water stress; (ii) people living in rainfed areas subject to very high drought frequency ***or*** living in irrigated areas subjected to very high water stress. Two further classes were calculated following the same logic but considering people living in high (instead of very high) water-constrained areas. A similar approach was used to estimate the number of hectares of these same areas by summing the fractional proportions of the pixels. Results are shown in Tables A1 and A2 in the Statistical Annex.

STATISTICAL ANNEX

NOTES ON THE STATISTICAL ANNEX

KEY

The following conventions are used in the tables in this annex:

0 or 0.0 = nil or negligible

– = not applicable

Numbers presented in Tables A1 and A2 can be replicated starting from the original data sources and then following the operations of data management implemented by the authors through the RStudio software. To separate decimals from whole numbers a full point (.) is used.

TECHNICAL NOTES

TABLE A1

Hectares and people living in agricultural areas with water shortages and scarcity, by country or territory

Sources: FAO elaboration based on: (i) FAO. 2020. *SDG Indicator 6.4.2 on water stress*; (ii) FAO. 2019. Earth Observation. Agricultural Stress Index System (ASIS): Historic Agricultural Drought Frequency (1984–2018*)*. In: *FAO* [online]. [5 August 2020]. www.fao.org/giews/earthobservation/asis/index_1.jsp?type=131; (iii) FAO & International Institute for Applied Systems Analysis (IIASA). 2020. *Global Agro-Ecological Zones (GAEZ v4.0)*. Laxenburg, Austria and Rome; (iv) International Food Policy Research Institute. 2019. Global Spatially-Disaggregated Crop Production Statistics Data for 2010 Version 1.0. Harvard Dataverse. In: *Harvard Dataverse* [online]. [Cited 5 August 2020]. https://dataverse.harvard.edu/citation?persistentId=doi:10.7910/DVN/PRFF8V; and (v) Schiavina, M., Freire, S. & MacManus, K. 2019. GHS population grid multitemporal (1975-1990-2000-2015), R2019A. In: *European Commission* [online]. [Cited 6 August 2020]. http://data.europa.eu/89h/0c6b9751-a71f-4062-830b-43c9f432370f

The first group – **Rainfed areas with very high drought frequency AND Irrigated areas with very high water stress** – indicates: (i) the number of hectares (in thousands) affected by very high drought frequency in rainfed cropland or pastureland *and* by very high water stress in irrigated areas; and (ii) the number of people (in thousands) living in rural or urban areas with very high drought frequency in rainfed areas *and* very high water stress in irrigated areas. It excludes settlements of more than 20 000 inhabitants. Note that, given the pixel size, small urban centres or peri-urban areas where agriculture is practised are included in the population count. Therefore, the population included is not strictly rural.

The second group – **Rainfed areas with very high drought frequency OR Irrigated areas with very high water stress** – indicates: (i) the number of hectares (in thousands) affected by either very high drought frequency in rainfed cropland or pastureland *or* by very high water stress in irrigated areas; and (ii) the number of people (in thousands) living in rural or urban areas with either very high drought frequency in rainfed areas *or* very high water stress in irrigated areas. It excludes settlements of more than 20 000 inhabitants. As per the first group, due to pixel size, the population included is not strictly rural.

The third group – **Rainfed areas with high drought frequency AND Irrigated areas with high water stress** – indicates: (i) the number of hectares (in thousands) affected by high drought frequency in rainfed cropland or pastureland *and* by high water stress in irrigated areas; and (ii) the number of people (in thousands) living in rural or urban areas with high drought frequency in rainfed areas *and* high water stress in irrigated areas. It excludes settlements of more than 20 000 inhabitants. As per the first group, due to pixel size, the population included is not strictly rural.

The fourth group – **Rainfed areas with high drought frequency OR Irrigated areas with high water stress** – indicates: (i) the number of hectares (in thousands) affected by either high drought frequency in rainfed cropland or pastureland *or* by high water stress in irrigated areas; and (ii) the number of people (in thousands) living in rural or urban areas with either high drought frequency in rainfed areas *or* high water stress in irrigated areas. It excludes settlements of more than 20 000 inhabitants. As per the first group, due to pixel size, the population included is not strictly rural.

TABLE A2

Hectares and share of land by production system with water shortages and scarcity, by country or territory

Sources: FAO elaboration based on: (i) FAO. 2020. *SDG Indicator 6.4.2 on water stress*; (ii) FAO. 2019. Agricultural Stress Index System (ASIS): Historic Agricultural Drought Frequency (1984–2018*)*. In: *FAO* [online]. [5 August 2020]. www.fao.org/giews/earthobservation/asis/index_1.jsp?type=131; (iii) FAO & International Institute for Applied Systems Analysis (IIASA). 2020. *Global Agro-Ecological Zones (GAEZ v4.0)*. Laxenburg, Austria, & Rome; (iv) International Food Policy Research Institute. 2019. Global Spatially-Disaggregated Crop Production Statistics Data for 2010 Version 1.0. Harvard Dataverse. In: *Harvard Dataverse* [online]. [Cited 5 August 2020]. https://dataverse.harvard.edu/citation?persistentId=doi:10.7910/DVN/PRFF8V

The first group – **Irrigated cropland with high or very high water stress** – indicates the number of hectares (in thousands) affected by high or very high water stress in irrigated areas. The column "Share of irrigated cropland" reports the proportion of hectares affected by high or very high water stress in relation to the total extent of irrigated areas.

The second group – **Low-input rainfed cropland with high or very high drought frequency** – indicates the number of hectares (in thousands) affected by high or very high drought frequency in rainfed cropland with low-input production. The column "Share of low-input rainfed" reports the proportion of hectares affected by high or very high drought frequency in relation to the total extent of rainfed cropland with low-input production.

The third group – **High-input rainfed cropland with high or very high drought frequency** – indicates the number of hectares (in thousands) affected by high or very high drought frequency in rainfed cropland with high-input production. The column "Share of high-input rainfed" reports the proportion of hectares affected by high or very high drought frequency in relation to the total extent of rainfed cropland high-input production.

The fourth group – **Pastureland with high or very high water drought frequency** – indicates the number of hectares (in thousands) affected by high or very high drought frequency in rainfed pastureland areas. The column "Share of pastureland" reports the proportion of hectares affected by high or very high drought frequency in relation to the total extent of pastureland.

The fifth group – **Share of land for which no data were available** – indicates the share of land for which no data were available in relation to the total extent of irrigated areas, of rainfed cropland with low-input production, of rainfed cropland with high-input production, and of pastureland areas, respectively.

TABLE A1

HECTARES AND PEOPLE LIVING IN AGRICULTURAL AREAS WITH WATER SHORTAGES AND SCARCITY, BY COUNTRY OR TERRITORY

COUNTRY/ TERRITORY	Rainfed areas with very high drought frequency AND Irrigated areas with very high water stress			Rainfed areas with very high drought frequency OR Irrigated areas with very high water stress			Rainfed areas with high drought frequency AND Irrigated areas with high water stress			Rainfed areas with high drought frequency OR Irrigated areas with high water stress		
	Hectares	Population		Hectares	Population		Hectares	Population		Hectares	Population	
		Rural	Urban		Rural	Urban		Rural	Urban		Rural	Urban
	Thousands			Thousands			Thousands			Thousands		
WORLD	8 053	13 727	23 167	340 127	498 187	629 345	53 717	122 747	139 864	552 294	749 572	1 064 280
AFRICA	484	518	553	110 952	31 832	49 127	2 941	4 842	5 319	158 902	91 156	148 005
Northern Africa	483	518	553	3 161	14 352	19 429	1 911	2 753	3 612	22 681	38 039	89 486
Algeria	206	156	174	1 513	8 955	11 284	257	237	354	3 069	2 792	3 670
Egypt	0	0	0	100	55	44	6	51	296	3 273	22 189	61 550
Libya	101	89	24	606	1 492	2 007	0	0	0	587	587	155
Morocco	13	33	89	381	1 625	2 369	1 109	1 897	1 997	3 874	6 501	9 894
Sudan	0	0	0	143	106	48	540	568	964	10 998	5 278	13 484
Tunisia	164	240	266	418	2 119	3 678	0	0	0	880	692	732
Sub-Saharan Africa	1	0	0	107 791	17 480	29 698	1 030	2 089	1 707	136 221	53 117	58 519
Eastern Africa	0	0	0	82 748	14 182	17 009	455	1 364	1 629	17 057	29 677	27 463
Burundi	0	0	0	0	0	0	5	35	0	6	584	579
Djibouti	0	0	0	78	11	44	0	0	0	0	0	0
Eritrea	0	0	0	491	102	262	58	9	21	912	261	1 493
Ethiopia	0	0	0	30 303	3 196	5 046	214	210	1 051	3 711	4 418	12 893
Kenya	0	0	0	32 947	8 071	4 961	12	186	0	2 288	10 977	2 295
Madagascar	0	0	0	129	204	30	0	0	0	2 573	984	435
Mozambique	0	0	0	20	7	0	50	142	74	137	488	514
Rwanda	0	0	0	32	91	685	24	149	39	264	2 755	1 229
Somalia	0	0	0	16 044	1 436	2 150	0	0	0	719	194	109
South Sudan	0	0	0	1 112	33	0	9	0	0	392	235	716
Uganda	0	0	0	146	152	37	71	623	404	765	3 488	4 623
United Republic of Tanzania	0	0	0	1 445	848	3 769	6	9	40	4 880	5 037	1 505
Zambia	0	0	0	0	0	0	0	0	0	13	45	1 021
Zimbabwe	0	0	0	0	31	27	6	1	0	397	210	52
Middle Africa	0	0	0	1 514	196	302	0	0	0	10 514	1 297	6 764
Angola	0	0	0	437	6	0	0	0	0	3 341	504	1 275
Cameroon	0	0	0	1	0	0	0	0	0	313	174	2 378
Chad	0	0	0	909	67	21	0	0	0	6 689	421	807
Congo	0	0	0	1	1	0	0	0	0	0	4	0
Democratic Republic of the Congo	0	0	0	10	46	0	0	0	0	31	128	2 279
Equatorial Guinea	0	0	0	97	59	245	0	0	0	69	20	0
Gabon	0	0	0	60	16	37	0	0	0	60	16	0
Sao Tome and Principe	0	0	0	1	1	0	0	0	0	10	30	25
Southern Africa	1	0	0	21 986	1 145	1 679	503	710	31	74 277	8 676	5 564
Botswana	0	0	0	1	0	0	167	5	0	48 055	1 044	663
Eswatini	0	0	0	0	0	0	0	0	0	53	326	62

TABLE A1 (CONTINUED)

COUNTRY/ TERRITORY	Rainfed areas with very high drought frequency AND Irrigated areas with very high water stress			Rainfed areas with very high drought frequency OR Irrigated areas with very high water stress			Rainfed areas with high drought frequency AND Irrigated areas with high water stress			Rainfed areas with high drought frequency OR Irrigated areas with high water stress		
	Hectares	Population		Hectares	Population		Hectares	Population		Hectares	Population	
		Rural	Urban		Rural	Urban		Rural	Urban		Rural	Urban
	Thousands			Thousands			Thousands			Thousands		
Lesotho	0	0	0	0	0	0	0	0	0	21	112	51
Namibia	0	0	0	21 620	532	74	0	0	0	15 849	720	366
South Africa	1	0	0	366	612	1 605	336	705	31	10 298	6 473	4 422
Western Africa	0	0	0	1 543	1 957	10 708	72	14	47	34 374	13 467	18 728
Benin	0	0	0	34	142	1 045	0	0	0	30	130	182
Burkina Faso	0	0	0	0	0	0	0	0	0	1 594	620	374
Côte d'Ivoire	0	0	0	34	158	3 547	0	0	0	235	376	160
Ghana	0	0	0	128	408	729	0	0	0	153	741	1 018
Guinea	0	0	0	0	0	0	0	0	0	1	8	962
Guinea-Bissau	0	0	0	1	2	0	0	0	0	6	9	0
Liberia	0	0	0	33	53	689	0	0	0	215	179	212
Mali	0	0	0	152	129	0	0	0	0	9 115	2 025	561
Mauritania	0	0	0	249	130	24	71	14	46	9 410	1 340	418
Niger	0	0	0	9	1	0	0	0	0	7 715	1 889	773
Nigeria	0	0	0	55	741	4 381	0	0	0	3 030	3 916	9 638
Senegal	0	0	0	847	192	189	1	1	2	2 771	1 953	3 819
Sierra Leone	0	0	0	0	0	0	0	0	0	96	274	612
Togo	0	0	0	0	3	102	0	0	0	2	7	0
AMERICA	644	206	397	29 083	7 800	19 435	10 214	4 272	6 827	112 322	52 852	94 331
Latin America and the Caribbean	644	206	397	22 325	5 927	16 907	3 532	2 330	4 726	61 223	22 799	41 424
Caribbean	0	0	0	111	171	403	0	0	0	458	821	476
Antigua and Barbuda	0	0	0	0	2	0	0	0	0	0	0	0
Aruba	0	0	0	2	14	0	0	0	0	0	0	0
Bahamas	0	0	0	25	0	0	0	0	0	249	77	105
British Virgin Islands	0	0	0	0	0	0	0	0	0	0	0	0
Cuba	0	0	0	63	47	403	0	0	0	30	22	0
Dominican Republic	0	0	0	5	16	0	0	0	0	18	48	0
Guadeloupe	0	0	0	0	0	0	0	0	0	1	10	0
Haiti	0	0	0	0	0	0	0	0	0	92	234	137
Jamaica	0	0	0	3	1	0	0	0	0	36	133	0
Puerto Rico	0	0	0	10	67	0	0	0	0	9	143	7
Saint Kitts and Nevis	0	0	0	0	0	0	0	0	0	3	8	0
Trinidad and Tobago	0	0	0	3	24	0	0	0	0	20	145	227
United States Virgin Islands	0	0	0	0	0	0	0	0	0	1	1	0
Central America	132	44	42	1 621	1 832	3 496	2 196	1 592	2 908	10 861	12 585	27 649
Belize	0	0	0	5	10	0	0	0	0	0	0	0
Costa Rica	0	0	0	5	0	0	0	0	0	84	102	124

TABLE A1
(CONTINUED)

COUNTRY/ TERRITORY	Rainfed areas with very high drought frequency AND Irrigated areas with very high water stress			Rainfed areas with very high drought frequency OR Irrigated areas with very high water stress			Rainfed areas with high drought frequency AND Irrigated areas with high water stress			Rainfed areas with high drought frequency OR Irrigated areas with high water stress		
	Hectares	Population		Hectares	Population		Hectares	Population		Hectares	Population	
		Rural	Urban		Rural	Urban		Rural	Urban		Rural	Urban
	Thousands			Thousands			Thousands			Thousands		
El Salvador	0	0	0	2	19	63	0	0	0	1	12	0
Guatemala	0	0	0	43	37	0	0	0	0	30	53	0
Honduras	0	0	0	17	4	0	0	0	0	5	8	0
Mexico	132	44	42	1 533	1 747	3 421	2 196	1 592	2 908	10 698	12 366	27 525
Nicaragua	0	0	0	4	0	0	0	0	0	32	36	0
Panama	0	0	0	11	15	12	0	0	0	10	8	0
South America	512	162	355	20 593	3 924	13 008	1 336	738	1 818	49 904	9 393	13 299
Argentina	0	0	0	14 967	443	1 039	786	171	230	29 063	1 877	3 230
Bolivia (Plurinational State of)	0	0	0	269	30	10	0	0	0	1 247	264	19
Brazil	0	0	0	908	259	114	0	0	0	14 724	3 788	965
Chile	512	162	355	782	1 262	7 354	0	0	0	1 302	15	0
Colombia	0	0	0	1 035	153	418	0	0	0	198	208	272
Ecuador	0	0	0	87	87	197	10	5	0	524	336	62
Guyana	0	0	0	1	0	0	0	0	0	8	9	0
Paraguay	0	0	0	2	0	0	0	0	0	75	7	0
Peru	0	0	0	1 548	1 372	2 804	539	563	1 588	1 314	2 251	5 736
Uruguay	0	0	0	0	0	0	0	0	0	90	9	10
Venezuela (Bolivarian Republic of)	0	0	0	993	318	1 072	0	0	0	1 359	630	3 005
Northern America	0	0	0	6 758	1 873	2 528	6 683	1 941	2 102	51 099	30 053	52 908
Canada	0	0	0	6	0	0	0	0	0	10 419	434	499
Greenland	0	0	0	21	0	0	0	0	0	0	0	0
United States of America	0	0	0	6 731	1 873	2 528	6 683	1 941	2 102	40 680	29 619	52 409
ASIA	6 924	13 003	22 217	71 964	452 630	557 364	40 422	113 420	127 696	171 878	557 154	776 446
Central Asia	167	71	44	5 218	7 238	4 532	4 640	8 316	4 828	40 129	17 252	17 614
Kazakhstan	0	0	0	3 071	378	638	1 696	1 000	688	31 540	4 560	4 945
Kyrgyzstan	0	0	0	0	0	0	247	653	563	1 143	2 422	2 143
Tajikistan	0	0	0	12	864	278	527	1 365	349	515	2 220	2 222
Turkmenistan	167	71	44	1 418	2 226	1 667	255	293	34	3 291	669	112
Uzbekistan	0	0	0	716	3 769	1 948	1 916	5 006	3 194	3 640	7 381	8 192
Eastern Asia	447	1 516	6 830	17 654	153 247	146 966	2 453	17 507	15 247	45 133	194 497	227 326
China, Hong Kong SAR	0	0	0	0	0	0	0	0	0	1	84	1 755
China	439	1 516	6 830	17 466	151 722	137 433	2 394	17 314	15 027	40 272	176 587	185 937
Democratic People's Republic of Korea	0	0	0	3	32	75	59	193	220	1 181	7 261	13 591
Japan	0	0	0	72	1 132	5 545	0	0	0	139	2 011	6 861
Mongolia	7	0	0	83	89	24	0	0	0	2 766	67	24
Republic of Korea	0	0	0	22	211	1 164	0	0	0	771	8 466	19 020

TABLE A1
(CONTINUED)

COUNTRY/ TERRITORY	Rainfed areas with very high drought frequency AND Irrigated areas with very high water stress			Rainfed areas with very high drought frequency OR Irrigated areas with very high water stress			Rainfed areas with high drought frequency AND Irrigated areas with high water stress			Rainfed areas with high drought frequency OR Irrigated areas with high water stress		
	Hectares	Population		Hectares	Population		Hectares	Population		Hectares	Population	
		Rural	Urban		Rural	Urban		Rural	Urban		Rural	Urban
	Thousands			Thousands			Thousands			Thousands		
Taiwan Province of China	0	0	0	8	63	2 725	0	0	0	1	21	137
South-eastern Asia	46	330	3 003	4 170	43 036	103 878	717	1 619	1 248	5 380	25 488	24 174
Brunei Darussalam	0	0	0	1	11	0	0	0	0	0	0	0
Cambodia	0	0	0	120	406	103	0	0	0	605	1 823	432
Indonesia	46	330	3 003	3 255	37 712	91 453	0	0	0	212	581	326
Lao People's Democratic Republic	0	0	0	1	1	0	0	0	0	7	23	0
Malaysia	0	0	0	17	7	0	0	0	0	28	140	2
Myanmar	0	0	0	84	511	689	0	0	0	1 094	2 799	2 580
Philippines	0	0	0	54	173	649	0	0	0	121	2 342	2 789
Singapore	0	0	0	0	0	1 368	0	0	0	1	7	357
Thailand	0	0	0	70	571	2 749	717	1 619	1 248	2 418	10 045	9 392
Timor-Leste	0	0	0	14	275	0	0	0	0	0	0	0
Viet Nam	0	0	0	554	3 369	6 868	0	0	0	895	7 729	8 297
Southern Asia	5 918	10 070	10 361	40 617	230 036	267 946	26 417	78 110	96 042	62 419	289 545	457 423
Afghanistan	90	328	54	943	5 970	9 333	2 367	3 915	3 383	3 976	4 906	3 312
Bangladesh	0	0	0	0	0	0	1 741	14 328	8 820	2 763	42 425	76 351
Bhutan	0	0	0	8	0	0	0	0	0	36	457	185
India	4 664	7 153	5 808	20 111	125 751	158 060	18 603	56 852	79 397	43 851	212 554	352 981
Iran (Islamic Republic of)	966	1 989	4 160	4 877	8 399	25 527	3 603	2 643	4 189	8 774	6 607	11 912
Nepal	0	0	0	21	0	0	11	21	5	1 136	19 565	8 372
Pakistan	146	335	107	14 125	79 213	70 550	93	352	248	1 790	2 957	4 276
Sri Lanka	52	265	233	534	10 702	4 476	0	0	0	94	74	32
Western Asia	347	1 016	1 978	4 305	19 072	34 040	6 194	7 866	10 330	18 817	30 373	49 910
Armenia	0	0	0	0	0	0	39	94	315	279	1 339	1 180
Azerbaijan	0	0	0	269	375	1 021	1 425	1 205	691	1 304	2 346	2 185
Bahrain	0	0	0	1	54	546	0	0	0	0	0	0
Cyprus	0	0	0	0	0	0	22	35	53	50	479	363
Georgia	0	0	0	0	0	0	17	95	137	260	511	93
Iraq	0	0	0	107	747	1 273	393	786	1 166	3 420	6 142	19 632
Israel	0	0	0	4	21	52	1	13	14	167	2 116	4 023
Jordan	0	0	0	45	229	1 932	60	236	513	86	1 336	1 124
Kuwait	0	0	0	4	109	156	0	0	0	2	3	0
Lebanon	1	2	0	1	5	0	146	564	1 476	127	1 404	675
Oman	0	0	0	59	1 664	1 375	0	0	0	5	10	0
Palestine	0	0	0	0	0	0	2	18	32	42	769	1 858
Qatar	0	0	0	12	304	905	0	0	0	0	0	0
Saudi Arabia	196	444	442	1 702	3 182	5 726	0	0	0	207	137	99
Syrian Arab Republic	130	484	1 172	584	3 078	4 613	1 004	1 932	1 008	2 027	2 945	1 985

TABLE A1 (CONTINUED)

COUNTRY/ TERRITORY	Rainfed areas with very high drought frequency AND Irrigated areas with very high water stress			Rainfed areas with very high drought frequency OR Irrigated areas with very high water stress			Rainfed areas with high drought frequency AND Irrigated areas with high water stress			Rainfed areas with high drought frequency OR Irrigated areas with high water stress		
	Hectares	Population		Hectares	Population		Hectares	Population		Hectares	Population	
		Rural	Urban		Rural	Urban		Rural	Urban		Rural	Urban
	Thousands			Thousands			Thousands			Thousands		
Turkey	0	0	0	866	496	2 253	3 086	2 889	4 926	10 834	10 780	16 644
United Arab Emirates	0	0	0	269	1 177	3 761	0	0	0	0	0	0
Yemen	20	86	364	381	7 632	10 428	0	0	0	8	57	48
EUROPE	0	0	0	889	5 354	3 129	140	214	22	18 060	47 789	45 001
Eastern Europe	0	0	0	711	170	70	7	0	0	12 789	4 649	4 496
Bulgaria	0	0	0	0	0	0	0	0	0	51	52	38
Poland	0	0	0	0	0	0	0	0	0	33	46	0
Romania	0	0	0	0	0	0	0	0	0	857	1 696	2 075
Russian Federation	0	0	0	605	77	0	7	0	0	11 845	2 854	2 383
Ukraine	0	0	0	106	92	70	0	0	0	2	0	0
Northern Europe	0	0	0	3	15	0	0	0	0	148	245	794
Denmark	0	0	0	2	12	0	0	0	0	125	185	53
Ireland	0	0	0	0	2	0	0	0	0	0	0	0
Lithuania	0	0	0	0	0	0	0	0	0	3	0	0
Sweden	0	0	0	0	0	0	0	0	0	17	42	112
United Kingdom of Great Britain and Northern Ireland	0	0	0	0	0	0	0	0	0	4	18	629
Southern Europe	0	0	0	79	195	119	133	214	22	3 948	18 326	14 472
Albania	0	0	0	4	2	0	0	0	0	72	367	564
Bosnia and Herzegovina	0	0	0	0	0	0	0	0	0	0	2	0
Croatia	0	0	0	2	1	0	0	0	0	5	17	0
Greece	0	0	0	1	0	0	0	0	0	173	265	172
Italy	0	0	0	14	41	100	25	62	22	1 239	9 841	4 918
Malta	0	0	0	0	0	0	0	0	0	1	17	0
Montenegro	0	0	0	4	32	0	0	0	0	1	4	0
North Macedonia	0	0	0	0	0	0	0	0	0	13	48	76
Portugal	0	0	0	11	65	0	0	0	0	144	735	193
Madeira Islands	0	0	0	0	0	0	0	0	0	3	79	20
San Marino	0	0	0	0	0	0	0	0	0	0	21	0
Serbia	0	0	0	0	0	0	0	0	0	0	0	0
Spain	0	0	0	43	53	19	108	152	0	2 297	6 929	8 530
Western Europe	0	0	0	96	4 975	2 940	0	0	0	1 175	24 569	25 240
Austria	0	0	0	0	0	0	0	0	0	29	163	809
Belgium	0	0	0	32	2 912	1 239	0	0	0	8	396	44
France	0	0	0	36	1 566	1 402	0	0	0	563	8 374	9 767
Germany	0	0	0	0	0	0	0	0	0	136	8 171	6 131
Luxembourg	0	0	0	0	0	0	0	0	0	0	124	21
Netherlands	0	0	0	29	498	299	0	0	0	408	6 844	8 106

TABLE A1
(CONTINUED)

COUNTRY/ TERRITORY	Rainfed areas with very high drought frequency AND Irrigated areas with very high water stress			Rainfed areas with very high drought frequency OR Irrigated areas with very high water stress			Rainfed areas with high drought frequency AND Irrigated areas with high water stress			Rainfed areas with high drought frequency OR Irrigated areas with high water stress		
	Hectares	Population		Hectares	Population		Hectares	Population		Hectares	Population	
		Rural	Urban		Rural	Urban		Rural	Urban		Rural	Urban
	Thousands			Thousands			Thousands			Thousands		
Netherlands Antilles	0	0	0	0	0	0	0	0	0	17	41	64
Switzerland	0	0	0	0	0	0	0	0	0	13	457	299
OCEANIA	0	0	0	127 239	571	290	0	0	0	91 133	621	497
Australia and New Zealand	0	0	0	127 116	532	132	0	0	0	90 851	547	463
Australia	0	0	0	127 057	489	131	0	0	0	90 851	547	463
New Zealand	0	0	0	58	43	0	0	0	0	0	0	0
Melanesia	0	0	0	123	38	159	0	0	0	282	74	34
Fiji	0	0	0	2	1	0	0	0	0	61	35	0
New Caledonia	0	0	0	2	1	0	0	0	0	54	10	0
Papua New Guinea	0	0	0	113	25	159	0	0	0	153	28	34
Solomon Islands	0	0	0	2	7	0	0	0	0	0	0	0
Vanuatu	0	0	0	5	5	0	0	0	0	14	0	0

NOTE: For statistical purposes, the data for China do not include those for China, Hong Kong SAR and Taiwan Province of China. The data for Portugal and Netherlands do not include those for Madeira Islands and Netherlands Antilles, respectively.

TABLE A2
HECTARES AND SHARE OF LAND BY PRODUCTION SYSTEM WITH WATER SHORTAGES AND SCARCITY, BY COUNTRY OR TERRITORY

COUNTRY/ TERRITORY	Irrigated cropland with high or very high water stress		Low-input rainfed cropland with high or very high drought frequency		High-input rainfed cropland with high or very high drought frequency		Pastureland with high or very high drought frequency		Share of land for which no data were available			
	Hectares	Share of irrigated cropland	Hectares	Share of low-input rainfed	Hectares	Share of high-input rainfed	Hectares	Share of pasture-land	Irrigated cropland	Low-input rainfed cropland	High-input rainfed cropland	Pasture-land
	Thousands	Percentage	Thousands	Percentage	Thousands	Percentage	Thousands	Percentage	Percentage			
WORLD	170 887	62.0	77 093	14.0	50 708	8.0	655 502	14.2	0.1	5.3	1.7	27.8
AFRICA	9 560	72.2	12 632	7.5	4 351	12.9	246 735	22.0	0.0	10.2	6.6	28.4
Northern Africa	8 068	99.6	2 214	17.2	1 883	24.5	16 072	19.1	0.0	3.1	0.7	39.2
Algeria	565	99.9	442	14.6	18	9.9	4 018	28.7	0.1	1.8	1.2	45.1
Egypt	3 376	100.0	2	45.2	0	0.0	0	0.0	0.0	0.0	0.0	99.8
Libya	462	99.9	36	13.9	29	17.3	767	19.4	0.1	0.0	0.0	71.2
Morocco	1 459	99.9	949	31.4	1 158	30.0	1 810	16.9	0.1	1.1	0.5	42.0
Sudan	1 826	98.2	609	10.3	455	17.3	8 791	17.2	0.0	4.9	1.0	31.8
Tunisia	379	99.9	175	27.6	222	25.8	686	17.2	0.1	3.3	0.4	70.8
Western Sahara	–	–	–	–	–	–	0	0.0	–	–	–	100.0
Sub-Saharan Africa	1 493	29.0	10 418	6.7	2 468	9.5	230 663	22.2	0.0	10.8	8.3	27.5
Eastern Africa	219	9.1	5 261	11.1	1 256	13.4	93 522	21.9	0.0	18.9	16.1	35.2
Burundi	3	15.1	4	0.4	1	0.5	3	0.3	0.0	0.5	0.5	5.5
Comoros	0	0.0	–	–	–	–	0	0.0	13.5	–	–	32.1
Djibouti	0	0.0	–	–	–	–	78	27.0	0.0	–	–	73.0
Eritrea	6	29.9	168	28.6	19	17.6	1 269	29.8	0.0	5.7	7.3	35.9
Ethiopia	88	30.0	1 818	18.0	552	19.3	31 771	40.4	0.0	11.9	7.7	38.5
Kenya	14	14.1	916	37.4	183	28.6	34 134	73.4	0.0	7.2	5.6	18.4
Madagascar	0	0.0	58	3.0	7	2.0	2 637	6.5	0.0	14.3	5.3	0.7
Malawi	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.8	0.4	56.8
Mayotte	–	–	–	–	–	–	0	0.0	–	–	–	100.0
Mozambique	74	62.5	49	1.4	41	3.8	42	0.1	0.0	39.8	58.7	64.3
Rwanda	8	97.2	206	22.9	52	22.8	53	7.6	0.0	7.0	7.7	23.6
Somalia	0	0.0	160	27.8	4	32.0	16 599	40.8	0.1	71.9	60.0	53.4
South Sudan	8	100.0	251	8.7	107	38.1	1 147	2.3	0.0	65.4	41.4	18.9
Uganda	9	99.9	555	8.4	37	7.9	381	4.4	0.0	13.6	14.8	30.1
United Republic of Tanzania	1	0.5	800	12.3	247	15.5	5 282	10.6	0.0	10.7	10.5	39.2
Zambia	0	0.0	12	0.3	1	0.1	0	0.0	0.0	35.9	23.8	25.6
Zimbabwe	8	4.7	264	6.1	4	1.7	126	0.6	0.0	12.7	7.2	75.7
Middle Africa	0	0.1	197	0.8	11	0.3	11 820	5.1	0.0	18.0	8.1	32.1
Angola	0	0.0	0	0.0	0	0.0	3 778	6.4	0.0	8.8	5.3	10.5
Cameroon	0	0.0	0	0.0	0	0.0	313	2.1	0.0	9.0	1.2	10.2
Central African Republic	0	0.0	0	0.0	0	0.0	0	0.0	0.0	38.4	46.7	12.1
Chad	0	0.5	110	1.6	7	1.1	7 481	17.1	0.0	4.0	2.7	4.4
Congo	0	0.0	1	0.2	0	0.4	0	0.0	0.0	21.2	17.8	19.7
Democratic Republic of the Congo	0	0.0	37	0.3	1	0.1	3	0.0	0.0	30.3	17.9	91.4
Equatorial Guinea	–	–	32	19.4	1	8.6	132	21.8	–	0.2	0.1	10.0

TABLE A2
(CONTINUED)

COUNTRY/ TERRITORY	Irrigated cropland with high or very high water stress		Low-input rainfed cropland with high or very high drought frequency		High-input rainfed cropland with high or very high drought frequency		Pastureland with high or very high drought frequency		Share of land for which no data were available			
	Hectares	Share of irrigated cropland	Hectares	Share of low-input rainfed	Hectares	Share of high-input rainfed	Hectares	Share of pasture-land	Irrigated cropland	Low-input rainfed cropland	High-input rainfed cropland	Pasture-land
	Thousands	Percentage	Thousands	Percentage	Thousands	Percentage	Thousands	Percentage	Percentage			
Gabon	0	0.0	11	3.4	3	4.1	106	2.7	0.0	37.2	22.3	20.9
Sao Tome and Principe	0	0.0	5	70.7	0	68.4	7	29.3	0.0	0.0	0.0	6.2
Southern Africa	1 260	81.0	1 770	16.2	735	17.3	93 002	52.5	0.0	15.0	5.7	25.3
Botswana	4	94.3	31	14.3	1	12.8	48 187	95.7	0.0	80.7	71.3	0.4
Eswatini	49	100.0	3	2.3	1	3.2	0	0.0	0.0	8.9	8.9	40.6
Lesotho	0	0.0	19	6.6	2	10.5	0	0.0	0.0	19.6	14.0	14.0
Namibia	0	0.0	40	6.4	1	7.5	37 427	80.1	0.0	77.3	54.6	3.0
South Africa	1 207	81.0	1 676	17.4	730	17.4	7 388	9.7	0.0	9.4	5.4	55.5
Western Africa	13	1.3	3 190	4.5	466	5.1	32 318	16.0	0.0	2.2	1.5	8.1
Benin	0	0.0	12	0.5	3	0.4	49	0.9	0.0	0.9	0.6	16.7
Burkina Faso	0	0.0	304	9.0	109	9.5	1 181	6.0	0.0	0.5	0.3	0.2
Côte d'Ivoire	0	0.0	189	2.6	46	3.7	34	0.3	0.0	8.8	3.1	8.6
Gambia	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.3	0.2	0.1
Ghana	0	0.0	75	1.8	50	3.1	156	1.5	0.0	1.7	0.5	13.4
Guinea	0	0.0	1	0.0	0	0.0	0	0.0	0.1	3.2	2.2	3.5
Guinea-Bissau	0	0.0	6	1.9	2	1.3	0	0.0	1.0	0.8	0.6	14.9
Liberia	0	0.0	29	5.8	3	5.3	216	4.7	0.0	14.3	8.5	6.1
Mali	1	0.3	691	11.4	70	6.0	8 505	22.8	0.0	3.2	2.5	3.5
Mauritania	12	24.4	88	24.3	2	32.1	9 628	74.6	0.0	31.2	13.0	4.4
Niger	0	0.0	33	1.4	7	1.1	7 684	25.6	0.0	2.0	2.9	3.7
Nigeria	0	0.0	1 063	3.2	32	3.3	1 990	5.1	0.0	0.2	0.1	14.6
Senegal	1	0.6	690	16.0	140	17.9	2 788	24.8	0.0	4.5	3.0	24.9
Sierra Leone	0	0.0	9	0.5	1	0.8	85	4.0	0.0	3.4	1.5	5.1
Togo	0	0.0	0	0.0	0	0.0	2	0.1	0.0	0.0	0.0	22.2
AMERICA	14 229	29.6	4 162	4.4	19 483	8.7	114 389	8.0	0.2	1.9	1.1	26.1
Latin America and the Caribbean	6 964	35.9	4 162	4.4	2 018	4.8	74 579	9.8	0.3	1.9	1.3	17.2
Caribbean	0	0.0	65	1.6	11	0.7	492	6.9	0.3	4.4	2.1	18.1
Anguilla	–	–	–	–	–	–	0	0.0	–	–	–	0.0
Antigua and Barbuda	0	0.0	0	1.5	0	1.1	0	0.0	1.9	0.0	0.0	0.0
Aruba	–	–	–	–	–	–	2	100.0	–	–	–	0.0
Bahamas	–	–	0	0.0	0	0.0	274	95.2		100.0	100.0	4.8
Barbados	0	0.0	–	–	–	–	0	0.0	0.7	–	–	100.0
British Virgin Islands	0	0.0	0	0.0	–	–	0	80.3	100.0	100.0	–	19.7
Cuba	0	0.0	11	0.5	4	0.5	78	2.2	0.4	1.2	0.4	28.4
Dominica	–	–	0	0.0	0	0.0	0	0.0	–	4.2	6.0	100.0
Dominican Republic	0	0.0	2	0.2	1	0.2	20	1.3	0.0	8.8	5.8	6.2
Grenada	0	0.0	–	–	–	–	0	0.0	21.5	–	–	100.0
Guadeloupe	0	0.0	0	0.0	0	0.0	1	7.6	2.7	0.4	0.0	0.0

TABLE A2
(CONTINUED)

COUNTRY/ TERRITORY	Irrigated cropland with high or very high water stress		Low-input rainfed cropland with high or very high drought frequency		High-input rainfed cropland with high or very high drought frequency		Pastureland with high or very high drought frequency		Share of land for which no data were available			
	Hectares	Share of irrigated cropland	Hectares	Share of low-input rainfed	Hectares	Share of high-input rainfed	Hectares	Share of pasture-land	Irrigated cropland	Low-input rainfed cropland	High-input rainfed cropland	Pasture-land
	Thousands	Percentage	Thousands	Percentage	Thousands	Percentage	Thousands	Percentage	Percentage			
Haiti	0	0.0	6	1.1	5	1.2	81	7.5	0.7	1.5	0.8	2.9
Jamaica	0	0.0	29	12.4	1	11.6	9	2.8	0.0	20.3	14.3	24.1
Martinique	0	0.0	0	0.0	0	0.0	0	0.0	28.9	13.7	0.0	0.0
Montserrat	–	–	0	0.0	0	0.0	0	0.0	–	100.0	100.0	100.0
Puerto Rico	0	0.0	9	9.6	0	10.1	9	3.6	0.2	9.9	1.7	5.9
Saint Kitts and Nevis	0	0.0	0	0.0	0	0.0	3	82.5	7.7	13.6	6.4	16.2
Saint Lucia	0	0.0	0	0.0	0	0.0	0	0.0	4.5	0.0	0.0	45.9
Saint Vincent and the Grenadines	–	–	–	–	–	–	0	0.0	–	–	–	100.0
Trinidad and Tobago	0	0.0	8	9.0	0	2.7	15	17.8	1.1	7.8	9.2	4.4
Turks and Caicos Islands	–	–	–	–	–	–	0	0.0	–	–	–	26.2
United States Virgin Islands	0	0.0	–	–	–	–	1	18.6	13.6	–	–	0.0
Central America	4 780	70.2	98	0.8	135	0.9	9 798	9.9	0.0	3.1	1.7	50.1
Belize	0	0.0	0	0.0	0	0.0	5	0.9	0.0	7.5	1.9	15.4
Costa Rica	0	0.0	4	1.1	6	4.3	79	4.4	0.1	3.9	7.2	13.5
El Salvador	0	0.0	1	0.3	3	0.5	0	0.0	0.0	0.1	0.1	1.1
Guatemala	0	0.0	2	0.6	10	0.7	62	1.4	0.0	2.7	2.6	14.9
Honduras	0	0.0	3	0.4	2	0.2	17	0.5	0.0	1.2	1.2	9.3
Mexico	4 780	75.1	77	0.9	107	1.0	9 596	11.6	0.0	3.1	1.7	57.7
Nicaragua	0	0.0	4	0.5	5	0.4	28	0.7	0.1	0.2	0.0	8.7
Panama	0	0.0	7	1.6	3	0.8	11	0.7	0.0	11.6	8.5	15.1
South America	2 184	19.2	4 000	5.0	1 872	7.3	64 288	9.8	0.4	1.6	0.9	12.2
Argentina	490	27.5	2 256	16.1	1 675	15.5	40 396	22.9	2.0	0.5	0.2	19.4
Bolivia (Plurinational State of)	0	0.0	17	1.0	36	3.2	1 464	3.9	0.0	9.5	2.8	14.0
Brazil	0	0.0	1 477	2.8	89	1.5	14 066	5.2	0.1	1.6	0.3	8.6
Chile	436	23.0	1	0.8	0	0.1	2 157	10.7	0.1	3.5	1.7	15.1
Colombia	0	0.0	36	1.3	16	0.7	1 180	3.0	0.1	3.5	3.7	7.6
Ecuador	72	8.5	49	3.3	7	1.5	493	5.5	0.0	0.1	0.1	7.5
Falkland Islands (Malvinas)	–	–	–	–	–	–	0	0.0	–	–	–	0.4
French Guiana	0	0.0	0	0.0	0	0.0	0	0.0	0.0	28.7	38.7	55.9
Guyana	0	0.0	4	2.2	4	7.5	1	0.1	1.7	0.4	0.3	38.9
Paraguay	0	0.0	50	1.7	25	1.3	2	0.0	0.0	1.1	0.8	15.9
Peru	1 187	70.5	3	0.3	1	0.1	2 212	5.8	0.0	3.1	3.3	13.7
Suriname	0	0.0	0	0.0	0	0.0	0	0.0	0.0	6.0	0.3	44.7
Uruguay	0	0.0	89	7.7	0	0.0	0	0.0	0.0	0.0	0.0	0.1
Venezuela (Bolivarian Republic of)	0	0.0	17	0.9	17	1.6	2 318	6.5	0.1	3.3	2.9	7.0

TABLE A2
(CONTINUED)

COUNTRY/ TERRITORY	Irrigated cropland with high or very high water stress		Low-input rainfed cropland with high or very high drought frequency		High-input rainfed cropland with high or very high drought frequency		Pastureland with high or very high drought frequency		Share of land for which no data were available			
	Hectares	Share of irrigated cropland	Hectares	Share of low-input rainfed	Hectares	Share of high-input rainfed	Hectares	Share of pasture-land	Irrigated cropland	Low-input rainfed cropland	High-input rainfed cropland	Pasture-land
	Thousands	Percentage	Thousands	Percentage	Thousands	Percentage	Thousands	Percentage	Percentage			
Northern America	7 265	25.4	0	99.0	17 465	9.6	39 810	5.9	0.2	0.0	1.0	36.2
Canada	0	0.0			9 069	23.2	1 357	0.4	0.0		0.9	36.0
Greenland	–	–	–	–	–	–	21	0.1	–	–	–	52.3
Saint Pierre et Miquelon	–	–	–	–	–	–	0	0.0	–	–	–	7.7
United States of America	7 265	26.1	0	99.0	8 396	5.9	38 433	12.0	0.2	0.0	1.1	35.6
ASIA	144 002	77.6	54 393	24.3	14 579	10.9	78 214	9.9	0.1	4.1	4.0	28.2
Central Asia	9 214	95.9	11 979	58.0	1 459	37.2	27 502	23.7	0.0	1.0	1.9	14.7
Kazakhstan	1 577	79.9	11 753	58.6	1 036	33.7	21 940	23.8	0.0	1.0	2.2	14.7
Kyrgyzstan	1 064	100.0	32	20.2	39	19.7	255	2.9	0.0	0.7	0.1	1.2
Tajikistan	705	100.0	30	18.7	36	20.9	283	7.3	0.0	2.3	0.9	3.9
Turkmenistan	1 742	100.0	44	82.4	88	80.3	3 259	61.9	0.0	2.6	2.3	25.4
Uzbekistan	4 126	100.0	120	58.2	260	70.0	1 766	30.7	0.0	0.0	0.0	32.9
Eastern Asia	34 989	59.3	2 868	9.4	4 589	7.9	23 240	6.1	0.1	1.1	0.7	17.5
China, Hong Kong SAR	1	89.6	0	0.0	–	–	0	0.0	10.4	0.0	–	0.0
China	32 955	61.7	2 776	9.7	4 457	8.1	20 384	6.2	0.0	0.7	0.5	17.8
Democratic People's Republic of Korea	1 233	93.3	0	0.0	0	0.0	10	0.5	0.5	0.1	0.1	18.7
Japan	0	0.0	23	6.9	57	4.4	132	3.5	0.4	0.6	0.8	59.3
Mongolia	29	49.4	64	19.7	70	17.5	2 694	6.0	0.0	8.5	8.0	11.8
Republic of Korea	771	99.2	0	0.1	2	0.4	19	1.1	0.8	0.2	0.0	0.4
Taiwan Province of China	0	0.0	4	3.4	4	1.7	1	0.4	0.7	69.9	65.3	49.9
South-eastern Asia	5 636	34.5	1 507	4.3	1 464	3.4	1 705	1.5	0.2	7.5	10.9	69.4
Brunei Darussalam	0	0.0	1	5.0	1	9.3	0	0.0	0.0	75.8	66.4	98.1
Cambodia	0	0.0	494	16.5	65	19.0	166	3.8	0.0	1.0	0.2	45.8
Indonesia	3 104	72.0	92	0.7	109	0.7	208	0.5	0.2	7.2	8.1	72.4
Lao People's Democratic Republic	0	0.0	5	1.1	1	1.3	1	0.0	0.0	7.7	2.7	68.4
Malaysia	0	0.0	10	0.7	31	0.6	3	0.1	0.5	35.3	31.3	86.3
Myanmar	0	0.0	354	4.9	162	9.5	662	3.7	0.6	0.7	0.2	45.6
Philippines	0	0.0	30	0.9	48	0.8	98	1.5	0.2	25.1	22.8	87.8
Singapore	–	–	0	0.0	0	8.6	1	16.1	–	0.0	89.4	0.3
Thailand	2 518	50.9	266	4.8	382	4.5	40	0.3	0.0	5.0	2.2	97.6
Timor-Leste	14	98.8	0	0.0	0	0.0	0	0.0	1.2	0.2	0.4	100.0
Viet Nam	0	0.0	256	14.8	666	16.8	527	5.2	0.4	0.5	0.5	47.6
Southern Asia	81 598	94.1	30 822	26.7	4 458	19.4	18 494	16.6	0.0	4.6	0.9	38.7
Afghanistan	3 214	100.0	1 945	42.6	48	34.0	2 168	9.7	0.0	16.4	38.6	24.7
Bangladesh	3 564	96.4	548	20.6	372	17.9	20	2.2	0.2	2.0	0.3	48.3

TABLE A2
(CONTINUED)

COUNTRY/ TERRITORY	Irrigated cropland with high or very high water stress		Low-input rainfed cropland with high or very high drought frequency		High-input rainfed cropland with high or very high drought frequency		Pastureland with high or very high drought frequency		Share of land for which no data were available			
	Hectares	Share of irrigated cropland	Hectares	Share of low-input rainfed	Hectares	Share of high-input rainfed	Hectares	Share of pasture-land	Irrigated cropland	Low-input rainfed cropland	High-input rainfed cropland	Pasture-land
	Thousands	Percentage	Thousands	Percentage	Thousands	Percentage	Thousands	Percentage	Percentage			
Bhutan	35	100.0	0	0.1	0	0.0	8	1.8	0.0	6.3	0.0	12.3
India	51 888	91.2	23 008	25.1	3 917	21.5	8 416	29.2	0.0	0.4	0.2	15.7
Iran (Islamic Republic of)	6 899	99.9	4 112	41.8	83	24.7	7 126	21.3	0.1	17.5	14.4	38.7
Nepal	1 138	100.0	8	1.3	2	0.2	21	0.3	0.0	1.4	4.4	41.8
Pakistan	14 319	100.0	1 196	21.3	1	11.5	637	3.8	0.0	41.2	1.7	90.8
Sri Lanka	541	99.5	5	2.4	35	2.5	99	5.9	0.5	1.4	0.7	84.4
Western Asia	12 566	90.9	7 217	32.7	2 608	40.5	7 272	11.1	0.0	3.9	0.6	27.2
Armenia	286	100.0	13	6.7	3	8.0	16	0.8	0.0	0.2	0.0	0.6
Azerbaijan	1 437	100.0	149	33.6	33	38.6	1 379	28.1	0.0	0.9	5.0	1.5
Bahrain	1	100.0	–	–	–	–	0	0.0	0.0	–	–	100.0
Cyprus	43	99.6	0	0.0	0	0.0	28	6.0	0.4	0.2	0.0	34.6
Georgia	224	74.9	34	6.8	1	0.4	19	0.7	0.0	3.6	1.4	2.0
Iraq	3 526	100.0	372	18.7	4	16.4	18	0.2	0.0	31.6	12.8	77.3
Israel	167	99.9	0	0.6	4	1.6	2	0.6	0.1	0.0	0.1	38.5
Jordan	75	99.9	16	21.5	18	14.0	82	11.8	0.1	7.1	3.3	68.9
Kuwait	6	100.0	–	–	–	–	0	0.0	0.0	–	–	100.0
Lebanon	107	100.0	26	21.3	6	7.7	136	25.3	0.0	0.0	0.0	4.6
Oman	59	98.2	0	0.0	0	0.0	5	1.9	1.8	100.0	100.0	94.4
Palestine	22	100.0	0	0.0	0	0.0	21	7.0	0.0	69.7	2.5	15.4
Qatar	12	100.0	–	–	–	–	0	0.0	0.0	–	–	100.0
Saudi Arabia	1 724	99.9	0	35.7	0	38.9	380	13.1	0.1	64.3	61.1	86.9
Syrian Arab Republic	1 262	100.0	676	58.9	839	68.9	968	25.3	0.0	2.9	0.8	54.3
Turkey	2 956	71.4	5 931	33.8	1 700	38.4	4 198	11.2	0.1	1.0	0.3	13.0
United Arab Emirates	269	99.9	0	0.0	0	0.0	0	0.0	0.1	100.0	100.0	100.0
Yemen	390	100.0	0	18.8	0	0.0	20	3.2	0.0	81.2	100.0	96.5
EUROPE	3 095	11.8	2 372	5.7	9 332	4.2	4 289	0.6	0.1	1.1	0.2	17.3
Eastern Europe	8	0.1	2 112	7.0	7 885	5.2	3 501	0.6	0.0	1.0	0.2	13.9
Belarus	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.0	0.0	4.5
Bulgaria	0	0.0	7	0.3	11	1.2	33	0.9	0.0	0.0	0.0	3.0
Czechia	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.0	0.0	10.9
Hungary	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.0	0.0	4.2
Poland	0	0.0	4	0.1	29	0.3	0	0.0	0.1	0.1	0.1	3.1
Republic of Moldova	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.0	0.0	0.3
Romania	0	0.0	104	7.9	753	11.8	0	0.0	0.0	0.5	0.0	3.0
Russian Federation	8	0.2	1 981	10.9	7 001	7.7	3 467	0.6	0.1	1.6	0.2	14.7
Slovakia	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.0	0.0	14.3
Ukraine	0	0.0	16	0.4	91	0.3	0	0.0	0.0	0.1	0.0	0.3
Northern Europe	0	0.0	28	0.8	109	0.8	13	0.0	0.6	0.3	0.3	51.4
Denmark	0	0.0	22	7.4	91	6.3	13	1.4	0.8	0.4	0.3	56.7

TABLE A2 (CONTINUED)

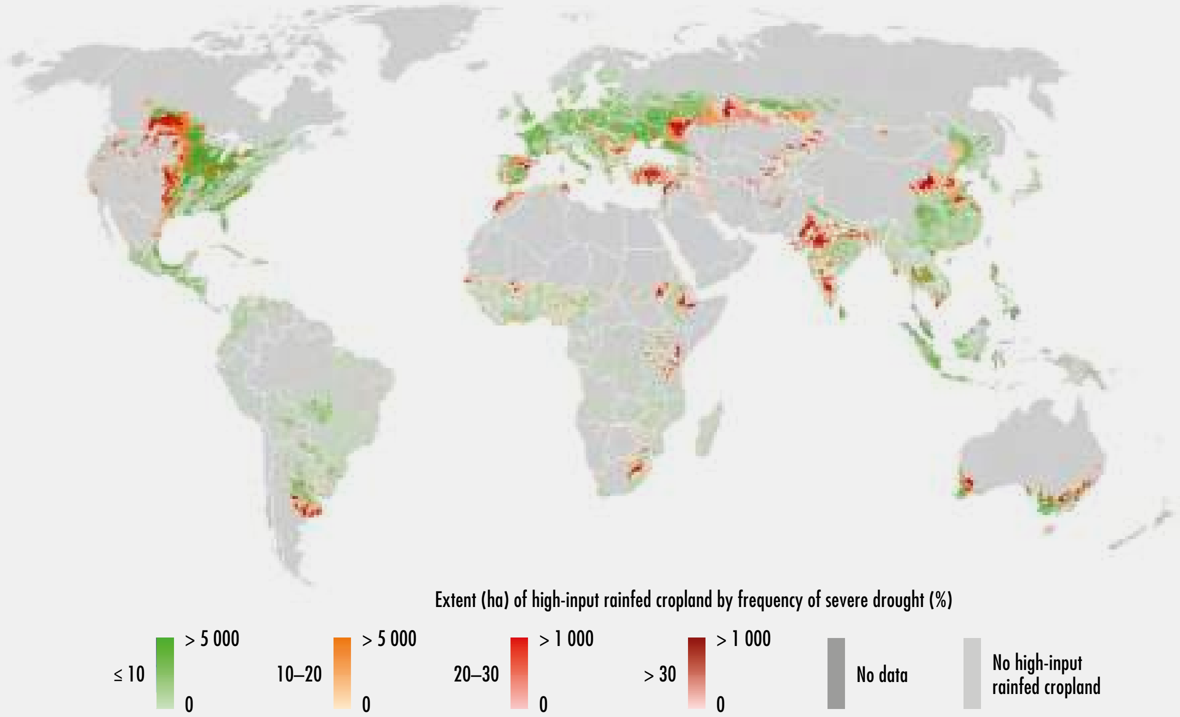
COUNTRY/ TERRITORY	Irrigated cropland with high or very high water stress		Low-input rainfed cropland with high or very high drought frequency		High-input rainfed cropland with high or very high drought frequency		Pastureland with high or very high drought frequency		Share of land for which no data were available			
	Hectares	Share of irrigated cropland	Hectares	Share of low-input rainfed	Hectares	Share of high-input rainfed	Hectares	Share of pasture-land	Irrigated cropland	Low-input rainfed cropland	High-input rainfed cropland	Pasture-land
	Thousands	Percentage	Thousands	Percentage	Thousands	Percentage	Thousands	Percentage	Percentage			
Estonia	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.0	0.0	6.4
Faroe Islands	–	–	–	–	–	–	0	0.0	–	–	–	0.0
Finland	0	0.0	0	0.0	0	0.0	0	0.0	0.3	0.4	0.2	97.3
Iceland	–	–	–	–	–	–	0	0.0	–	–	–	44.8
Ireland	0	0.0	0	0.0	0	0.0	0	0.0	0.5	2.2	1.8	0.5
Isle of Man	–	–	–	–	–	–	0	0.0	–	–	–	0.0
Latvia	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.1	0.0	2.8
Lithuania	0	0.0	0	0.0	3	0.1	0	0.0	0.0	0.0	0.0	5.0
Norway	0	0.0	0	0.0	0	0.0	0	0.0	1.1	0.1	0.3	96.8
Sweden	0	0.0	6	1.0	11	0.6	0	0.0	0.6	0.4	0.1	66.6
United Kingdom of Great Britain and Northern Ireland	0	0.0	0	0.0	4	0.1	0	0.0	0.2	0.6	0.4	0.8
Guernsey	–	–	–	–	–	–	0	0.0	–	–	–	0.0
Jersey	–	–	–	–	–	–	0	0.0	–	–	–	0.0
Southern Europe	2 037	20.2	178	3.1	1 197	4.4	747	2.0	0.2	1.7	0.9	26.0
Albania	0	0.0	40	9.1	7	8.1	29	2.7	0.0	1.3	0.1	3.5
Andorra	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.0	0.0	5.7
Bosnia and Herzegovina	0	0.0	0	5.3	0	0.0	0	0.0	0.0	0.0	0.0	13.4
Croatia	0	0.0	3	1.6	2	0.1	2	0.1	0.3	0.0	0.0	11.4
Greece	0	0.0	10	2.7	78	4.1	87	2.0	0.4	0.4	0.0	0.5
Holy See	0	0.0	–	–	–	–	–	–	0.0	–	–	
Italy	1 197	31.7	13	0.6	25	0.5	42	0.6	0.2	0.1	0.2	21.2
Madeira Islands	3	98.1	–	–	–	–	0	0.7	1.9	–	–	11.9
Malta	0	0.0	1	29.9	0	34.2	0	0.0	0.3	0.0	0.0	66.7
Montenegro	0	0.0	0	1.9	3	0.9	2	0.4	0.0	0.0	2.0	2.7
North Macedonia	0	0.0	1	0.6	2	0.5	10	1.2	0.0	1.3	1.0	1.2
Portugal	0	0.0	24	7.1	55	3.9	76	3.2	0.2	3.1	0.6	59.6
San Marino	0	100.0	0	0.0	0	0.0	0	0.0	0.0	0.0	0.0	86.3
Serbia	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.0	0.2	25.2
Slovenia	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.0	0.0	4.7
Spain	837	23.8	86	4.0	1 024	8.3	500	3.6	0.2	3.5	1.8	39.1
Western Europe	1 050	26.1	53	2.4	141	0.5	27	0.1	0.1	0.9	0.0	6.5
Austria	0	0.0	5	5.9	24	1.9	0	0.0	0.0	1.0	0.2	9.0
Belgium	40	99.9	0	0.0	0	0.0	0	0.0	0.0	0.0	0.0	4.0
France	423	14.7	48	4.3	117	0.8	10	0.1	0.0	0.3	0.1	5.6
Germany	136	26.8	0	0.0	0	0.0	0	0.0	0.0	0.0	0.0	6.1
Liechtenstein	–	–	0	0.0	0	0.0	0	0.0	–	0.0	0.0	0.0
Luxembourg	0	100.0	0	0.0	0	0.0	0	0.0	0.0	0.0	0.0	0.0
Monaco	0	0.0	0	0.0	0	0.0	0	0.0	60.6	0.0	0.0	0.0

TABLE A2
(CONTINUED)

COUNTRY/ TERRITORY	Irrigated cropland with high or very high water stress		Low-input rainfed cropland with high or very high drought frequency		High-input rainfed cropland with high or very high drought frequency		Pastureland with high or very high drought frequency		Share of land for which no data were available			
	Hectares	Share of irrigated cropland	Hectares	Share of low-input rainfed	Hectares	Share of high-input rainfed	Hectares	Share of pasture-land	Irrigated cropland	Low-input rainfed cropland	High-input rainfed cropland	Pasture-land
	Thousands	Percentage	Thousands	Percentage	Thousands	Percentage	Thousands	Percentage	Percentage			
Netherlands	437	97.2	0	0.0	0	0.0	0	0.0	0.5	10.1	0.3	6.1
Netherlands Antilles	–	–	–	–	–	–	17	93.1	–	–	–	6.9
Switzerland	13	32.2	0	0.0	0	0.0	0	0.0	0.0	0.3	0.1	14.4
OCEANIA	0	0.0	3 533	17.2	2 963	12.9	211 876	40.3	0.1	2.4	0.9	45.0
Australia and New Zealand	0	0.0	3 521	17.6	2 960	12.9	211 485	41.4	0.1	1.6	0.6	44.9
Australia	0	0.0	3 519	18.6	2 957	13.6	211 432	42.4	0.0	0.2	0.1	45.5
New Zealand	0	0.0	2	0.2	3	0.3	53	0.4	0.2	25.4	10.3	19.4
Melanesia	0	0.0	12	2.1	3	1.6	391	2.6	0.0	30.1	37.7	50.3
Fiji	0	0.0	0	0.0	0	0.0	63	19.3	0.0	0.0	0.0	36.3
New Caledonia	–	–	2	4.3	0	6.6	53	7.2	–	5.9	2.0	3.8
Papua New Guinea	–	–	5	1.6	3	1.4	259	1.9	–	32.7	38.7	52.2
Solomon Islands	–	–	0	0.8	0	0.4	1	1.7	–	76.9	79.1	36.2
Vanuatu	–	–	5	5.9	0	5.3	14	4.5	–	57.3	58.4	95.5

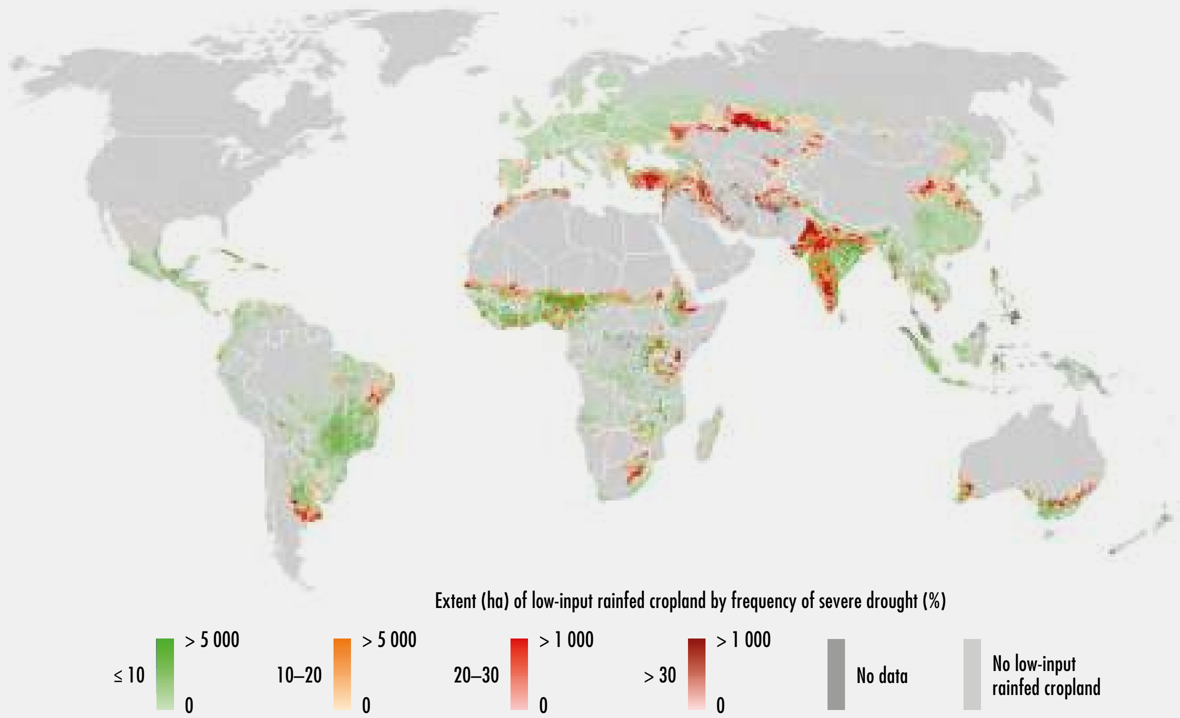
NOTE: For statistical purposes, the data for China do not include those for China, Hong Kong SAR and Taiwan Province of China. The data for Portugal and Netherlands do not include those for Madeira Islands and Netherlands Antilles, respectively.

FIGURE A1
HISTORICAL DROUGHT FREQUENCY ON HIGH-INPUT RAINFED CROPLAND, 1984–2018



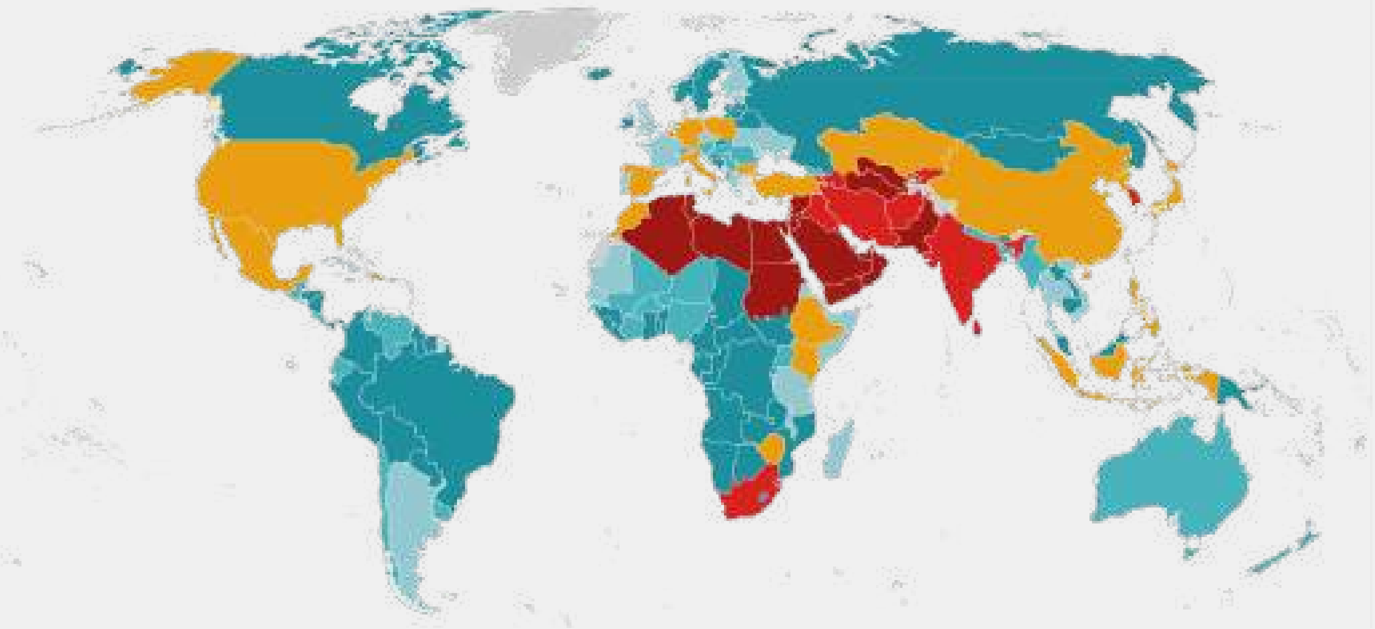
NOTE: For a description of the legend, see the notes of Figure 5, p. 28.
SOURCE: FAO elaboration based on FAO. 2019,[1] FAO & IIASA. 2020,[2] and IFPRI. 2019.[3]

FIGURE A2
HISTORICAL DROUGHT FREQUENCY ON LOW-INPUT RAINFED CROPLAND, 1984–2018



NOTE: For a description of the legend, see the notes of Figure 5, p. 28.
SOURCE: FAO elaboration based on FAO. 2019,[1] FAO & IIASA. 2020,[2] and IFPRI. 2019.[3]

FIGURE A3
SDG INDICATOR 6.4.2 – LEVEL OF WATER STRESS AT COUNTRY LEVEL, 2015

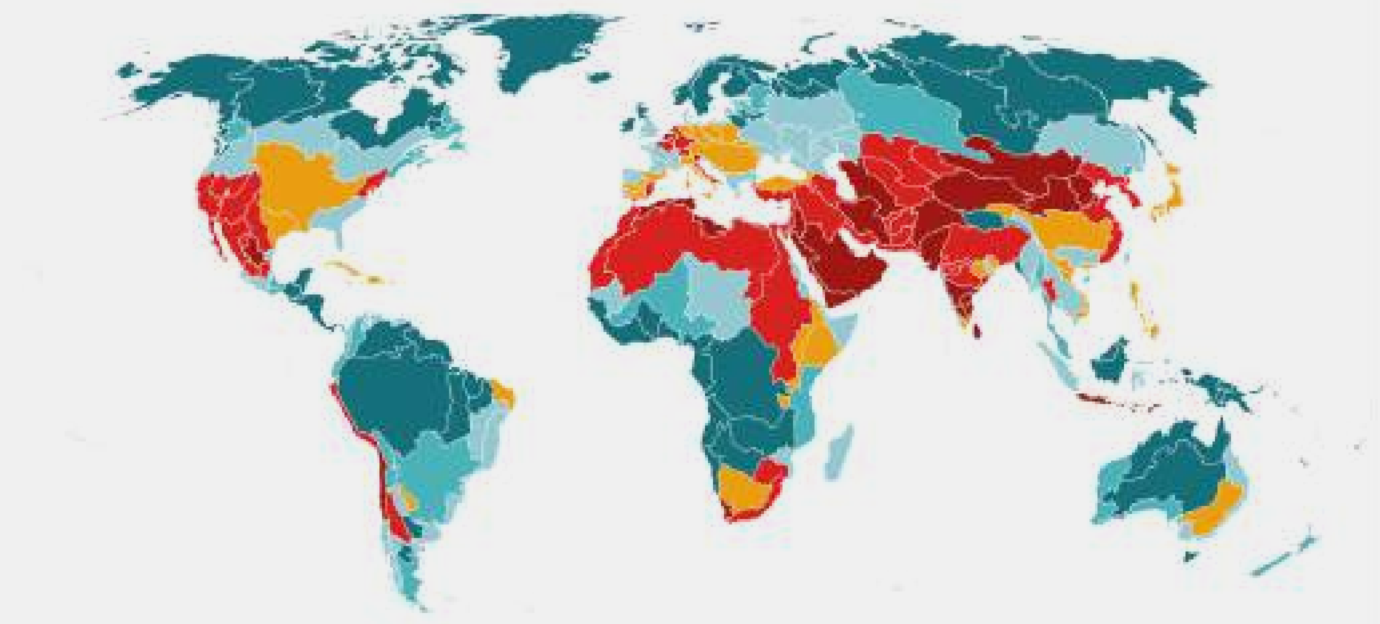


SDG Indicator 6.4.2 level of water stress: freshwater withdrawal as a proportion of available freshwater resources (%)

≤ 5 | 5–10 | 10–25 | 25–50 | 50–100 | > 100 | No data

NOTE: For a description of the legend, see the notes of Figure 7, p. 30.
SOURCE: FAO. 2020.[4]

FIGURE A4
SDG INDICATOR 6.4.2 – LEVEL OF WATER STRESS AT BASIN LEVEL, 2015



SDG Indicator 6.4.2 level of water stress: freshwater withdrawal as a proportion of available freshwater resources (%)

≤ 5 | 5–10 | 10–25 | 25–50 | 50–100 | > 100

NOTE: For a description of the legend, see the notes of Figure 7, p. 30.
SOURCE: FAO. 2020.[4]

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CHAPTER 1

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CHAPTER 2

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CHAPTER 4

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CHAPTER 5

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THE STATE OF THE WORLD

2020 THE STATE OF FOOD AND AGRICULTURE

OVERCOMING WATER CHALLENGES IN AGRICULTURE

Intensifying water constraints threaten food security and nutrition. Thus, urgent action is needed to make water use in agriculture more sustainable and equitable. Irrigated agriculture remains by far the largest user of freshwater, but scarcity of freshwater is a growing problem owing to increasing demand and competition for freshwater resources. At the same time, rainfed agriculture is facing increasing precipitation variability driven by climate change. These trends will exacerbate disputes among water users and inequality in access to water, especially for small-scale farmers, the rural poor and other vulnerable populations.

The State of Food and Agriculture 2020 presents new estimates on the pervasiveness of water scarcity in irrigated agriculture and of water shortages in rainfed agriculture, as well as on the number of people affected. It finds major differences across countries, and also substantial spatial variation within countries. This evidence informs a discussion of how countries may determine appropriate policies and interventions, depending on the nature and magnitude of the problem, but also on other factors such as the type of agricultural production system and countries' level of development and their political structures. Based on this, the publication provides guidance on how countries can prioritize policies and interventions to overcome water constraints in agriculture, while ensuring efficient, sustainable and equitable access to water.

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