Improving agricultural water use efficiency and productivity in the Middle East

Pressures, status, impacts and responses

Blue Peace
IN THE MIDDLE EAST

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ABOUT BLUE PEACE IN THE MIDDLE EAST

The Blue Peace in the Middle East initiative is a structured and dynamic network of prominent institutions from partner countries in the region with the long-term vision of transforming water from a potential source of conflict into a potential instrument of cooperation and peace through concrete actions.

In partnership with Swiss Agency for Development and Cooperation (SDC), SUEN functions as the Coordination Office of the initiative as from January 1st, 2019.

Website: **www.bluepeacemiddleeast.org**

ABOUT TURKISH WATER INSTITUTE (SUEN)

SUEN is a think-tank established to develop water policies, provide consultation to decision makers, coordinate between organizations and institutions and enhance scientific research and strategic ideas with a focus on creating a common platform for water governance.

SUEN works in close cooperation with national and international water-related institutions on issues such as sustainable water management, development of water policies, and capacity building to address local and global water issues.

Website: **www.suen.gov.tr**

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GLOSSARY

Adaptive management: in complex situations there may never be sufficient information to come to an optimum decision. In such situations managers may decide to take a flexible planning approach, backed by strong monitoring and information management systems, that allow constant adaptation and upgrading of plans and activities.

Adequacy: describes the amount of water needed to fill the soil in the crop root zone. This is measured by the ratio of the average depth of water added to the root zone to the average depth required.

Consumptive use: water withdrawn which evaporates or transpires from vegetation and is no longer available for societal/economic use.

Beneficial consumption: water evaporated or transpired for the intended purpose such as transpiration from an irrigated crop.

Non-beneficial consumption: water evaporated or transpired for purposes other than the intended use, such as evaporation from water surfaces, riparian vegetation, waterlogged land.

Closed river basin: a river basin is described as closed when there is no longer enough water to meet both social and environmental needs and demand exceeds supply (see also 'open river basin').

Conveyance efficiency: is the ratio of the volume of water delivered to the farms to the volume diverted from a river or reservoir.

Distribution efficiency: for an irrigation scheme describes water losses in the tertiary (or distribution system) that delivers water from the conveyance network to individual farms/fields. This part of the system is mostly under the control of farmers or WUAs. Distribution efficiency is the ratio of the volume of water delivered to the farm to the volume diverted from the conveyance network.

Deficit irrigation: is an irrigation strategy that is used during drought-sensitive growth stages of a crop. Outside these periods, irrigation may be limited or even unnecessary if rainfall provides a minimum supply of water.

Efficiency: refers to using less resource to produce a product with least waste of time and effort. Insulating buildings improves energy use efficiency and driving fuel-efficient cars consume less fossil fuel. In agriculture efficiency refers to using less water to produce a crop or undertake a production process.

Farm efficiency: is the ratio of the volume of water required by the crop to the volume of water delivered to the farm.

Gross water requirement: is the amount of water diverted to meet crop evapotranspiration including losses from percolation/seepage.

Integrated water resource management (IWRM): the co-ordinated development and management of water, land, and related resources to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.

Farm irrigation efficiency: describes the efficiency of the whole scheme and is the product of the conveyance efficiency, distribution efficiency, and farm irrigation efficiency.

Non-consumptive use: can be recoverable and non-recoverable. Recoverable is water that can be captured and reused, such as flows to drains that return to the river system and percolation from irrigated fields to aquifers; return flows from sewage systems. Non-recoverable is water lost that cannot be used, such as flows to saline groundwater sinks, deep aquifers that are not economically exploitable, or flows to the sea.

Open river basin: a river basin is described as open when there is more than enough water to meet both social and environmental needs and supply exceeds demand.

Return flows: originate as water losses from canals and farms but return to a basin as drainage and seepage. They are either recoverable (e.g. returned to a river or an aquifer) and are available for others to use or non-recoverable (flowing to the sea, polluted, or returned to economically unviable sinks).

Uniformity: water must be evenly spread across the field if crops are to grow and yield uniformly.
For sprinkler irrigation, uniformity is commonly described using the Christiansen Coefficient of Uniformity (CU).
For surface and drip irrigation Distribution Uniformity (DU) is an alternative measure.

Water accounting: is the systematic quantitative assessment of the status and trends in water supply, demand, distribution, accessibility and use in specified domains, producing information that informs water science, management and governance to support sustainable development outcomes for society and the environment.

Water auditing: connects water accounting and water governance. It builds on water accounting to advise water governance. By examining trends in water supply, demand and productivity, water auditing examines features of water governance such as institutions, public and private expenditure, laws and the wider politicaleconomy of water in specified domains.

Water management: concerns the active management of water on a daily, weekly, seasonal, and annual basis using combined operations involving people, infrastructure, finance, and other inputs and resources.

Water productivity: is the ratio of output (physical, economical, or social) to the amount of water depleted in producing the output. It is measured in kg/m^3 or US\$/m^3.

Water governance: is the range of political, social, economic, and administrative systems that are in place to develop and manage water resources and the delivery of water services, at different levels of society. Governance comprises the rules, mechanisms, and processes through which water resources are accessed, used, controlled, transferred, and related conflicts managed.

Water saving: is understood to be genuinely saved water that is made available for use elsewhere in a river basin.

Water scarcity: is excess of water demand over supply and is largely driven by human, economic, and societal factors.

Water shortage: is a natural phenomenon when demand exceeds supply during periods of drought.

Water use: any deliberate application of water to a specified purpose. The term does not distinguish between uses that remove water from further use (evaporation, transpiration, flows to sinks) and uses that have little quantitative impact on water availability (navigation, hydropower, most domestic uses).

Water use efficiency as measured for UN Sustainable Development Goal (SDG) 6: this is indicator 6.4.1 within SDG 6 and is defined as the gross value added per unit of water used, expressed in US\$/m^3. The rationale is to provide information on efficiency of the economic and social use of water resources. It can help to formulate water policy by focusing attention on those sectors or regions with low water-use efficiency in terms of monetary value.

Water use efficiency as measured for a river basin: this is defined as the ratio of the amount of water used in a river basin to the amount of water available in the basin.

Water withdrawals: refers to water diverted from rivers, lakes, and aquifers for societal/economic use.

ABBREVIATIONS

BPME	Blue Peace in the Middle East
DSİ	General Directorate of State Hydraulic Works (Turkey)
ET	Evapotranspiration
FAO	Food and Agriculture Organization
FLW	Food loss and waste
GAP	Southeastern Anatolia Project in Turkey
GDP	Gross Domestic Product
GFS	Granular Filtration System
GWP	Global Water Partnership
ICARDA	International Centre for Agricultural Research in the Dry Lands
ha	Hectare (10 000 m^2)
ICT	Information and Communication Technology
IFA	International Fund for Agricultural Development
IMT	Irrigation Management Transfer
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management
JICA	Japan International Cooperation Agency
l	Litre
NARC	National Agriculture Research Centre (Jordan)
NGO	Non-Governmental Organisation
OECD	Organisation for Economic Cooperation and Development
O&M	Operation and Maintenance
PIM	Participatory Irrigation Management
RAS	Recirculating Aquaponics System
RCP	Representative Concentration Pathways
RS	Remote Sensing
SDC	Swiss Agency for Development and Cooperation
SDG	Sustainable Development Goal
SPI	Standardised Precipitation Index
SUEN	Turkish Water Institute
SWOT	Strengths, Weaknesses, Opportunities, Threats
TAGEM	General Directorate of Agricultural Research and Policies (Turkey)
UNDRR	United Nations Disaster Risk Reduction
UN	United Nations
UNESCO	United Nations Educational Scientific and Cultural Organization
US$	United States Dollars
WA&A	Water Accounting and Auditing
WaPOR	Water Productivity Open-Access Portal
WP	Water Productivity
WSiA	Water Stewardship in Agriculture
WUA	Water User Association
WUE	Water Use Efficiency

EXECUTIVE SUMMARY

This report is prepared under the umbrella of the “Blue Peace Middle East (BPME)" initiative. It focuses on water scarcity, the challenges this brings to irrigated agriculture, and the options available to improve water use efficiency (WUE) and, in turn, increase water productivity and crop production. The countries evaluated in this report include Iran, Iraq, Jordan, Lebanon, Syria and Turkey. Although Iran and Syria are not currently active members of BPME, given their location and relevance to this review, they are included in this study.

Irrigated agriculture plays a vital role in the economies, livelihoods and well-being of people living in the studied countries, but the sector is under severe pressure. More than 75% of available freshwater resources are already withdrawn for agriculture, mostly irrigation, exceeding 90% in some countries. Growing rural and urban populations, economic growth, improvements in lifestyle, and changing diets are driving water demand and have led FAO to predict that if the world continues “business as usual”, the water demand for irrigation could double by 2050. Concerns also come from migration and rural employment, the impacts of climate change on water resources and agriculture, the damage that economic growth can inflict on the aquatic environment, and the challenges of coping with unexpected shocks, such as floods, droughts, and latterly COVID-19.

Water scarcity radically changes everything about how we plan and manage water for irrigation

As water scarcity increases, irrigated agriculture has acquired a reputation for inefficiency. Reports suggest that as much as 50% of water withdrawals never reach the crops and are lost through seepage in canal systems and poor on-farm water management, creating further problems such as water-logging, salinity, and pollution. Thus, agriculture is seen as the main culprit of water scarcity and conversely the sector where efficiency improvements could release water for others to use. However, this is easily said but not easily achieved in practice. Water scarcity radically changes everything about how we plan and manage water for irrigation.

This report describes the significant challenges facing irrigation and the options available to improve performance. It follows a DPSIR approach (Driver-Pressure-State-Impact-Response) that briefly sets out the current state of water resources and agriculture in the region, the trends, drivers and pressures that impact and threaten them and the risks this creates. From this, appropriate responses/actions are recommended.

Getting water for irrigation right will be essential for sustainable and resilient food production. But the challenges are multi-faceted, and there is no simple “one size fits all” solution to the growing water scarcity problem. For this reason, this report offers a range of options available and possible solution pathways to enhance WUE, water productivity, and crop production in irrigated agriculture. Planners and policymakers are encouraged to select and bundle options into programmes and projects best suited to their local and national circumstances, priorities, and capabilities. These will most likely be a mix of technical and institutional options.

Although there are many differences, there are also similarities among the countries studied. Such synergies offer opportunities for collaboration on research, training, and sharing information for the benefit of all.

State of water and agriculture

The state of water and agriculture across the countries studied establishes the serious concerns over water scarcity and its impacts on irrigated agriculture. Countries have much in common, such as increasing populations, reducing water availability per capita, a heavy dependency on freshwater to grow food, feed, and fibre and meet food security targets while recognising the need to sustain the natural aquatic environment on which the sustainability of natural resources depend. All report low levels of water productivity and WUE. However, the differences are striking as countries have adopted strategies that fit their unique natural resource endowments and socio-economic circumstances. Surface irrigation methods, for example, still dominate in countries with large irrigated areas such as Iran, Iraq, Syria, and Turkey. In contrast, hi-tech systems, such as sprinkler and drip irrigation, are more common in Jordan and Lebanon, where irrigated areas are much smaller and water is relatively scarce. It is no coincidence that Jordan and Lebanon quote the highest levels of on-farm WUE efficiency, which encourages others to switch to hi-tech methods. However, caution is needed. If the intention is to save water for others to use, investing in hi-tech systems alone may benefit some farmers but may not produce the desired water savings for others.

Pressures and threats

Globally, the most prominent pressures and threats to irrigated farming come from water scarcity, deteriorating water quality, and salinity which degrades the quality of land and soils. Climate change is now ever-present and is responsible for changing temperatures and rainfall patterns and raising the severity and frequency of droughts.

A SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis involving 156 national irrigation experts and a study of the published and grey literature confirmed that these global issues directly affect irrigation in the Middle East. The top threats identified included increasing salinity, growing populations, water scarcity impacts on food security and rural employment, and the mismatch between administrative and river basin boundaries in the implementation of basin-scale management of water resources. Jordan flagged treated wastewater as a critical alternative water source.

Response options and actions

“Business as usual” will not be an option as global freshwater withdrawals for irrigation, already more than 70%, are predicted to double by 2050, creating unacceptable environmental disasters in many stressed river basins, increasing competition for resources, and causing new social challenges and conflicts over land and water. As the primary water user, it is incumbent on irrigated agriculture to use water resources wisely and reduce these problems.

Although this report initially reviews WUE as the primary metric to assess the state of irrigated agriculture, it also challenges the usefulness of this approach under water scarcity conditions. WUE values of 35% to 50%, reported across the region, suggest that only a small portion of withdrawals are usefully used by crops. This may be valid for individual farms, but so-called “losses” do not just disappear. Instead they return to the river basin and are often used by other farmers downstream.

Thus, WUE of individual farms may be only 50%, but the overall water used by crops in a river basin will be much higher. “Real” water savings are still possible as some losses are recoverable, but the savings are likely to be much less than originally anticipated. Switching to hi-tech solutions may not always produce water savings at scale.

To address water scarcity, this report focuses less on WUE as a metric to measure performance and more on practical and appropriate metrics that account for real water savings, improvements in water productivity (more crop per drop) and production, how water contributes to food security and people's livelihoods and sustains the aquatic environment. New tools such as Water Accounting and Auditing (WA&A) combined with Remote Sensing (RS) are described that enable water resource planners to account for irrigation water use including return flows and real water savings. Systems are being developed to measure crop water use over large areas and enable irrigation managers to allocate and control water for irrigation.

Five main areas for action are recommended that can facilitate a transition towards efficient, reliable, and sustainable water irrigation management.

Action area I: concerns **good water governance** which is underpinned by strong formal and informal institutions and a workforce that is well informed on modern irrigation practices. Without this, technological and management innovations are unlikely to succeed. It requires a robust institutional framework to establish and implement good water policies, laws and regulations, and a strong administration to implement them.

Inclusive governance is also essential in recognising the symbiotic nature of water, land and soils and the need for coherent and integrated policies that enable the many land and water management objectives to be fulfilled. This requires multi-stakeholder engagement at all levels and across disciplines that will be critical to achieving integrated water resource management, a central plank in achieving SDG 6 – the water goal. Introducing Water Stewardship in Agriculture (WSiA) is an integral part of good governance.

Action area II: is about **embracing innovative technologies** and management to address water scarcity and drought. There are myriad options available. These include modernising large-scale irrigation schemes, automating canal systems, transitioning towards participatory irrigation management and transferring responsibilities to Water User Associations (WUAs). New planning, design and evaluation technologies, such as water accounting and auditing, Information and Communication Technology (ICT) and automation, are helping to modernise existing schemes and inform new designs. Many activities beyond the farm also contribute to making wise use of limited water resources, including plant breeding to boost yields and tolerance to drought and salinity, adopting the principles of the circular economy, and reducing food losses and waste to improve resource use efficiency.

Action area III: concerns **implementing integrated solutions** at scale. Integrated approaches to resource use can help define critical resource thresholds and lead to beneficial outcomes when they are brought together in workable packages, including technical, institutional, governance, and financial support.

Action area IV: refers to **investing in long-term sustainability** in the irrigation sector. Irrigation can be costly, but the investment will need to be weighed against the cost of inaction and the impacts on water security, land and soil degradation and food insecurity. Internationally, investment is shifting from infrastructure solutions towards sustaining productivity and improving governance, integrating systems at scale, innovations in technology and management and strengthening the capacities of organisations, including water-user and producer organisations. The private sector should also be encouraged to engage in public-private investment, including farmers as investors rather than as recipients of aid.

Action area V: addresses the overwhelming need to enhance **cooperation across the region**.The Blue Peace Middle East initiative offers an excellent example of a regional platform that enables people from different nations to undertake joint research and training addressing water scarcity and reap the benefits of collaboration that shares problems and solutions. More is needed.

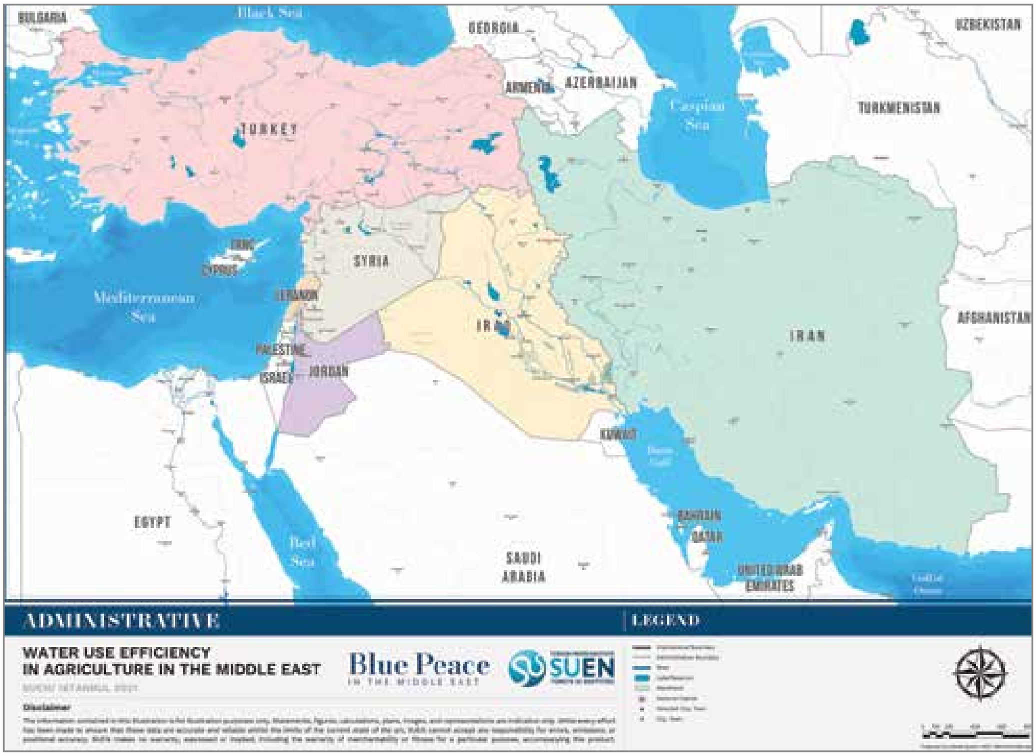
1

Increasing water scarcity

This report is prepared under the umbrella of the “Blue Peace in the Middle East” (BPME) initiative. It focuses on water scarcity, the challenges this brings to irrigated agriculture, and the options available to improve water resource use efficiency and, in turn, increase water productivity and crop production. The countries evaluated in this report include Iran, Iraq, Jordan, Lebanon, and Turkey. Although Iran and Syria are not currently active members of BPME, given their location and relevance to this review, they are included in this study.

Irrigated agriculture plays a vital role in the economies, livelihoods and well-being of people living in the studied countries. More than 75% of the available freshwater resources are already withdrawn for agriculture, and this can exceed 90% in some countries. The water demand is set to increase against a background of growing rural and urban populations, economic growth, improvements in lifestyle, and changing diets that are more water-rich. Concerns also come from migration and rural employment, the impacts of climate change on water resources and agriculture, the potential damage that economic growth can inflict on the aquatic environment, and the challenges of coping with unexpected shocks, such as floods droughts, and latterly COVID-19.

Figure 1.1 Countries evaluated in this study



In the past, when water was plentiful and demands were low, irrigation design and practice have served countries well. Designing and constructing new irrigation systems were done independently, with little thought to the impact on existing and other planned withdrawals in a river basin. Today, circumstances are very different. Countries face severe water scarcity, and planning and implementing water projects in silos is no longer an option. Each country will need to develop an integrated approach in line with the United Nations (UN) Sustainable Development Goal 6 (SDG 6) to establish a means of optimal use of limited water resources among the various users.

As scarcity has increased, irrigated agriculture has acquired an international reputation for inefficiency. Reports suggest that as much as 50% of withdrawals never reach the crops and are lost through seepage in canal systems and poor on-farm water management, creating further problems such as water-logging, salinity, and pollution. The UN review of SDG 6 (the 'water goal') suggests that agriculture, as the primary user of water and potentially wasteful, offers significant water savings. ***"Saving just a fraction can significantly alleviate water stress in other sectors, particularly in arid countries where agriculture consumes a considerable amount of the available water resources"*** (UN, 2018). Thus agriculture is seen not just as the main culprit creating water scarcity but also providing the solutions to sustainable water use.

Getting water for irrigation right will be essential for sustainable and resilient food production. But the challenges facing irrigation are multi-faceted. Resource endowments, environmental and socioeconomic circumstances vary considerably among the countries in this study. As such, there is no simple 'one size fits all' solution to the growing water scarcity problem. For this reason, this report offers a range of options available and possible solution pathways to enhance water resource efficiency, water productivity, and crop production in irrigated agriculture while ensuring sustainable agriculture and food security for all.

Getting water for irrigation right will be essential for sustainable and resilient food production

Planners and policymakers are encouraged to select and bundle options into programmes and projects best suited to their local and national circumstances, priorities, and capabilities. These will most likely be a mix of technical and institutional options. Although there are many differences, there are also similarities among the countries studied. Such synergies offer opportunities for collaboration on research, training, and sharing information for the benefit of all.

This report is structured using the DPSIR approach (Driver-Pressure-State-Impact-Response) that sets out the current state of resources the drivers and pressures that impact and threaten them and the risks this creates. From this, appropriate responses/ actions can be determined and acted upon.

Chapter 2 briefly reviews the state of water resources and irrigated agriculture in each country and compares and contrasts the extent of irrigation to highlight common problems and the potential for shared solutions and collaboration.

Chapter 3 presents the results of a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis based on a survey undertaken among irrigation and water resources professionals in each country to assess the pressures and risks facing irrigated agriculture, and evidence available in the published and grey literature. This on-the-ground survey helps establish what local professionals understand are the priorities in their countries that will inform the responses.

Chapter 4 responds to the findings in chapter 3. First, the chapter describes how irrigation professionals worldwide are responding to water scarcity and are questioning the 'classical' metric of water use efficiency (WUE), developed in the 1970s. They ask if this concept is still fit for purpose in the current conditions of acute water scarcity, and if so, under what circumstances. Some are turning to more practical metrics to evaluate irrigation performance, such as water productivity, crop production, and "real" water savings. Second, the chapter offers a range of innovative, tried and tested technologies and management options that can significantly improve the performance of large irrigation systems and on-farm irrigation practices.

Chapter 5 concludes with policy options based on the issues raised and the opportunities for continuing dialogue and cooperation among the BPME countries.

This report complements a report published by SUEN in 2020, ***"Improving irrigation water use efficiency: A synthesis of options to support capacity development,"*** as part of the the same project. This addressed the need to develop and increase capacity to support irrigation modernisation in the face of growing water scarcity across the Middle East.

2 The state and trends in water and agriculture

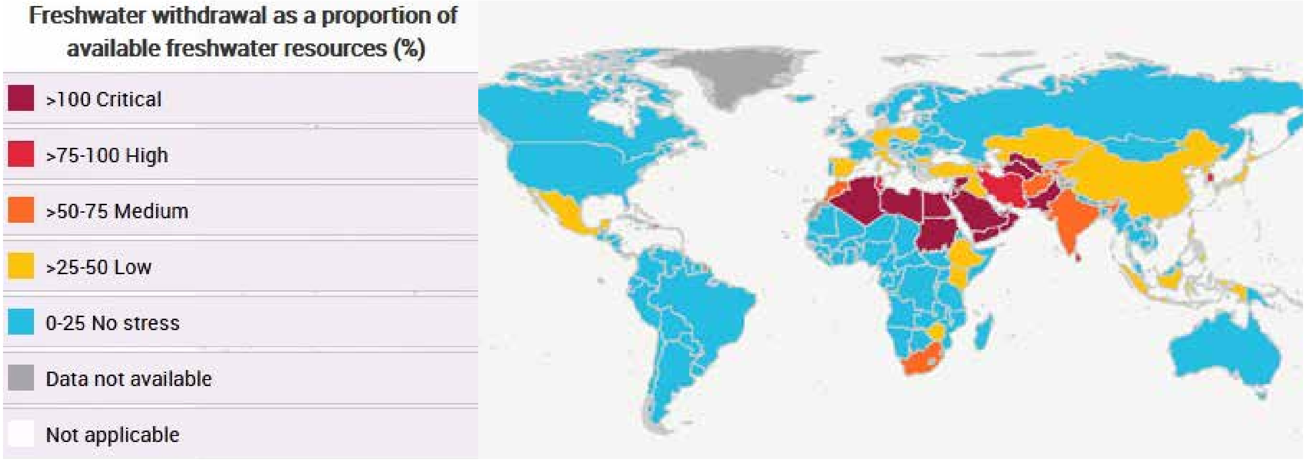
2.1 Introduction

Globally irrigated agriculture accounts for over 70% of freshwater withdrawals. The Middle Eastern countries are mainly arid and semi-arid, agriculture depends largely on irrigation, and average water withdrawals exceed 75%.

In some countries, withdrawals are over 90% (Nazari *et al.*, 2018). Water scarcity is a major concern as the demand for food increases with rapid population growth, inadequate and unreliable rainfall, high evaporation, insufficient water storage, and poor water resources management. Sudden shifts in socio-political structures also threaten food security, resulting in hunger and poverty in extreme cases.

The extent of water scarcity is highlighted by Sustainable Development Goal (SDG) 6, often referred to as the “water goal”. SDG target 6.4.2 measures water stress at a national level as a ratio of freshwater withdrawals including environmental flows, to the available freshwater resources. Values for the countries being studied serve to reinforce the concerns over water scarcity (Figure 2.1).

Figure 2.1 Water stress levels by country



Country	**Iran**	**Iraq**	**Jordan**	**Lebanon**	**Syria**	**Turkey**
Water stress (%)	81.29	47.13	100.08	58.79	124.36	45.38

Source: FAO; UN Water, 2021

The following summarizes critical water resources and irrigation data in each country in this study to compare and contrast the extent of irrigation and highlight common problems and the potential for share solutions.

Most data are from the internationally recognised FAO (Food and Agriculture Organization) AQUASTAT database (FAO AQUASTAT, 2021), but some may be outdated for various reasons. Thus, data published by government and research organisations within countries complement AQUASTAT data. Although this has highlighted some inconsistencies, overall, they provide a helpful picture of water resources, irrigation, and trends.

2.2 Iran

Iran lies in western Asia. The climate is arid and semi-arid, with an average annual rainfall of 252 mm. More than 50% of the population live in the west and north, where 70% of water resources are located. Iran is a water-scarce country and has confronted severe drought as well as aridity in recent years (Hayati and Karami, 2005). Lack of water is a significant limitation for agricultural development as population increases and living standards rise (Riahi, 2002).

Table 2.1 summarises country-level data on cultivated land, water resources, and water use based on FAO AQUASTAT data and in-country sources.

2.2.1 Land, water and agriculture

Iran has a robust agricultural sector, contributing almost 20% of Gross Domestic Product (GDP) in 2020 and employing 23% of the nation’s workforce. Some 18 million ha are devoted to agricultural production. Although 15 million ha is potentially irrigable, only 8.5 million ha are equipped for irrigation, and about 90% of the area is in production (Abbasi *et al.,* 2015).

Iran is among the countries that suffer from water shortages resulting from population growth and climate change. The total annual water withdrawal per capita is 1 630 m^3. According to the SDG Indicator 6.4.2, Iran has a high water stress level of 81.3% (UN Water, 2018) (high-stress category is >75-100%) even though the renewable water resources are relatively high compared to other countries (Nazari *et al.,* 2018) (Moridi, 2017).

The total renewable water resources is estimated at 124 km^3/yr, about 59% from surface runoff 41% from groundwater (Saatsaz, 2020). Iran is divided into six main and 30 sub-basins. About 52% of the total renewable water resources are located in the Central Plateau (Markazi), 25% around the Persian Gulf basin; 10% around the Caspian Sea, 7% in the Hāmūn basin and 3% in each the Urmia Lake and Sarakhs basins.

Wheat and barley are the main crops cultivated. Wheat dominates, accounting for 70% of cereal production. Irrigated wheat only accounts for one-third of the total wheat area; thus, the bulk of the wheat crop depends on seasonal rainfall. Most of the rainfed wheat crop is in the northwest of the country. Small amounts of rice and maize are also grown.

Table 2.1 Iran: Land and water data from FAO AQUASTAT and in-country sources

	FAO AQUASTAT		**In-country sources**	
Areas	**Data**	**Year**	**Data**	**Source**
Country area (1 000 ha)	174 515			
Cultivated area (1 000 ha)	16 477		18 000	(Abbasi et *al.*,2015)
Area equipped for irrigation (1 000 ha)	8 700	2009	8 500	(Abbasi et *al.*,2015)
Surface irrigation (1 000 ha)	7 432			
Sprinkler irrigation (1 000 ha)	280			
Drip irrigation (1 000 ha)	420			
Actual area irrigated (1 000 ha)	6 423	2006	7 560	(Abbasi et *al.*,2015)
As % of cultivated area	52%			
Population (1 000)	79 109	2015	84 000	(Keshavarz *et al.*, 2005) (Anonymous, 2021)
Water resources				
Total renewable water resources (km^3/yr)	137		124	(Saatsaz, 2020)
Total renewable per capita (m^3/yr)	1 732	2014	1 630	(Keshavarz *et al.*, 2005) (Anonymous, 2021)
Water withdrawals				
Agriculture (km^3/yr)	86	2004	85	(Keshavarz et *al.*, 2005) (Anonymous, 2021)
Municipal (km^3/yr)	6.2	2004		
Industry (km^3/yr)	1.1	2004		
Total water withdrawal per capita (m^3)	1 301	2004	1 630	(Nazari *et al.*, 2018) (Moridi, 2017)
Surface water (km^3/yr)	39.85	2004		
Groundwater (km^3/yr)	53.1	2004		
Environmental flows (km^3/yr)	22.7	(FAO; UN Water, 2021)		
Water stress (SDG Indicator 6.4.2)	81.3%	(FAO; UN Water, 2021)		

Agriculture is the most significant freshwater user accounting for over 90% of all withdrawals, though water productivity and water use efficiency are reported as low (Anonymous, 2021). Domestic withdrawals account for 7% and industry 2% (Nazari *et al.,* 2018) (Figure 2.2a).

Agriculture exploits surface and groundwater resources, with groundwater accounting for 58% of withdrawals for irrigation. Iran is among the world's top groundwater users (Nazari *et al.,* 2018). The private sector is involved in drilling groundwater wells for irrigation. Surface water accounts for 35% and 7% from recycled wastewater (Figure 2.2b).

Traditional surface irrigation practices, for example, are generally used in the Lake Urmia Basin, one of Iran's most important water resources. However, declining flows into the lake since the 1990s have led farmers to withdraw water from rivers and wells (Faramarzi, 2012).

Although the area under sprinkler irrigation has grown to 15% of the irrigated area in recent years, surface irrigation still dominates irrigated agriculture accounting for 71% of the irrigated area, and drip 14% (Abbasi *et al.,* 2017) (Figure 2.2c).

Water productivity and efficiency

Keshavarz compared water use for different crops grown in Iran with world average water use (Table 2.2) (Keshavarz *et al.,* 2005) to illustrate the excessive water use for crop production.

The Karkheh River Basin is also an important area for irrigated farming. Production, water productivity, and economic value are illustrated in Table 2.3 (Qureshi *et al.,* 2010). Rainfed productivity ranged from 0.3-0.5 kg/m^3 for wheat, 0.3 to 0.6 kg/m^3 for barley, and 0.1 to 0.3 kg/m^3 for chickpea. A single irrigation application at sowing or springtime improved water productivity of wheat from 0.4 to 0.48 kg/m^3 and barley from 0.45 to 0.8 kg/m^3 (Tavakoli *et al.,* 2007).

Although Iran's food security is highly dependent on irrigated agriculture because of the arid and semi-arid climatic conditions, reports suggest that WUE is low at 35%, and gross water use is high at 10 400 m^3/ha (Faramarzi, 2012).

Table 2.2 Water use in the world and Iran for some crops (m^3/ha)

Crops	World average	In Iran
Wheat	4 500-6 500	6 400
Melon	7 000-10 500	17 900
Sugarbeet	5 500-7 500	10 000-18 000
Rice	4 500-7 000	10 000-18 000
Sugarcane	15 000-25 000	20 000-30 000
Corn	5 000-8 000	10 000-13 000

Source: Keshavarz *et al.,* 2005

In Bushehr Province, water productivity was measured for a range of crops and demonstrated that localised irrigation raised productivity more than 4-fold: wheat 0.21 to 0.45 kg/m^3, tomatoes 2.88 to 12.77 kg/m^3, tobacco 0.18 to 0.19 kg/m^3, watermelon 2.67 to 7.73 kg/m^3, lemon 1.40 to 1.97 kg/m^3 and palm 0.48 to 1.7 kg/m^3 (Nazari and Liaghat, 2016).

Experimental studies using hi-tech[1] irrigation suggested 29% water saving for alfalfa, 35% for forage corn, and 6% for rapeseed.

Table 2.3 Water and economic productivity for irrigated areas of the Karkheh River Basin in Iran

Parameter	Basin average	
	Wheat	Maize
Yields (kg/ha)	3 547	6 675
Applied water (m^3/ha)	5 379	8 490
Water productivity (kg/m^3)	0.66	0.79
Water productivity gross value of product (US$/m^3)	0.15	0.13

Source: Qureshi *et al.,* 2010

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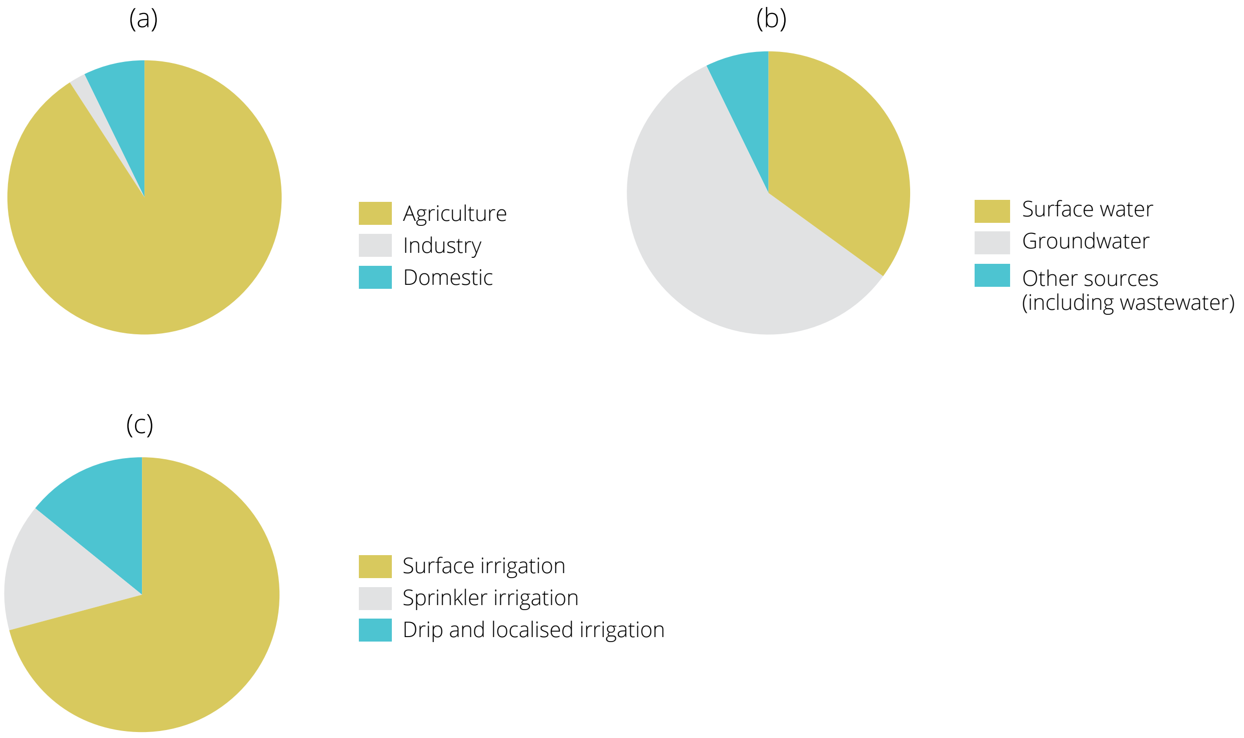
[1] Hi-tech refers to any technical intervention designed to improve water delivery to farmers, examples include sprinkler and drip irrigation

Figure 2.2 Iran: (a) sectoral water distribution (b) water sources used for irrigation (c) irrigation systems (%)



Sources: Nazari *et al.*, 2018; Abbasi *et al.*, 2017

Based on these results, 1.0 m^3 of irrigation water increased the economic productivity of water by 37% for alfalfa, 200% for corn, and 250% for rapeseed (Zamani *et al.*, 2021). These results demonstrated the potential for irrigation to increase production and water productivity.

Irrigation management

The government is primarily responsible for planning and managing water resources and allocation. The Ministry of Energy is responsible for allocating and issuing domestic, agricultural, and industrial permits. The Water Affairs Department is in charge of planning, developing, and managing water resources within the Ministry of Energy, including conservation. The Ministry of Agriculture is responsible for irrigation systems, including secondary and tertiary canal systems, on-farm development and irrigation methods, and agricultural drainage. The Ministry also has responsibility for distributing water to farmers and collecting water fees. In 1943, the government established an independent irrigation institute at Karaj to develop and supervise all irrigation projects in the country.

2.2.2 Drought issues

Iran has a history of drought, which was particularly severe over the past 30 years (FAO, 2018b). The droughts of 1998–2001 and 2003–2011 affected many farm families and rural communities across central, eastern, and southern Iran. For some, drought is a recurring phenomenon, and it is considered a normal part of the environment.

The drought of 1998-2001 affected 37 million people in 12 out of 30 provinces and caused severe water and food shortages. Between 1988 and 2006, more than 60% of the country at some time experienced drought.

2.3 Iraq

Iraq's climate is mainly semi-arid, but the north and northeastern mountainous regions experience a Mediterranean climate. Rainfall is seasonal and occurs in the winter from December to February, except in the north and northeast, where the rainy season is from November to April. The average annual rainfall is estimated at 216 mm but ranges from 1 200 mm in the northeast to less than 100 mm over 60% of the country in the south (Jaradat, 2020; Al-Ansari *et al.,* 2021).

Table 2.4 summarises country-level data on cultivated land, water resources, and water use available from FAO AQUASTAT and in-country sources.

Table 2.4 Iraq: Land and water data from FAO AQUASTAT and in-country sources

	FAO AQUASTAT		**In-country sources**	
Areas	**Data**	**Year**	**Data**	**Source**
Country area (1 000 ha)	43 505			
Cultivated area (1 000 ha)	5 300	2018	5 900	(JICA, 2016)
Area equipped for irrigation (1 000 ha)	3 525	1990		
Surface irrigation (1 000 ha)	n/a		90%	(UN, 2013)
Sprinkler irrigation (1 000 ha)	n/a			
Drip irrigation (1 000 ha)	n/a			
Actual area irrigated (1 000 ha)	1 935	1990	1 600	(JICA, 2016)
As % of cultivated area	63.5%			
Population (1 000)	36 423	2015		
Water resources				
Total renewable water resources (km^3/yr)	89.86			
Total renewable per capita (m^3/yr)	2 467	2014		
Water withdrawals				
Agriculture (km^3/yr)	52	2000		
Municipal (km^3/yr)	4.3	2000		
Industry (km^3/yr)	9.7	2000		
Total water withdrawal per capita (m^3)	2 646	2000	2 250	(Jaradat, 2002)
Surface water (km^3/yr)	n/a			
Groundwater (km^3/yr)	n/a			
Environmental flows (km^3/yr)	18.66	(FAO; UN-Water, 2021)		
Water stress (SDG Indicator 6.4.2)	47.13%	(FAO; UN-Water, 2021)		

2.3.1 Land, water and agriculture

Agriculture contributes 4% of GDP to the country's economy. The total cultivated area is about 5.9 million. Irrigation dominates agricultural production and food security, with 3.5 million ha equipped for irrigation, though this estimate dates back to 1990. Current estimates suggest that only 1.6 million ha is currently irrigated (JICA, 2016) (FAO, 2018c), largely the result of damage and lack of maintenance of irrigation infrastructure during the country's political turmoil. Rainfed cropping is practised on some 2.4 million ha, mainly in the north of the country, though rainfall can be sparse and unreliable, so cropping is mostly confined to the winter months (Al-Ansari *et al.*, 2021).

Although Iraq suffers from water shortages resulting from population growth and climate change, the total annual water withdrawal per capita is 2 250 m^3, which is higher than most other countries in the region. However, the country faces severe water problems. The main reasons for this are topographic, geographical, and management factors (Jaradat, 2002).

According to the SDG Indicator 6.4.2, Iraq has a medium stress level of 47.3% (UN Water, 2018) (medium stress category is >50-75%).

Most of Iraq's water comes from the Euphrates and Tigris rivers, flowing from catchments in Turkey and Iran through Syria and into Iraq. Some 50% of the Tigris river flow originates within the national borders, but 90% of the Euphrates flow comes from outside (FAO, 2003a). Within Iraq, water resources are divided among five main basins; Euphrates, Tigris, Greater Zab, Lesser Zab and Diyala. Although each basin is managed independently, the Greater Zab, Lesser Zab and Diyala rivers are tributaries of the Tigris river, which joins the Euphrates river in southern Iraq to form the Shatt-al Arab river. About 83% is withdrawn for irrigation, 13% is for domestic use, and 4% for industry (Omran *et al.*,2014) (Figure 2.3a). Irrigation accounts for 94% surface water and 6% groundwater (FAO AQUASTAT, 2021) (Figure 2.3b). Groundwater use is low compared to other countries in the region.

Iraq suffers from high levels of salinity in both land and water resources. While salinity levels in the Tigris river close to the border with Turkey are about 280 ppm, this increases to about 1 800 ppm downstream at Basrah. Similarly, salinity in the Euphrates river at the Syria-Iraq border is about 600 ppm, while downstream at Samawah, it reaches more than 1 200 ppm (Al-Ansari *et al.,* 2014).

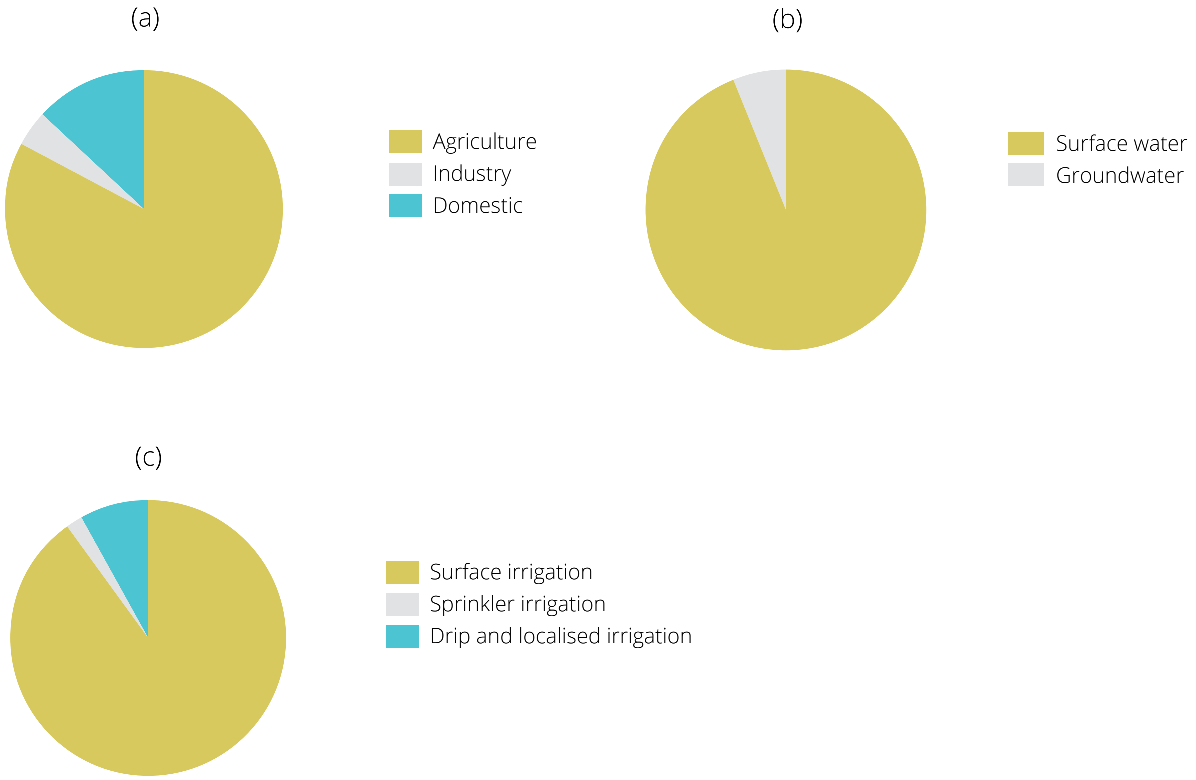
Surface irrigation is the main method used, accounting for 90% of the irrigated area, pressurized irrigation systems, sprinkler and drip irrigation, accounts for only 10% (UN, 2013) (Figure 2.3c).

Water productivity and efficiency

The average water withdrawn for irrigation is 10 450 m^3/ha (Omran, *et al.*, 2014). The average level of WUE is 35% (JICA, 2016; Al-Ansari *et al.*, 2021). This is very low and is seen as a serious threat to the sustainable use of water resources, though it is not clear how this value was measured.

Irrigation water productivity is also low; the main reasons are inefficient irrigation on farms, poor fertilizer management and crop protection, and the lack of agricultural equipment and new crop varieties. Water productivity measurements available list 0.2-0.4 kg/m^3 for wheat and 0.5 kg/m^3 for paddy. The net return of irrigation water is approximately US% 0.025/m^3. The cost of irrigation water is low at US$ 0.006/m^3 (Oweis *et al.*, 2017). Despite the low cost of water, the net return of water is very low.

Figure 2.3 Iraq: (a) sectoral water distribution (b) water sources used for irrigation (c) irrigation systems (%)



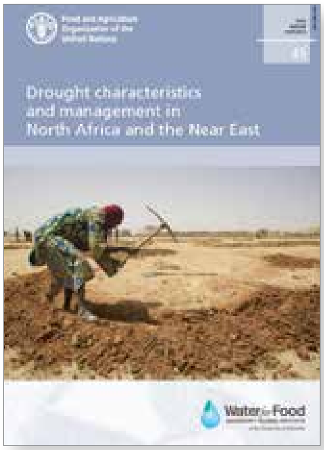
Sources: Omran *et al.*, 2014; FAO AQUASTAT, 2021

Irrigation management

The Ministry of Water Resources and the Ministry of Agriculture are responsible for the efficient use of irrigation water, improving farming practices, and introducing market-oriented agricultural production. The Ministry of Water Resources is in charge of national water planning, operating major dams, hydropower stations, and irrigation pumping stations serving most of the irrigated area. Other ministries with water interests include the Ministry of Energy, the Ministry of Municipalities and Public Works, the Ministry of Environment, and local governorates responsible for economic and human resources.

At the scheme/farm level, Iraq promotes water user associations (WUAs) to encourage farmer participation in irrigation management (Box 2.1).

2.3.2 Drought issues



Drought characteristics and management in North Africa and the Near East

In a study conducted by United Nations Educational Scientific and Cultural Organization (UNESCO) in 2014, almost all governorates were considered drought-prone areas (FAO, 2018a). The standardised precipitation index (SPI) calculated for each governorate showed that drought severity had worsened significantly since 2000. Drought events were recorded in 2000, 2006, 2008, and 2009. Eleven governorates were affected by drought in 2008.

Iraq lacks an early warning system for drought and drought indicators, mainly due to a lack of accurate data on rainfall, temperature, and other meteorological parameters.

Box 2.1 Water user associations promote sustainable irrigation

Water User Associations (WUAs) and farmers' participation in irrigation were introduced between 2017 and 2021 as part of an institutional reform and modernisation programme to achieve a fair water distribution and efficient/reliable operation and maintenance, supported by the Government of Japan. The purpose was to develop a sustainable irrigation water management model for scaling out nationwide.

Two model sites were selected, in Basrah and Dhi-Qar governorates. A Participatory Irrigation Development Plan was formulated. This included five sub-action plans: a WUA management plan, a maintenance plan, an off-farm water management plan, an on-farm water management plan, and a plan for improving irrigation facilities.

An adaptive approach was taken to gradually refine functions and improve the performance of the model WUAs based on operating experience over several seasons. Training systems were developed to strengthen WUA capacities to scale-out the model nationwide, including elements of Irrigation Management Transfer (IMT). Third-country training was also undertaken to bring experiences from other countries into the programme.

See section 4.2 on modernising irrigation management.

2.4 Jordan

Jordan's climate is semitropical in the Rift Valley, Mediterranean in high areas, and continental in other deserts and plains (FAO AQUASTAT, 2021). The population is 9.8 million and is expected to double by 2050 (Venot *et al.*, 2013; MWI, 2016). Table 2.5 summarises country-level data on cultivated land, water resources, and water use available from FAO AQUASTAT and in-country sources.

Table 2.5 Jordan: land and water data from FAO AQUASTAT and in-country sources

	FAO AQUASTAT		**In-country sources**	
Areas	**Data**	**Year**	**Data**	**Source**
Country area (1 000 ha)	8 932			
Cultivated area (1 000 ha)	324		221	(Al-Kharabsheh and Ta'any, 2009)
Area equipped for irrigation (1 000 ha)	78.86	2004	90 000	(DOS, 2021)
Surface irrigation (1 000 ha)	13.86	2004		
Sprinkler irrigation (1 000 ha)	1	2004		
Drip irrigation (1 000 ha)	64	2004		
Actual area irrigated (1 000 ha)	76 20	2006	80.06	(DOS, 2021)
As % of cultivated area	31.9%	2015		
Population (1 000)	7 594	2014	9 800	(MWI, 2016)
Water resources				
Total renewable water resources (km^3/yr)	0.937			
Total renewable per capita (m^3/yr)	123.4	2014	93	(MWI, 2016)
Water withdrawals				
Agriculture (km^3/yr)	0.575	2015		
Municipal (km^3/yr)	0.491	2015		
Industry (km^3/yr)	0.038	2015		
Total water withdrawal per capita (m^3)	145.4	2015		
Surface water (km^3/yr)	0.279	2011		
Groundwater (km^3/yr)	0.624	2015		
Environmental flows (km^3/yr)	0.034	(FAO; UN Water, 2021)		
Water stress (SDG Indicator 6.4.2)	100.08%	(FAO; UN Water, 2021)		

2.4.1 Land, water and agriculture

Agriculture contributes 3% to GDP (Pitman, 2004). About 80% of the country is desert and steppe (Al-Kharabsheh and Ta'any, 2009). Cultivated land area is estimated to be 221 285 ha.

Jordan has a Mediterranean climate characterised by hot, dry summers and cool, wet winters and is divided into three main agro-ecological zones. The Jordan valley has a sub-tropical climate and average annual rainfall from 350 mm in the north to less than 50 mm in the south towards the Red Sea. It is important for growing irrigated vegetables, citrus, and bananas. High-value crops, such as tomatoes and fruit, are grown mainly for the export markets and are irrigated by surface water and wastewater (Humpal *et al.,* 2012)

The northern and southern highlands experience annual rainfall between 350-500 mm and are suited to cultivating wheat, summer vegetables, olives, and fruit trees. Irrigated crops use surface water, wastewater and groundwater pumped from deep wells (MWI, 2016).

The eastern and southern deserts include the *Badia* (semi-desert zone), which covers 80% of the country and experiences cool winters and hot summers with annual rainfall less than 200 mm. This is primarily rangeland for grazing and some rainfed crops using rainwater harvesting to collect sufficient water (Box 4.12). Marginal areas are suited to rainfed barley (Ziadat *et al.,* 2006).

Although the area equipped for irrigation is 90 000 ha, the net area irrigated in 2019 was only 80 057 ha (DOS, 2021). Approximately one-third of the total agricultural area is used to grow olive, followed by barley, wheat, tomatoes, potatoes, and other vegetables (González, 2018).

Table 2.6 summarises irrigated and non-irrigated areas for tree crops, field crops and vegetables for 2019 (Government of Jordan, 2019).

Jordan is the fourth most water-scarce country globally, with annual water withdrawals of only 97 m^3/capita. Agriculture is the highest water-consuming sector accounting for 53% of available water resources, although, in 2015, only 484 million m^3 of water was available to meet the demand for 700 million m^3. Thus only basic needs were met (MWI, 2016). Domestic use accounts for 42% and industry 5% (Anonymous, 2013) (Figure 2.4a).

Jordan's surface water resources come from the Jordan, Zarqa, and Yarmouk rivers. The Jordan river is salty and is not used directly for irrigation or drinking water. The Zarqa River is polluted by domestic and industrial wastes and is unsuitable for irrigation and drinking water, especially in the dry season. Only during flood periods does the water quality improve. However, the Yarmouk and Zarqa rivers provide most of the irrigation water for the Jordan Valley. Surface water consumption is estimated at 242.5 million m^3.

Table 2.6 Irrigated and rainfed areas for tree crops, field crops and vegetables (ha) in 2019

Crops	Total area	Irrigated area	Non-Irrigated area
Tree Crops	796 632	430 937	365 694
Field Crops	1 082 083	68 969	1 013 114
Vegetables	334 130	300 657	33 473

Source: Government of Jordan, 2019

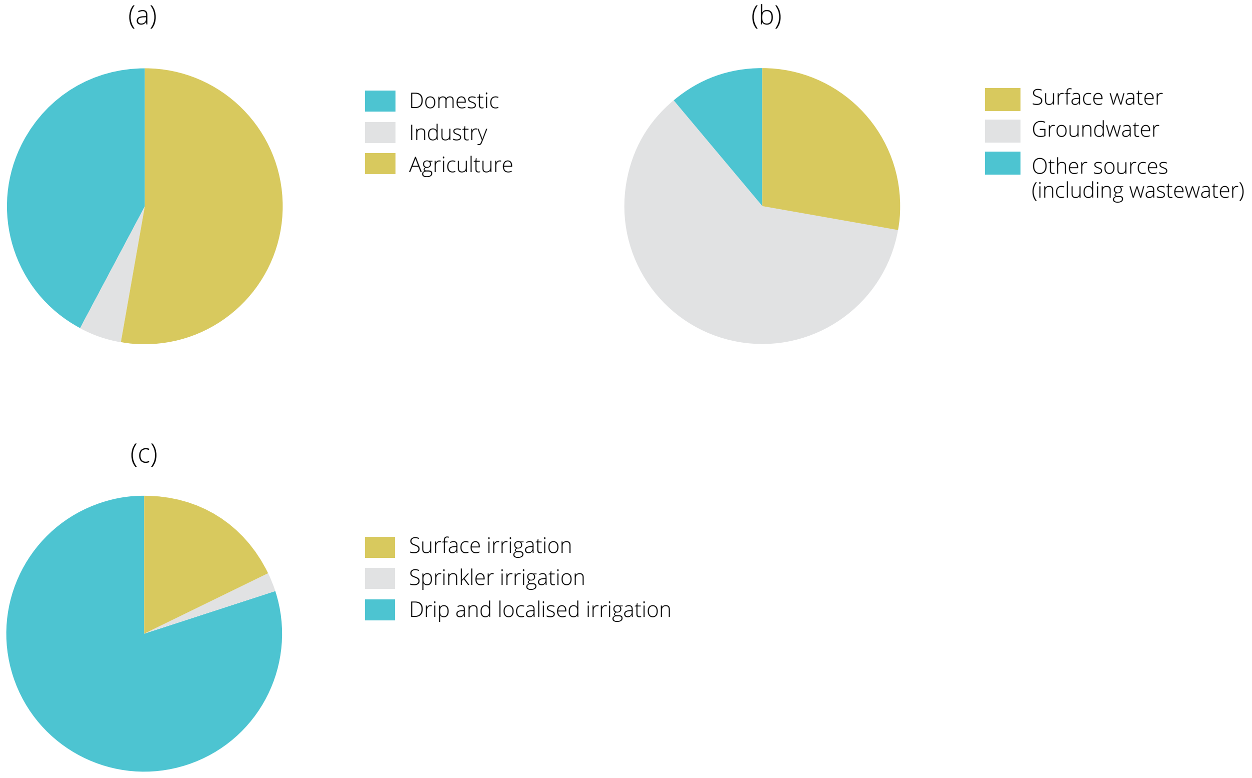
The Yarmouk Basin is an important water resource shared between Syria and Jordan, as are small parts of Zerqa and Azraq basins. Jordan accounts for 115 million m^3 via the King Abdullah Canal to irrigate land in the Jordan Valley. Jordan relies heavily on transboundary water resources with neighbouring countries: Israel, Saudi Arabia, and Syria (Hadadin *et al.*, 2010).

Groundwater resources account for over 60% of the total water used for irrigation, while 28% is from surface water, and 11% from treated wastewater (González, 2018) (Figure 2.4b). Total water use from all sources (surface water, renewable and non-renewable groundwater, brackish water and treated wastewater) in 2017 was 1.053 km^3/yr (MWI, 2020).

The safe groundwater yield is around 275 million m^3, but abstraction exceeds 450 million m^3 which threatens sustainable groundwater use (González, 2018).

Given the high level of water scarcity, interest in using domestic wastewater for irrigation is high (MWI, 2016). Over 90% of treated wastewaters are reused in agriculture (Naber*et al.,* 2019) (Box 2.2).

Figure 2.4 Jordan: (a) sectoral water distribution (b) water sources used for irrigation (c) irrigation systems (%)



Source: González, 2018

Box 2.2 Wastewater treatment and reuse for irrigation

Natural wastewater treatment systems are the most environmentally friendly and cost-effective technology. The National Agricultural Research Center (NARC) of Jordan improved and adapted the granular filtration system (GFS) as a natural greywater treatment system and showed that effluent was within the permissible limits for restricted irrigation set by the Jordanian authorities. Households that used the treated greywater saved 33% of their freshwater consumption and 35% of their monthly water bill.

Reusing treated greywater, which accounts for 50-80% of the total domestic wastewater generated, has excellent potential to reduce water stress. Plant weakness associated with using greywater, such as pests and lack of nutrients, was not observed. Nevertheless, GFS users faced two significant problems, frequent manual cleaning of GFS and the foul smell of greywater.

Source: Input by NARC, 2020

About 70 million m^3 of water from the Red Sea in the Gulf of Aqaba and brackish water available throughout the country are desalinated annually for domestic use (González, 2018). Desalination is not traditionally used. However, the growing water demand is likely to increase desalination in the future (Qtaishat *et al.*, 2017).

Drip irrigation dominates irrigated agriculture and accounts for 80% of the irrigated area. Surface irrigation accounts for 18% and sprinklers 2% (Figure 2.4c). Given scarce resources, Jordan uses hydroponics combined with aquaponic systems to enhance water productivity (Box 2.3).

Water productivity and efficiency

The average volume of water used in agriculture is approximately 6 000 m^3/ha. This is relatively low compared to other countries in the region. WUE is thus considered high at 70% (MWI, 2016) and is attributed to the extensive use of hi-tech micro and sprinkler irrigation (Humpal *et al.,* 2012) (Talozi, Al Sakaji and Altz-Stamm, 2015).
The average gross irrigation water use for vegetables is 9 600 m^3/ha, olives 5 500 m^3/ha, and orchards 10 000 m^3/ha. In 2002 water restrictions were introduced to prevent the over-abstraction of limited groundwater resources (Sixt, Klerkx and Griffin, 2018). Farmers were restricted to 3 600 m^3/ha for vegetables, 7 650 m^3/ha for citrus, and 12 550 m^3/ha for bananas (Venot, Molle and Hassan, 2007). Farmers must pay for water, but they are not charged the full economic cost of abstracting water. FAO reported that the cost of irrigation water in Jordan varies from US$ 0.07/m^3 to US$ 0.085/m^3 (FAO AQUASTAT, 2008). The charge for abstracting irrigation water from deep wells is applied gradually based on the amount of water used (Table 2.7). The government aims to achieve higher production per m^3 of irrigation water, though water productivity has not yet reached desired levels. One example involves fertigation trials on melon (Box 2.4).

Box 2.3 Recirculating aquaponics system (RAS)

Aquaponics, developed initially to clean up water recirculated for fish production, is integrated with hydroponics for crop production in glasshouses. This saves water and uses fertilizers from the fish water clean up.

The National Agriculture Research Center (NARC) research project between 2014-2015 indicated that the amount of irrigation water saved was about 62% of the amount of water used by traditional methods. Irrigation water productivity in the three growing systems was 11.2 kg/m^3 using traditional cultivation, 19.7 kg/m^3 using soil-less cultivation, and 37.3 kg/m^3 using RAS.

Source: Input by NARC, 2020

Table 2.7 Gradual increase in groundwater pricing for licenced and unlicenced wells (US$/$m^3$)

Amount of water used	Water prices in wells with former abstraction licence—2002 bylaw	Water prices in wells with former abstraction licence—2004 amendment	Water prices in wells without former abstraction licence
0–100 000 m^3	Free	Free	US$ 0.035
101 000–150 000 m^3	Free	Free	US$ 0.042
151 000–200 000 m^3	US$ 0.035	US$ 0.007	US$ 0.05
More than 200 000 m^3	US$ 0.085	US$ 0.085	US$ 0.098

Source: Hess et al., 2020; Venot, Molle and Hassan, 2007

Box 2.4 Improving water productivity using fertigation

Fertigation is an effective means of increasing water productivity in irrigation when water is scarce. Soluble fertilisers are injected into the irrigation water to improve water productivity, fertilizer use efficiency, and crop production while reducing environmental pollution and water consumption. The photographs illustrate fertigation trials on watermelon.

Source: Input by NARC, 2020

Irrigation management

The institutions responsible for managing irrigation are the Ministry of Water and Irrigation, the Jordan Valley Authority, and the Water Authority of Jordan. The Ministry of Water and Irrigation is in charge of policy and implementing irrigation strategy, planning, developing, and allocating water resources, preparing water master plans and the water budget, and developing human resources to support the water sector. The Jordan Valley Authority is responsible for constructing, operating, and maintaining water structures and irrigation schemes, collecting water charges, and improving irrigation efficiency. The Water Authority of Jordan is responsible for licencing groundwater abstraction for irrigation, preparing emergency drought plans, and implementing public awareness programmesto limit water use in all sectors.

Jordan river basin was also central to a water accounting study to support irrigation management (FAO; IHE Delft, 2020) (see section 4.2 and Box 4.9).

2.4.2 Drought issues

Using 1938-2005 rainfall data, drought analysis confirmed recurring one-year droughts on a 10-year cycle with two and three-year droughts on a less frequent cycle occurring between 1975 and 2000 (FAO, 2018a). In a planned period of 25 years, a one-year drought has a 90% chance of happening, whereas a two-year or more drought has a 15% chance. Since 2000 more frequent 2-3 year droughts have occurred south of the Jordan river basin.

Rainfall data analysis using SPI indicates that successive droughts have occurred in 1947, 1960, and 1999 with severe droughts expected once every 20-25 years. The extreme droughts were rare events with return periods between 80 and 115 years.

2.5 Lebanon

Lebanon is a largely mountainous area covering over 1.1 million ha and has a Mediterranean climate with rainfall between October and March and a dry season from June, July, August, and September. The population is 6.8 million, with an annual growth rate is 1.75%. Table 2.8 summarises country-level data on cultivated land, water resources, and water use available from FAO AQUASTAT and in-country sources.

Table 2.8 Lebanon: land and water data from FAO AQUASTAT and in-country sources

	FAO AQUASTAT		In-country sources	
Areas	**Data**	**Year**	**Data**	**Source**
Country area (1 000 ha)	1 045			
Cultivated area (1 000 ha)	258	2016	230	(Worldometer, 2021a)
Area equipped for irrigation (1 000 ha)	104	1998	90	(Worldometer, 2021a)
As % of cultivated area	38.38%	1998		
Actual area irrigated (1 000 ha)	90	1998	90	(Worldometer, 2021a)
Surface irrigation (1 000 ha)	66.13	1998		
Sprinkler irrigation (1 000 ha)	28.24	1998		
Drip irrigation (1 000 ha)	28.78	1998		
Population (1 000)	5 851	2015	6 800	(Worldometer, 2021a)
Water resources				
Total renewable water resources (km^3/yr)	4.503		5	(Worldometer, 2021a)
Total renewable per capita (m^3/yr)	769	2014	740	(Worldometer, 2021a)
Water withdrawals				
Agriculture (km^3/yr)	0.78	2005		
Municipal (km^3/yr)	0.38	2005		
Industry (km^3/yr)	0.15	2005		
Total water withdrawal per capita (m^3)	320.7	2005		
Surface water (km^3/yr)	0.4	2005		
Groundwater (km^3/yr)	0.7	2005		
Environmental flows (km^3/yr)	1.421	(FAO; UN Water, 2021)		
Water stress (SDG Indicator 6.4.2)	58.79%	(FAO; UN Water, 2021)		

2.5.1 Land, water and agriculture

Agriculture contributes 5.5% to GDP. About 230 000 ha are cultivated, and 90 000 ha are irrigated, comprising medium and large-scale irrigation systems (Worldometer, 2021a).

The average annual precipitation is 661 mm based on the long-term data (Worldometer, 2021a). However, rainfall varies from 1 000-1 400 mm in the mountains, 600-800 mm in the coastal areas, 600 and 1 000 mm in southern Lebanon, and 200-600 mm in the Beqa'a region (MoA, 2003) (FAO, 2018a).

Lebanon's surface water storage capacity is limited, accounting for just 6% of water use. Rivers, streams, and lakes are the primary source of surface water. There are also numerous aquifer rock formations and karst canals where groundwater accumulation occurs (Zgheib, 2019).

Annual renewable water resources are 5 km^3 (Worldometer, 2021a), and 740 m^3/capita, this falls well below the international benchmark for water scarcity (1 000 m^3/capita). Lebanon shares surface and groundwater with neighbouring Syria and Israel. Transboundary rivers include the Orontes (Al-Assi), the Nahr el Kabir and the Hasban Asi, and the Al-Hasan (Riachi, 2016). The total annual water demand is about 1 260 million m^3, but estimates indicate this may rise to 2 820 million m^3 by 2030. Irrigation accounts for 810 million m^3, but the area under irrigation is expected to reach 140 000 ha by 2030, which will require some 1 120 million m^3 of water. This will create a projected annual deficit of some 500 million m^3 (World Bank, 2003) (Riachi, 2016). According to the current sectoral water distribution, agricultural withdrawals account for 61% of the available water resources, domestic use is 30%, and industry 9% (Bassil, 2010) (Figure 2.5a).

Groundwater is recharged from rainfall and snowmelt and accounts for almost half the withdrawals for irrigation (49%). Rivers and springs account for 39%, and the remaining 12% is treated wastewater (Bassil, 2010) (Riachi, 2016) (Figure 2.5b).

Water pollution and misuse are already straining resources (MoE, 2012). Riachi reported that non-conventional water resources, including desalination and treated wastewater, are not widely used for irrigation (Riachi, 2016).

Of the 80 000 deep wells, only 21 000 are registered. Much reliance is on groundwater for irrigation, and this resource is in danger of over-exploitation unless it is appropriately regulated (Riachi, 2016).

High-value fruits and vegetables are also increasingly grown as protected crops in greenhouses and are important export crops (World Bank, 2003).

Surface irrigation is still practised on 50% of the irrigated area, drip irrigation 25%, and sprinklers 25% (Bassil, 2010) (Figure 2.5c).

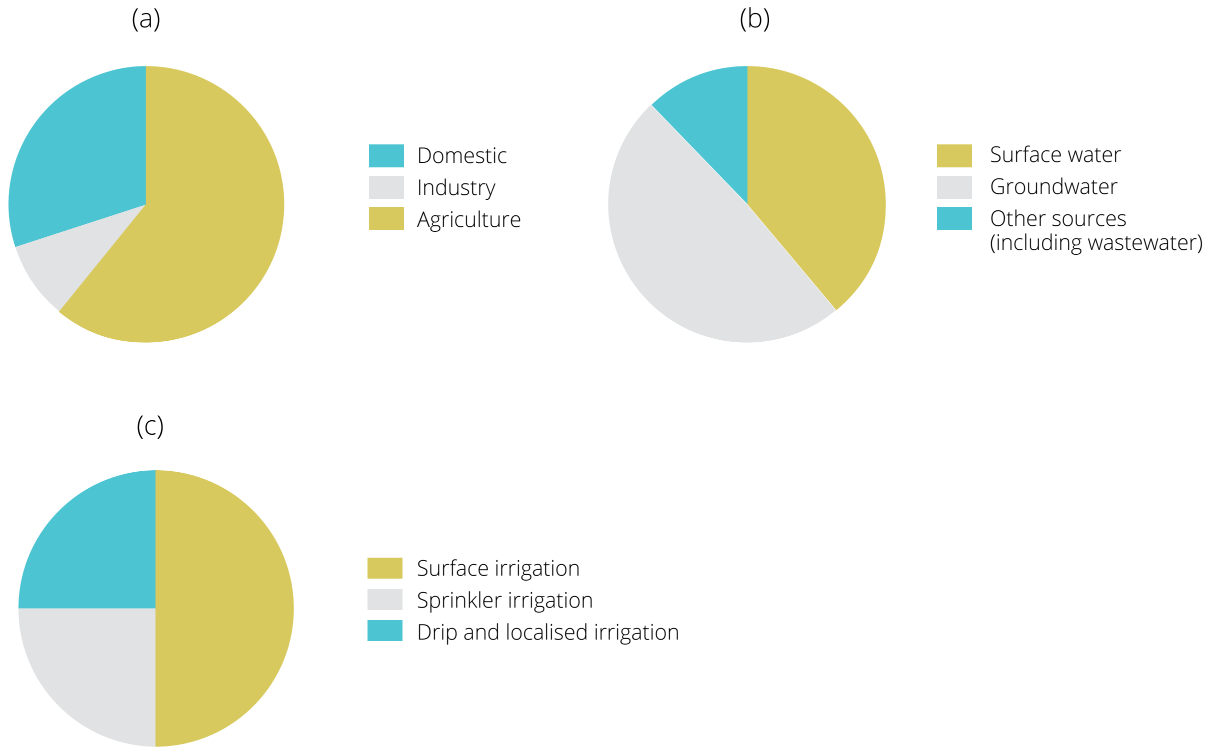
Lebanon charges for irrigation water and operates two tariffs. One is based on the area irrigated with charges made annually ranging from US$ 140 to 650/ha. The second is based on the volume used, and charges range from US$ 0.10 to 0.15/m^3. However, revenue collection levels are low (Bassil, 2010).

Water productivity and efficiency

The national average WUE is high, around 70% (Bassil, 2010). This is attributed to the use of hi-tech pressurized irrigation systems, although water use remains high at 9 000 m^3/ha (World Bank, 2003).

Water productivity values for irrigated grain maize vary between 1.54 -1.68 kg/m^3. However, this increased to 1.88 kg/m^3 under deficit irrigation (Karam *et al.,* 2003). The results indicate that irrigation management practices on-farm can influence water productivity.

Figure 2.5 Lebanon: (a) sectoral water distribution (b) water sources used for irrigation (c) irrigation systems (%)



Source: Bassil, 2010

Irrigation management

The Ministry of Agriculture is the authority responsible for agricultural water management. The Ministry of Energy and Water is responsible for water policy and hydraulic and electric projects implementation. The Water Authority, Regional Water Authority, and local water committees are involved in water resources management.

The Litani River Authority has special responsibilities and functions to develop and manage irrigation. Water and wastewater establishments have financial and administrative roles to implement hydraulic projects, irrigation schemes, and studies and investments.

The Litani river basin has also been involved in a water accounting study to support irrigation management (FAO; IHE Delft, 2019) (see section 4.2 and Box 4.9).

2.5.2 Drought issues

Lebanon experienced severe drought on eight occasions from the 1930s until the early 2000s, when annual rainfall was only 40% of the long-term average. Rainfall in 2013-2014 was one of the lowest since then compared to the average year (FAO, 2018a). The Lebanese Agriculture Research Institute reported a 57% decrease in rainfall in the Beqaa, while nationally, a 40-50% reduction was reported. Many springs ran dry, and most surface water flow ceased. These occurrences are anticipated to worsen as climate change takes its toll on the environment, resulting in decreasing and unpredictable annual rainfall and more frequent drought years.

2.6 Syria

Syria's climate is mainly semi-arid. The country has several borders and sits among Jordan in the south, Turkey in the north, Iraq in the east, Israel in the southwest, and the Mediterranean Sea in the northwest. Most arable land lies in the south-east and north-east because of favourable climatic conditions and available water resources. Syria's population was 18 million in 2015, and population growth is about 3% (Haddad *et al.*, 2008). Table 2.9 summarises country-level data on cultivated land, water resources, and water use available from FAO AQUASTAT and in-country sources.

Table 2.9 Syria: land and water data from FAO AQUASTAT and in-country sources

	FAO AQUASTAT		In-country sources	
Areas	**Data**	**Year**	**Data**	**Source**
Country area (1 000 ha)	18 518			
Cultivated area (1 000 ha)	5 733	2016		
Area equipped for irrigation (1 000 ha)	1 341	2010		
As % of cultivated area	23.4%	2010		
Actual area irrigated (1 000 ha)	1 210	2000		
Surface irrigation (1 000 ha)	1 043	2010		
Sprinkler irrigation (1 000 ha)	187.1	2010		
Drip irrigation (1 000 ha)	110.9	2010		
Population (1 000)	18 502	2015	18 000	(Haddad, *et al.*, 2008)
Water resources				
Total renewable water resources (km^3/yr)	16.8			
Total renewable per capita (m^3/yr)	908	2014	960	(Haddad, *et al.*, 2008)
Water withdrawals				
Agriculture (km^3/yr)	14.67	2003		
Municipal (km^3/yr)	1.475	2005		
Industry (km^3/yr)	0.615	2005		
Total water withdrawal per capita (m^3)	862.8	2005		
Surface water (km^3/yr)	n/a			
Groundwater (km^3/yr)	n/a			
Environmental flows (km^3/yr)	5.573	(FAO; UN Water, 2021)		
Water stress (SDG Indicator 6.4.2)	124.36%	(FAO; UN Water, 2021)		

2.6.1 Land, water and agriculture

Agriculture contributed 27% to national GDP in 2001, but this fell to 19% by 2011. Typical crops grown include wheat, barley, cotton, lentils, chickpeas, olives, sugar beet, grapes, pistachio nuts, and citrus fruit. The internal turmoil and conflicts in Syria directly affected agricultural production (FAO, 2017b). Syria was once self-sufficient in wheat production but is now an importer. Wheat and barley production has fallen by 55%, vegetables by 60%, and olive oil by 40%. The agricultural sector, including irrigation infrastructure, has suffered severe damage because of the conflict at a cost estimated at US$ 1.8-3.2 billion. Estimates suggest that it will cost between US$ 11-17 billion to restore infrastructure (Jaafar *et al.,* undated; Tull, 2017; FAO, 2017b).

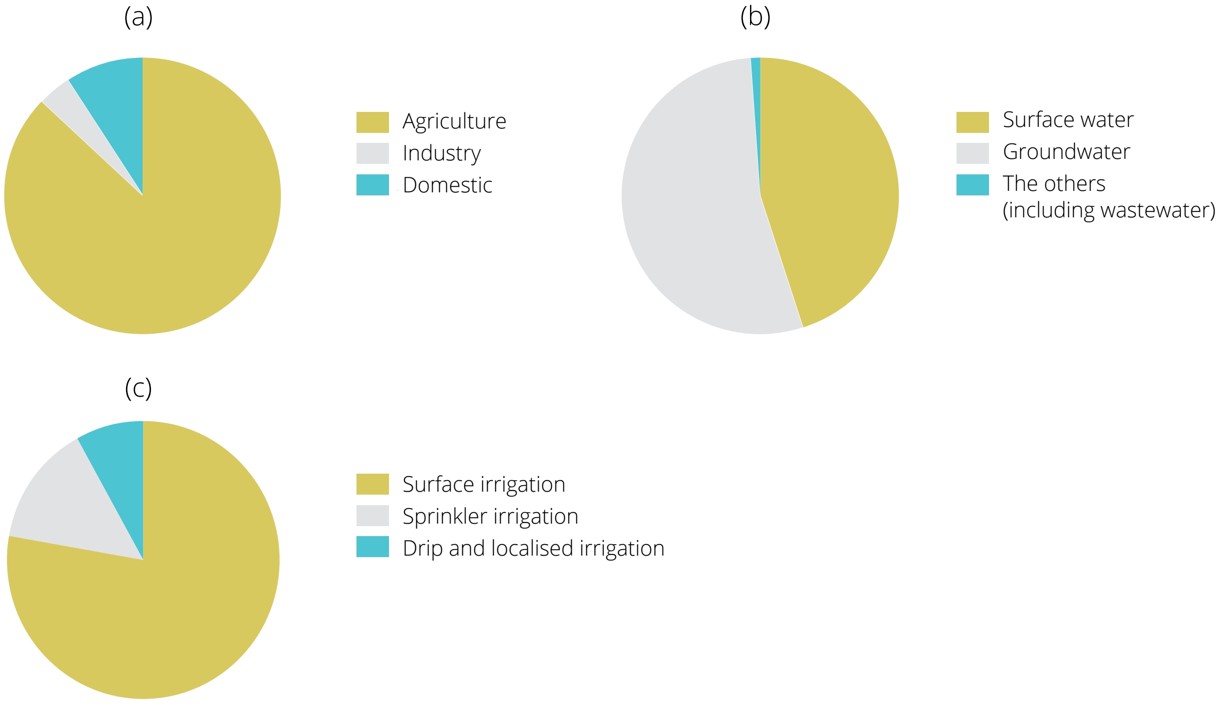
Total cultivated agricultural land is 5.7 million ha. The potential irrigated area is about 3 million ha, but the area equipped for irrigation is only 1.34 million ha. The actual irrigated area is 1.21 million ha.

Syria's climate has Mediterranean characteristics where winters are short and cold, and summers are hot and dry. The long-term average annual rainfall is 252 mm (Worldometer, 2021b).

Syria has seven hydrological basins: Barada and Awaj, Al-Yarmouk, Orontes, Tigris and Khabour, Euphrates and Aleppo, Desert and the Coastal Basin. There are 21 rivers, twelve of which are transboundary (Mourad *et al.,* 2012).

The total amount of renewable water resources is 16.8 billion m^3. However, Syria is among the countries with limited water resources and only 960 m^3/capita, which is below the threshold of 1 000 m^3/capita for water scarcity. The country may face absolute water scarcity below 500 m^3/capita by 2050 (Haddad *et al.,* 2008). Agriculture accounts for most water withdrawals at 87%, domestic withdrawals are 9%, and industry 4% (Figure 2.6a). Groundwater provides 54% of the water for irrigation and surface water 45% (Figure 2.6b).

Figure 2.6 Syria: (a) sectoral water distribution (b) water sources used for irrigation (c) irrigation systems (%)



Source: Haddad *et al.,* 2008; MAAR, 2010

Surface irrigation is practised on 78% of the irrigated area, sprinklers 14%, and drip 8% (Figure 2.6c).

Water scarcity is a major problem for public authorities as future demand is greater than available resources. Thus, WUE in agriculture is central to the nation's water policy discussions. One of the pillars of this policy is the adoption of modern irrigation technologies at the farm level, which is already profiting from considerable government support (Varela-Ortegaa and Sagardoy, 2001).

Some 72% of Syria's water comes from outside the country. The Euphrates originates in Turkey and flows through Syria and Iraq, and provides water for irrigation in the middle plains.

Studies predict that current water policies in Syria may not be sustainable. This will only be achieved in the medium term if a modernisation programme is coupled with a limited and selective expansion of irrigated areas. Water policies in Syria will need to rely progressively on demand management and the introduction of incentives, water-crop quotas, or tariffs to attain water conservation objectives.

Water productivity and efficiency

Varela-Ortegaa reported that the average amount of irrigation water used is 12 434 m^3/ha, and irrigation WUE is reported to be 35%. There are opportunities to reduce water use to 8 000 m^3/ha. Drip irrigation, for example, reduced water used to 7 995 m^3/ha and improved surface irrigation to 9 340 m^3/ha. Farm profits could rise by 38% using sprinkler irrigation and 67% using drip irrigation (Varela-Ortegaa and Sagardoy, 2001).

JICA reported that water used to grow cotton was as high as 17 130 m^3/ha and water productivity varied between 0.17–0.54 kg/m^3 (JICA, 2012). However, Çetin suggests that this could be increased to 0.80 kg/m^3 producing a 40% water saving and an increase in yield (Çetin *et al.,* 2021). Irrigation water productivity for sunflower was 0.43 kg/m^3, and maize was 0.50 kg/m^3.

Darouich attributes excess water use to surface irrigation methods (78%) (Figure 2.6c), the lack of land-levelling, and simple irrigation devices for controlling and measuring volumes of water used. Drip irrigation on cotton could produce water savings between 28-35% and increase water productivity to 0.61 kg/m^3 compared to graded furrow irrigation at 0.43 kg/m^3. Efficiency is not helped by the lack of fees charged for irrigation water. Only operation and maintenance fees are levied (Darouich *et al.,* 2014).

The majority of the irrigated area in the Lower Euphrates Valley faces high salinity. Soil salinization varies from 8 ds/m to 16 ds/m in the region (Haddad *et al.,* 2008).

Irrigation management

The Ministry of Water Resources is in charge of the management, development, and protection of water resources and executing water policies and strategic plans. The Ministry of Agriculture and Agrarian Reform is responsible for agricultural water allocation and modernizing irrigation systems. The Directorate of Irrigation and Water Use within the Ministry of Agriculture regulates on-farm irrigation by undertaking research, testing, piloting and demonstration programs for irrigation methods and wastewater reuse.

2.6.2 Drought issues

Since 2006, the country has endured four consecutive droughts. Poor and erratic rainfall since October 2007 has caused the worst drought in four decades. Rainfall in eastern Syria fell to 30% of the annual average in 2008 – the worst drought in 40 years. Between 1961 and 2009, drought affected four out of the five agricultural zones and lasted almost 10 consecutive years (FAO, 2018a).

2.7 Turkey

Turkey's land area is about 78.5 million ha. The population is 84 million, with an annual growth rate of 1.09% in 2020. In contrast, the population in the 1960s was only 28 million. The climate is influenced by the Mediterranean Sea and the continental climate of neighbouring countries. Annual rainfall varies across the country from 250 mm to 2 000 mm, the long term average being 574 mm (MGM, 2021). In 2020, agriculture contributed 6.6% to GDP. Table 2.10 summarises country-level data on cultivated land, water resources, and water use available from FAO AQUASTAT and in-country sources.

Table 2.10 Turkey: land and water data from FAO AQUASTAT and in-country sources

	FAO AQUASTAT		**In-country sources**	
Areas	**Data**	**Year**	**Data**	**Source**
Country area (1 000 ha)	78 535	2016		
Cultivated area (1 000 ha)	23 710	2016		
Area equipped for irrigation (1 000 ha)	5 340	2012	6 650 in 2021	(DSİ, 2021)
As % of cultivated area	22.45%	2012		
Actual area irrigated (1 000 ha)	5 280	2008		
Surface irrigation (1 000 ha)	4 690		61%	(TOB, 2021)
Sprinkler irrigation (1 000 ha)	500		22%	(TOB, 2021)
Drip irrigation (1 000 ha)	150		17%	(TOB, 2021)
Population (1 000)	78 666	2015	84 000	(DSİ, 2021)
Water resources				
Total renewable water resources (km^3/yr)	34	2008		
Total renewable per capita (m^3/yr)	2 690	2014	1 350	(DSİ, 2021)
Water withdrawals				
Agriculture (km^3/yr)	34	2008	44.3	(DSİ, 2021)
Municipal (km^3/yr)	6.2	2003	13.2	(DSİ, 2021)
Industry (km^3/yr)	4.3	2003		
Total water withdrawal per capita (m^3)	561.3	2008	687	(DSİ, 2021)
Surface water (km^3/yr)	29.54	2008	94	(DSİ, 2021)
Groundwater (km^3/yr)	12.42	2008	18	(DSİ, 2021)
Environmental flows (km^3/yr)	76.97	(FAO; UN Water, 2021)		
Water stress (SDG Indicator 6.4.2)	45.38%	(FAO; UN Water, 2021)		

2.7.1 Land, water and agriculture

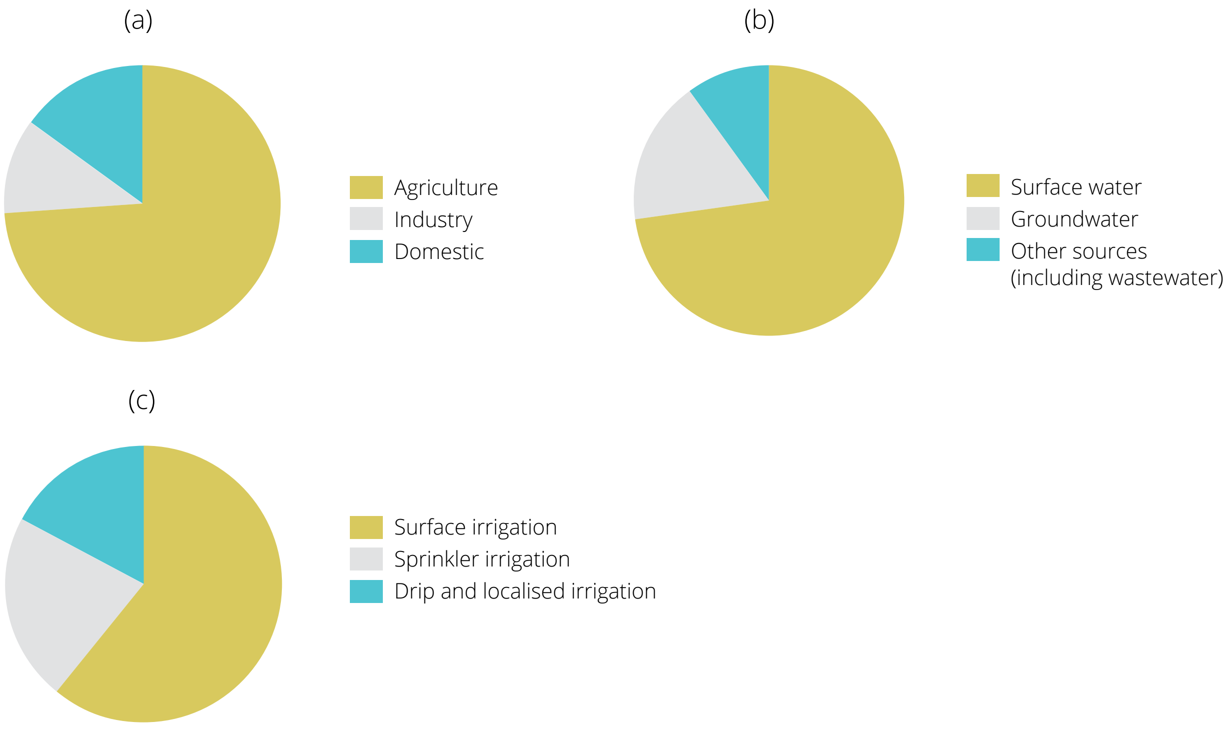
The cultivated agricultural land is 24 million ha. Irrigated agriculture contributes significantly to agricultural production and the country's economic and social life. According to Turkey's General Directorate of State Hydraulic Works (DSİ), the economically irrigable land is about 8.5 million ha, but there is potential to increase this to 12.5 million ha. Currently, 6.65 million ha are equipped for irrigation (DSİ, 2021).

Turkey comprises 25 river basins. Five of these: Aras, Çoruh, Euphrates-Tigris, Meriç-Ergene and Orontes are transboundary, and four: Akarçay, Burdur, Konya and Lake Van, are closed basins. DSİ reports that 94 billion m^3 of surface water and 18 billion m^3 are available annually, of which 57 billion m^3 is used. In 2014, the annual renewable water resource was 2 690 m^3/capita. This has fallen from over 4 000 m^3/capita in the 1970s to 1 350 m^3/capita in 2020 (DSİ, 2021) due to population growth. Climate change and population growth predictions indicate this could fall below 1 000 m^3/capita by 2050. The water stress index for 2021 was 45%. Water dependency from outside the country is 2%.

Agricultural irrigation withdrawals account for 74% of the water used, domestic use is 15%, and industry 11% (Figure 2.7a). Groundwater use for irrigation is growing, but surface water still dominates and is the primary resource. For irrigation, surface water accounts for 73% groundwater for 17%, and other sources, such as drainage water and wastewater accounts for 10% (DSİ, 2021) (Figure 2.7b).

According to the Ministry of Agriculture and Forestry (TOB), surface irrigation accounts for 61% of the irrigated area, sprinkler 22%, and drip 17% (TOB, 2021) (Figure 2.7c). The reduction in surface irrigation from 80% to 61% over the past decade is significant and results from government policy to invest in pressurised systems. Financial support (50%) is available for farmers switching to pressurized irrigation systems.

Figure 2.7 Turkey: (a) sectoral water distribution (b) water sources used for irrigation (c) irrigation systems (%)



Source: DSİ, 2021

Water productivity and efficiency

DSİ assessed the average national WUE at 50%, but the efficiency and, equally important, the water productivity needs more investigation. The gross amount of water used for irrigation is 10 200 m^3/ha, implying room for improvement. Turkey has set targets to increase WUE by 2023 (DSİ, 2021). The General Directorate of Agricultural Research and Policies (TAGEM), under the Ministry of Agriculture and Forestry, undertakes research (TAGEM, 2021). Water productivity values vary depending on the climate and soil characteristics of the region, crop variety, agricultural techniques, and irrigation methods, including sprinkler and drip irrigation. The average values of water productivity for a range of crops are listed in Table 2.11.

Examples of studies and research projects on water saving and increasing water productivity in agricultural irrigation are given below in Box 2.5, Box 2.6, and Box 2.7.

Box 2.5 Reuse of wastewater and drainage water

In Turkey, 7.2 billion m^3/year of treated wastewater is discharged from 602 wastewater treatment plants. The research undertaken by the General Directorate of Water Management of the Ministry of Agriculture and Forestry in 2019 assessed the reuse potential in residences, industry, tourism, energy production, and agriculture and determined best practices.

The result was an estimated countrywide annual reuse potential of 3.2 billion m^3, 44% of treated wastewater discharged. The research also concluded that there was potential to reuse 3.3 billion m^3 annually from drainage water returning from agricultural irrigation (return flows).

Pre-feasibility studies have been prepared for 25 basins to reuse 5.2 billion m^3 of wastewater and drainage water annually to irrigate 336 000 ha agricultural land and 31 million m^2 of green areas.

Table 2.11 Minimum, maximum and average values of irrigation productivity in irrigated areas (kg/m^3)

Field crops	Min-max WP	Average WP	Horticultural crops	Min-max WP	Average WP
Rice	0.39-0.53	0.46	Apricot	-	1.66
Sunflower	0.4-2.2	0.97	Apple	3.0-5.0	3.67
Cotton	0.31-1.3	0.98	Citrus	5.0-8.0	6.50
Wheat	0.88-2.15	1.53	Grape	1.92-20.0	8.58
Maize	0.67-4.19	2.35	Tomatoes	3.7-22.2	10.40
Alfalfa	1.03-2.88	2.36	Cucumber	14.8-43.0	23.16
Patatoes	3.6-14.0	7.10			
Sugarbeet	6.5-17.4	11.24			

Source: TAGEM, 2021

Irrigation management

The Ministry of Agriculture and Forestry, with its relevant general directorates, is the leading institution in the policy development and execution of the protection, development and use of land and water resources.

DSİ is charged with planning, designing, constructing, and operating water structures such as dams, flood control structures, irrigation and drainage structures, hydroelectric power plants, and water and wastewater treatment plants. DSİ is also responsible for basin master plans and feasibility studies, gauging streams and monitoring groundwater, soil analyses and classification, agricultural economy analyses, geological, hydraulic, geotechnical and geophysical surveys, and water quality analyses.

The General Directorate of Water Management is mandated to ensure coordination of water management, prepare river basin management plans, develop measures and set objectives and environmental standards for the management and protection of water environment and devise strategy and policies for flood risks by preparing flood management plans.

The General Directorate of Agricultural Reform is responsible for expanding modern irrigation systems.

The General Directorate of Agricultural Research and Policy is tasked with providing economic, social, and environmental benefits through high-quality agricultural research.

Water User Associations (WUAs) play an important role in operating, maintaining, repairing, and managing irrigation facilities in areas defined by the government and collecting water fees from farmers. A brief review of WUA development in Turkey is available in (SUEN, 2020).

Box 2.6 Targets for improving WUE in irrigation by 2023

Turkey's DSi policy shifted in 2003 from conventional open channel distribution to water-saving systems. Renewal needs have emerged due to the low water conveyance and farm efficiency in traditional irrigation networks and high energy losses in some irrigation areas.

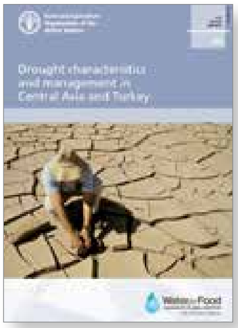
A project to determine the technical performance of drip irrigation systems was coordinated by TAGEM to provide evidence to support subsidisation policies. Using drip irrigation on various crops showed that water-saving and higher water productivity was possible. This contribution to the national economy and social welfare endorsed the use of state subsidies for drip irrigation.

Box 2.7 Improving WUE using informatics and remote sensing

Yield estimates for wheat under different irrigation and planting dates in the Central Anatolia Region were estimated using Aquacrop software to demonstrate actual crop yields and the maximum achievable yield to develop irrigation programmes and support decision-makers responsible for water allocation and distribution.

The use of remote sensing (RS) in precision agriculture grows especially using unmanned aerial vehicles (UAV). Alata Horticultural Research Institute started a project using RS in 2019 to determine and monitor the water stress caused by different water levels on the corn crop by taking images with high spatial and temporal resolution using multispectral and thermal cameras installed on UAVs. A similar project in the Southeastern Anatolia Project (GAP) Region studied crop patterns and the potential to decrease agricultural inputs using different RS methods. Wheat, corn, and cotton crops were monitored using aerial hyperspectral and satellite images and ground data. Using the results benefited agricultural practices such as sprinkler irrigation and fertigation. The research was carried out by the Scientific and Technological Research Council of Turkey (TUBITAK) and the Space Technologies Research Institute and was funded by the GAP Regional Development Administration.

2.7.2 Drought issues



Drought is one of the main natural challenges facing Turkey. In the Central Anatolian region, annual rainfall averages around 600 mm, but drought conditions occur more than once in four years (FAO, 2017a). The combination of rainfall deficiency and other climatic factors, especially high temperature, creates a severe risk of drought in the central and southeastern parts of the country, where agriculture is the primary economic sector.

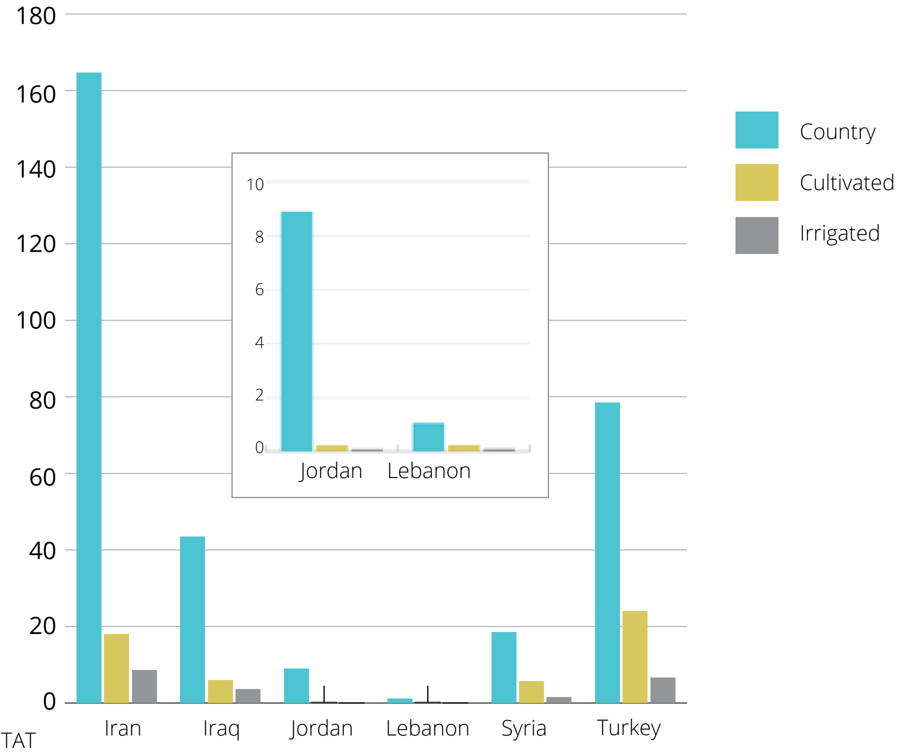
Most of the agricultural production areas, like central Anatolia (an important wheat production area), Mediterranean (mainly corn and citrus products), Southeast Anatolia (cotton and cereals), and the Aegean (fruits trees, cotton, corn), are predicted to suffer from more frequent and intense droughts in the future as the climate changes.

2.8 In summary

Figure 2.8 to Figure 2.14 bring together the data from across the study countries to compare and contrast differences and similarities in water resources and water use for irrigation. All the countries face the familiar challenges associated with predominantly arid and semi-arid climates and the uncertainties of climate change. They have common features such as growing populations, increasing water scarcity per capita, a heavy dependency on freshwater to grow food, feed, and fibre and meet food security targets while recognising the need to sustain the natural aquatic environment on which the sustainability of natural resources depend. However, the differences are striking as countries have adopted strategies that fit their unique natural resource endowments and socio-economic circumstances.

There are vast differences in the scale of irrigation among countries which influences the importance of irrigation to national GDP and food security (Figure 2.8).

Figure 2.8 Land, cultivated, and irrigated areas (1 000 ha)



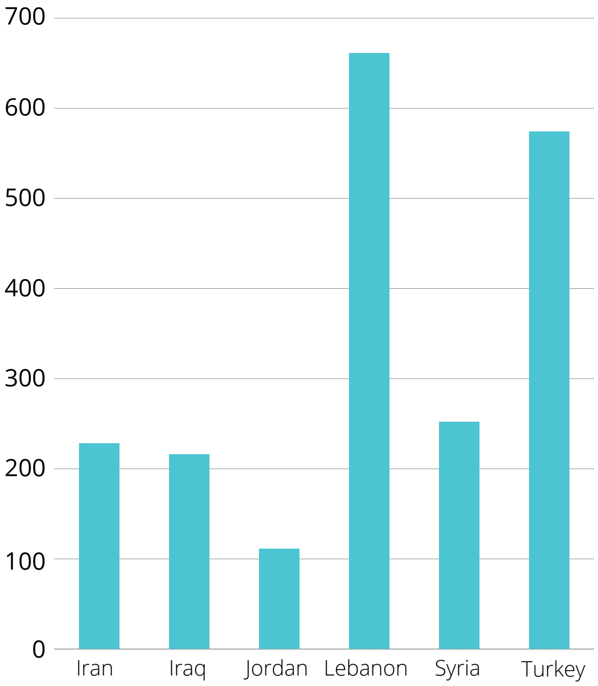
Source: FAO AQUASTAT

Annual average rainfall differs significantly from 111 mm in Jordan to 661 mm in Lebanon (Figure 2.9). Although Turkey and, to some extent, Iraq and Syria appear to have moderate rainfall, average values mask both the wetter areas where rainfed cropping is possible and the much drier arid areas where irrigation is essential for cropping.

Jordan has the lowest total annual renewable resources at 0.95 km^3 and Iran has the highest 137 km^3. All use significant amounts of water for agriculture primarily because of the extent of irrigated agriculture and the high evaporative crop demand (Figure 2.10).

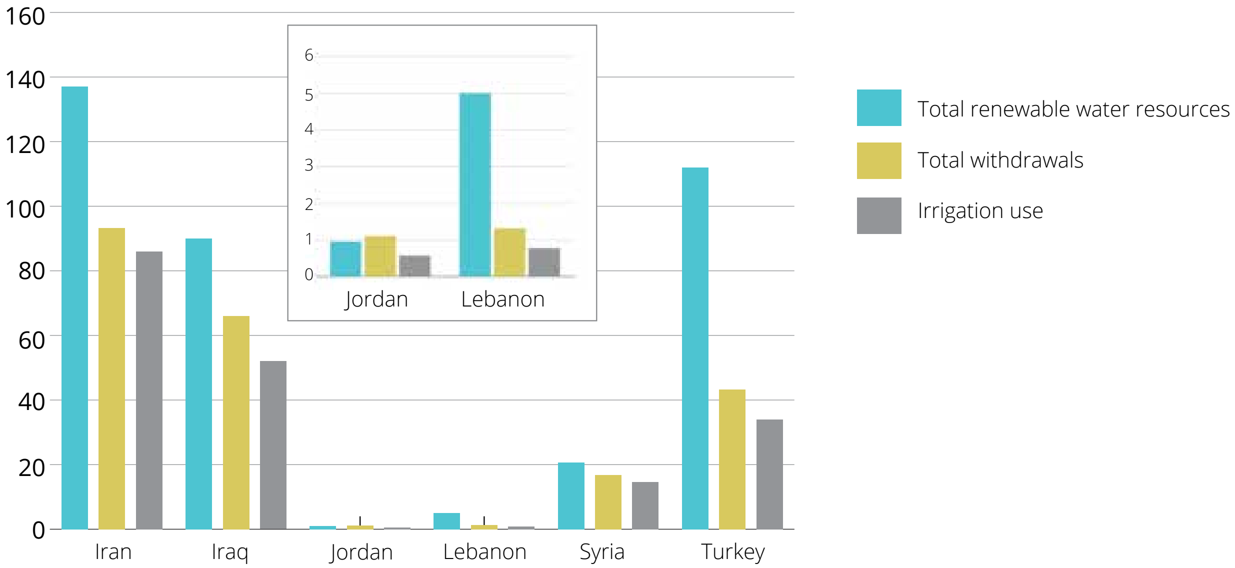
Jordan uses 53% of total water withdrawals for irrigated agriculture, Lebanon 61%, and Iran, Iraq, Syria and Turkey withdraw between 74% and 91% (Figure 2.10).

Figure 2.9 Annual average precipitation (mm)



Source: FAO AQUASTAT

Figure 2.10 Annual total renewable water resources, total water withdrawals, and irrigation water use (km$^{3/}$yr)



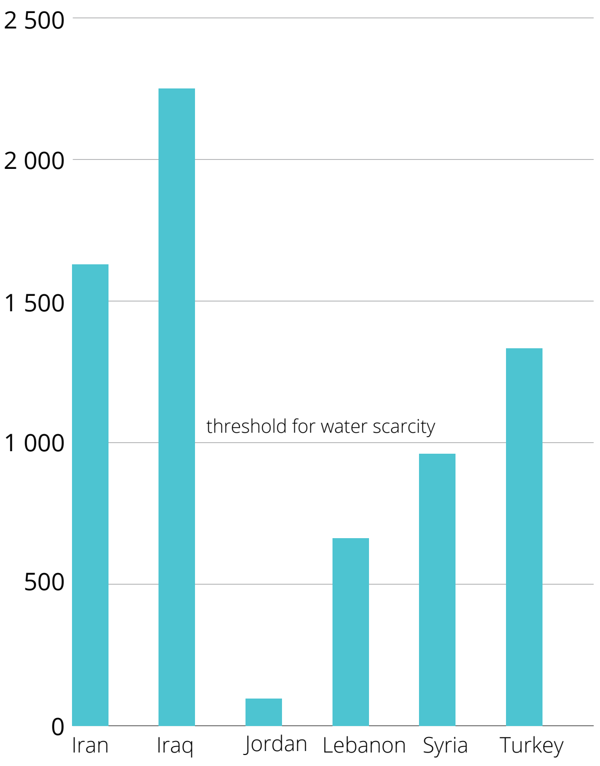
Source: FAO AQUASTAT

The renewable water resources per capita vary considerably among countries, the highest being Iraq and Iran and the lowest is Jordan at 97 m³/capita (Figure 2.11). This is seriously below the recognised threshold of 1 000 m³/capita for water scarcity and the level of absolute water scarcity of 500 m³/capita. These values are set to decrease as populations increase.

Iraq and Turkey rely heavily on surface water resources for irrigation, whereas Jordan, Lebanon and Syria withdraw mainly from groundwater. Other resources, including wastewater, provide modest amounts of water, but this may grow in the future (Figure 2.12).

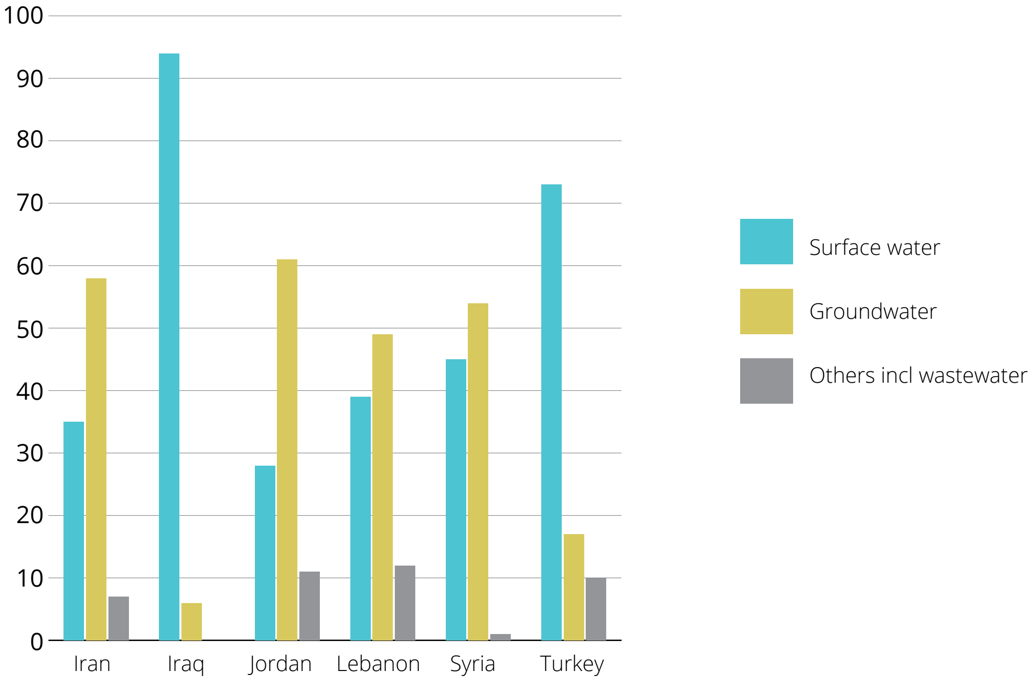
Common challenges include the view that WUE and water productivity urgently need improving to make the best use of available but limited resources (Figure 2.13). Irrigation withdrawals average between 6 000 m³/ha and 12 400 m³/ha to grow crops, and WUE tends to be poor in countries with high water use per hectare, 35% in Iran and Iraq, but much higher in countries with limited endowments, 70% in Jordan and Lebanon.

Figure 2.11 Annual renewable water resources (m³/capita)



Source: FAO AQUASTAT

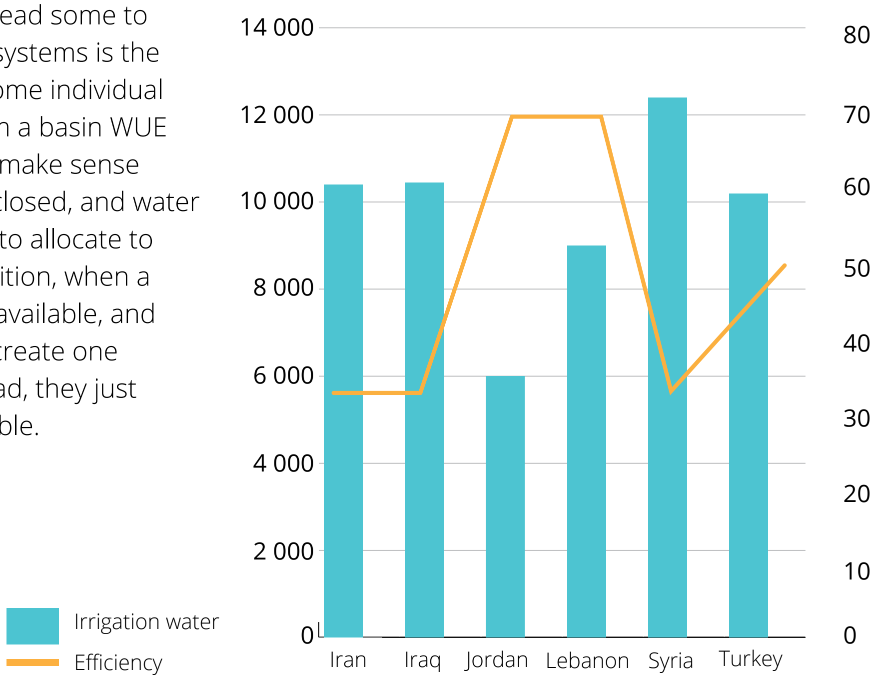
Figure 2.12 Water withdrawals for irrigation from different sources (%)



Source: FAO AQUASTAT

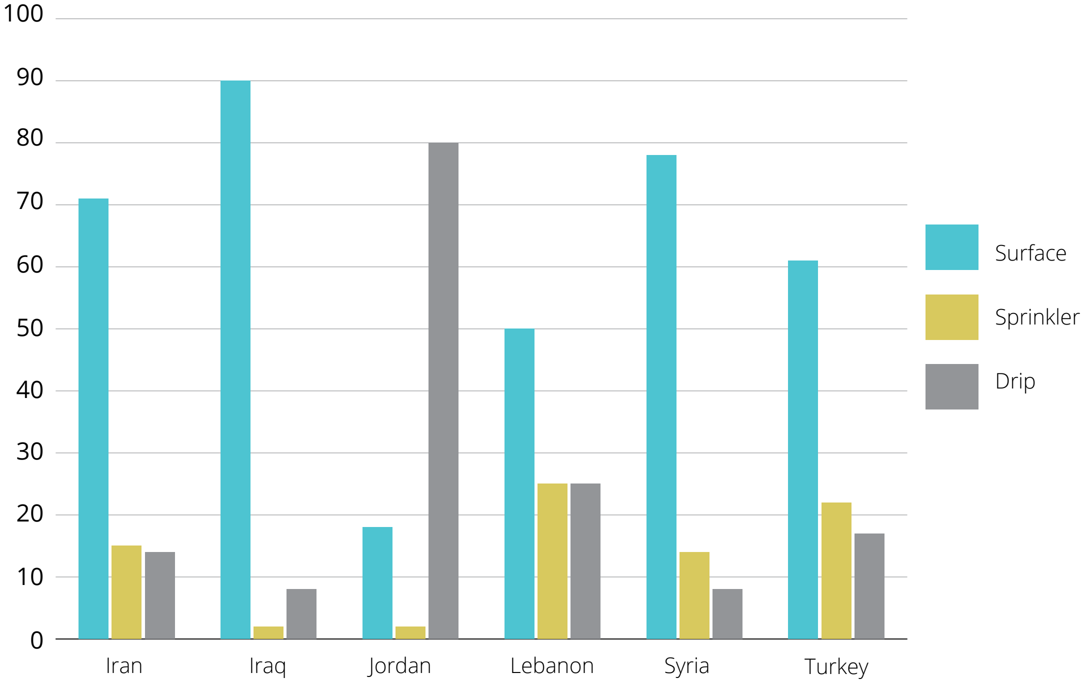
It is no coincidence that Jordan and Lebanon have the highest levels of efficiency (Figure 2.13) and the highest percentage of sprinkler and drip irrigation (Figure 2.14). This may lead some to assume that switching to hi-tech systems is the answer to increasing WUE. For some individual farms, this makes sense. But from a basin WUE perspective, this does not always make sense when water is scarce, basins are closed, and water managers are looking for savings to allocate to other users in the basin. By definition, when a basin is closed, no more water is available, and farm efficiency measures do not create one extra cubic metre of water. Instead, they just redistribute what is already available.

Figure 2.13 Irrigation water use (m^3/ha) and average irrigation water use efficiency (%)



Source: FAO AQUASTAT

Figure 2.14 Irrigation methods (% of total)



Source: FAO AQUASTAT

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3

Pressures and risks to irrigated agriculture

There are many pressures and risks to agricultural production. However, this chapter focuses on those affecting irrigated agriculture and rooted in water resources, land and soils, and their interaction with the climate, which sets temperature and rainfall events.

Human-induced pressures and risks can be added as the demand for natural resources intensifies from increasing population growth, economic growth and improved lifestyles, migration, and urban expansion. Pressures on productive land and water systems have steadily increased. In some places, systems are no longer able to maintain agricultural production, and degradation is visible as rivers run dry, and water pollution levels increase, leading to salinisation and loss of valuable agricultural land (FAO, 2021a).

Globally, the most prominent pressures and risks to irrigated farming come from water scarcity, deteriorating water quality, and salinity which degrades the quality of land and soils. Climate change is now ever-present and is responsible for changing temperatures and rainfall patterns and, particularly for increasing the severity and frequency of droughts.

This chapter reports on a SWOT (strengths, weaknesses, opportunities, threats) analysis to assess the pressures and risks to irrigated agriculture that impact the study countries. This was complemented with information available in the published literature. The information gathered was used to identify priority risk areas and inform chapter 4, which offers technical and institutional options to improve the performance of large irrigation schemes and irrigation performance on farms.

3.1 SWOT analysis

The SWOT analysis used a web-based multiple-choice questionnaire to which 156 irrigation experts responded from across the study countries

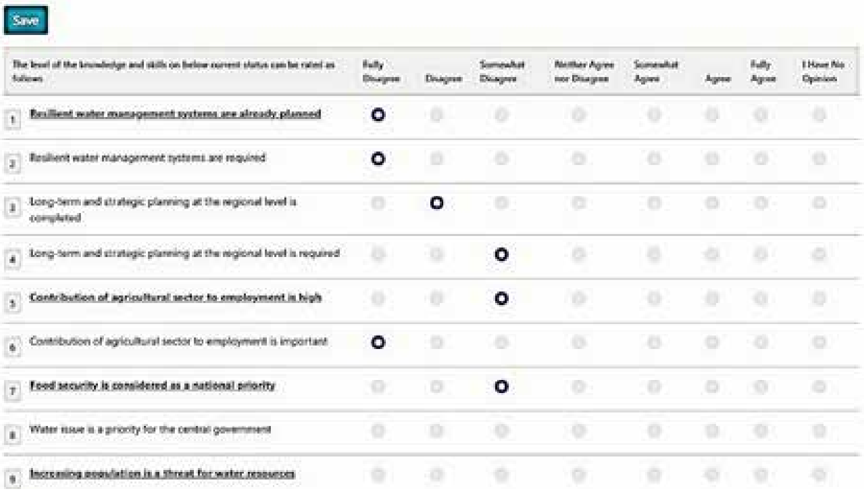
A total of 224 comprehensive questions were set.

They included issues around water planning (4), agricultural governance (35), agricultural planning (6), climate (11), communication (9), data on agriculture and water (9), dissemination and training (7), drainage (4), funding (10), irrigation efficiency (9), irrigation type (20), irrigation water source (8), soil quality (2), transboundary issues (5), wastewater management (12), water governance (40), water planning (18), water quality (5), water user associations (9).

Participants were asked to score each question/statement from "Fully agree" to "Fully disagree" to reflect their opinions. "I Have No Opinion" was also included as an option (Figure 3.1). To establish regional priorities, the survey analysis used overall weighted average scores. The answers to each question/statement were converted to a numerical score and normalised using the number of participants from each country.

The number of responses corresponding to "Somewhat Agree," "Agree," and "Strongly Agree" were compared to the number of responses corresponding to Disagree," "Disagree," and "Strongly Disagree," and the greater side was accepted as "Score" for that question/statement. The results of this analysis are presented in Figure 3.2.

Figure 3.1 SWOT sample questionnaire



	The level of the knowledge and skills on below current status can be rated as follows	Fully Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Fully Agree	I Have No Opinion
1	Resilient water management systems are already planned	●	○	○	○	○	○	○	○
2	Resilient water management systems are required	●	○	○	○	○	○	○	○
3	Long-term and strategic planning at the regional level is completed	○	●	○	○	○	○	○	○
4	Long-term and strategic planning at the regional level is required	○	○	●	○	○	○	○	○
5	Contribution of agricultural sector to employment is high	○	○	●	○	○	○	○	○
6	Contribution of agricultural sector to employment is important	●	○	○	○	○	○	○	○
7	Food security is considered as a national priority	○	○	●	○	○	○	○	○
8	Water issue is a priority for the central government	○	○	○	○	○	○	○	○
9	Increasing population is a threat for water resources	○	○	○	○	○	○	○	○

Although there will be variations across the region, many **strengths** were recognised. The top three strengths listed were agriculture product diversification and incomes (S1), agriculture's contribution to employment and GDP (S2), and organisations having clearly defined responsibilities for water management (S3).

High on the list of **weaknesses** were the need to improve legislation for agricultural water use (W1), unfair distribution of job opportunities between rural and urban employment (W2), and concerns about the dominant use of surface irrigation (W3). However, the latter did not reflect opinion in Jordan and Lebanon, where hi-tech systems are widely used. Turkey has also been investing in hi-tech over the past decade.

W4 is worthy of mention as all the countries were concerned about the lack of volumetric water measurement. This is a common worldwide problem that needs special attention. If you cannot measure water flowing into farms, you cannot possibly manage it properly. For W7, Jordan was the only country to separate sewage effluent from rainwater harvesting. Water harvesting is a common means of increasing water available for irrigation.

High on the list of threats was increasing salinity

If you cannot measure water flowing into farms, you cannot manage it

Opportunities included food security as a priority (O1), implementing water management projects with government support (O2), and the effects of climate change were well known (O3). Presumably, concerns are being built into future resilience planning. However, globally there is little evidence of this happening to date. Opportunities were highlighted to replace qanats with closed distribution systems (O8), although this may not be a priority in all BPME countries.

High on the list of **threats** was increasing salinity (T1), increasing population, and the impacts on future water and food security (T2), and the mismatch between basin boundaries and territorial organisations and administrative zones (T3).

Boundary mismatches are a common problem worldwide. They cause confusion, can duplicate efforts, and result in multiple allocations of the same water. There are also concerns over untreated wastewater for irrigation (T6). Jordan is an exception as treated wastewater is used as an alternative water source. Over abstraction from basins when water is scarce is a constant threat that needs addressing (T7).

Figure 3.2 High impact issues based on the SWOT analysis (top three issues highlighted)

Strengths

S1	**Agricultural products and incomes are diversified**
S2	**High contribution to employment and GDP in agriculture**
S3	**The responsibilities of organisations related to water management are clearly defined**
S4	Centralized governments implemented advanced and successful agricultural water management projects
S5	Resilient water management systems, including dams and reservoirs, are already planned/implemented
S6	Long term, reliable data for agricultural production and crop patterns are available
S7	Drought management plans prepared for agricultural basins/river basins
S8	Irrigation return flow reused
S9	Drip and sprinkler irrigation used in some regions
S10	Regulations for land consolidation are in force
S11	Stakeholders, NGOs, and research institutes are involved in agricultural water management
S12	Crop patterns are suitable for each agricultural region considering water availability
S13	Farmers are encouraged to increase the efficiency of irrigation via regulations
S14	The number of water user associations is adequate
S15	Treated wastewater used for irrigation
S16	Water tariffs in irrigation are reasonable

Weaknesses

W1	**The legislation on agricultural water use requires improvement**
W2	**The unfair distribution of job opportunities between rural and urban areas leads to migration**
W3	**Surface irrigation widely used**
W4	Water used for irrigation not metered
W5	Transmission of water and field applications are inefficient
W6	Pressurized irrigation coverage is low
W7	Sewage network coverage is inadequate, rainwater not collected separately
W8	Farmers participation in water user associations is low
W9	Dissemination of knowledge to farmers is inadequate
W10	Farmers not given enough incentives to increase WUE
W11	Regional long-term and strategic planning is weak

Opportunities

O1	**Food security is considered a priority**
O2	**Water management projects can be implemented with the support of governments**
O3	**The effects of climate change are well known**
O4	Surface irrigation systems replaced with sprinkler and drip irrigation
O5	Farmers are willing to take active participation
O6	Wastewater treatment coverage is adequate
O7	Regional water management institutions established
O8	Qanats are replaced with closed distribution systems

Threats

T1	**Salinity is increasing**
T2	**Growing population puts pressure on water resources and food security**
T3	**There is a mismatch between basin boundaries, territorial organisations, and administrative zones**
T4	Irrigation is heavily dependent on groundwater
T5	Open ditch distribution systems widely used for irrigation in the country
T6	Untreated wastewater used for irrigation
T7	Water use not restricted in basins where water quantity is critical
T8	Groundwater abstraction is greater than recharge

Information gathered on the issues facing irrigation from the published and grey literature is summarised in Box 3.1

Box 3.1 Evidence from published and grey literature

In Iran

Excessive use of water for irrigation results in low WUE and water productivity

Over-exploitation of groundwater resources for irrigation for which there are concerns over unregistered and illegal and no control over water withdrawals

More effective water management and regulations governing water use and monitoring (Nazari *et al.*, 2018)

Lack of awareness of potential water conservation practices (Faramarzi, 2012)

Need for:

- Effective irrigation water tariffs to inhibit misuse of water
- Volumetric water monitoring
- Stronger inter-institutional communications and better extension and training for farmers
- Stronger water governance framework to implement regulations and provide adequate monitoring
- Better irrigation distribution systems and water allocation procedures
- Land levelling and consolidation and drainage systems on lands using surface irrigation
- Farmer training on improved surface irrigation and pressurized irrigation methods
- More water harvesting.

Expand areas using pressurized irrigation systems using subsidies as an incentive

Increase use of wastewater for irrigation

Build capacity for integrated water resources management

Revise economic and investment structure of water sector (Moridi, 2017)

In Iraq

Reluctance among farmers to use and implement modern irrigation systems

Excessive irrigation water use using traditional surface irrigation methods

Lack of maintenance of irrigation infrastructure and canal leakage

Farmers unwilling to take up training and extension services

Farmers focus on income rather than water shortage

Farmers unwilling to pay for maintenance

Land degrading from salinity

Water user associations not very active

Poor cooperation between farmers and water managers and government

Inadequate water management due to political instability

Lack of an effective irrigation pricing policy

Insufficiencies in agricultural inputs

Water pollution from salinity and organic and inorganic wastes

Territorial conflicts

More research is needed on increasing water productivity and using modern irrigation methods

More reuse of wastewater needed for irrigation

In Jordan

Need to find ways of resolving the problems caused by water scarcity

Excessive withdrawal of groundwater, which exceeds the safe aquifer water reservoir limit

Water quality is deteriorating

Inadequate financial support for innovation in agriculture and irrigation

A lack of coordination among the various institutions involved (Al-Kharabsheh and Ta'any, 2009; Sixt *et al.,* 2018)

Difficulties in using wastewater as farmers are concerned about odour and hygiene and inadequately protected irrigation equipment (Venot *et al.,* 2007; Naber *et al.,* 2019).

Concerns persist over WUE and productivity

Need for more water harvesting and reuse of wastewater for irrigation

Need for farmers to pay for operation and maintenance of systems.

In Lebanon

Difficulties in measuring water volumes used in irrigation even though it is the sector using most water (Riachi, 2016)

Limited attention to the water conservation measures and water charges, collection rates are low, and pricing is not linked to WUE and does not encourage water savings

Low WUE in surface irrigation and water conveyance systems and increasing water pollution

Groundwater is over-exploited with long-term concerns about sustainability

Lack of coordination and cooperation between institutions and organisations responsible for water resources

Lack of sufficient stakeholder participation in irrigation management

Water pollution problems are increasing as the population grows with rapid urbanization.

In Syria

Poor WUE in irrigation

Over-exploitation of groundwater resources

Traditional surface irrigation persists, which has a reputation for inefficiency because of poor land levelling, salinisation and drainage problems

The relatively small landholdings (average 3 ha) affects WUE

The capacity building and extension services are insufficient

High population growth rate (3%) leads to greater agricultural water demand.

In Turkey

Excessive water use by farmers in some areas with surface irrigation

Insufficient land-levelling for surface irrigation

Inappropriate use of furrow and border irrigation methods relative to flow rates and soil texture/structure

Limited use of volumetric measurement of irrigation water

Impact of climate change bringing concerns about drought

Inappropriate cropping patterns, particularly monoculture.

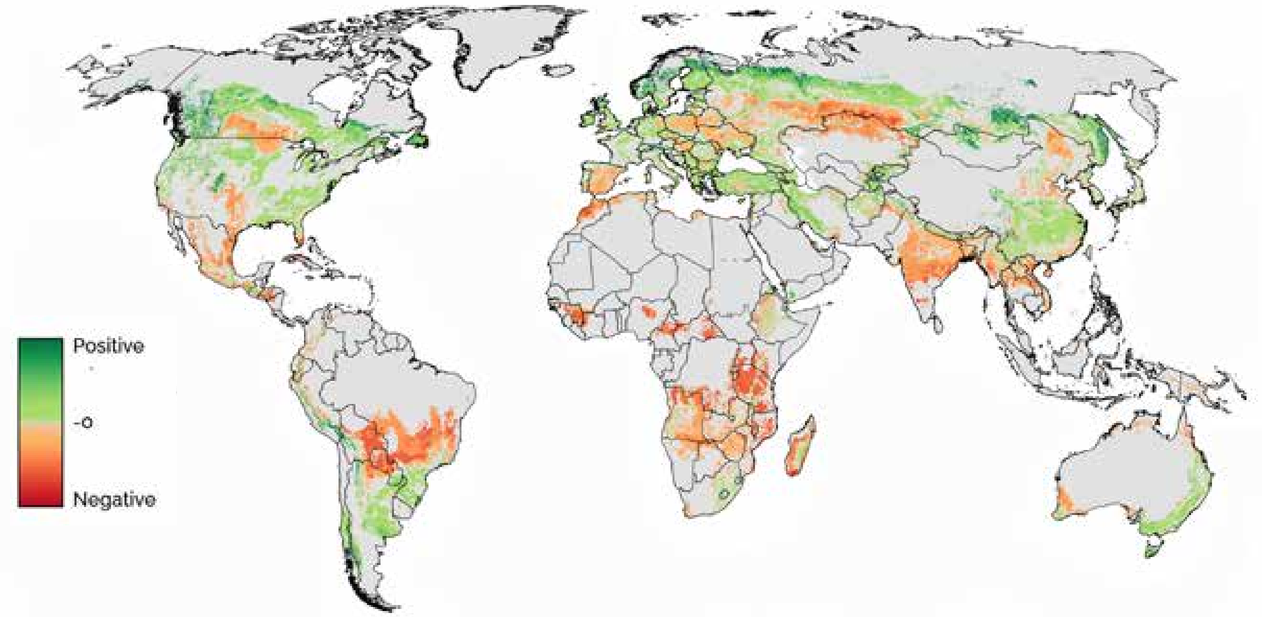
3.2 Climate change

Globally, climate change brings additional risks to agricultural production and other ecosystem services, particularly in countries where economic growth is needed most. Rising temperatures and changes in the hydrological cycle amplify the frequency and severity of extreme flood and drought events. Evidence shows that weather systems are causing significant shifts in agricultural production, cropping patterns, and crop yields.

Indications from studies undertaken by FAO predict that some regional crops will suffer as the climate changes while others will benefit. Rainfed wheat production for example is likely to increase in northern regions, such as Canada and Northern Eurasia and decline in most of Central Africa, Central Asia, and India (Figure 3.3).

In the Middle East, climate change is expected to alter crop yields and water availability (Waha *et al.*, 2017), but by how much is not known. However, a model study based on a set of plausible changes in crop yields and water scarcity offers an indication (though not a prediction) of what may happen in economic terms (Taheripour *et al.*, 2020). For crop yields, the scenario models a 5% reduction in yields for irrigated wheat and corn; 10% reduction for rainfed crops, 5% improvements in yields for oil crops (rainfed and irrigated); and no change in yields for vegetables, and a 20% reduction in water supplies, except for Turkey and Lebanon, where a 10% reduction was assumed. The analysis also assumed "business as usual" with no change in WUE. Based on these assumptions, the possible impact on GDP of increasing water scarcity is illustrated in Figure 3.4.

Figure 3.3 Land suitability shifts for rainfed wheat up to 2080s (RCP 8.5)



RCP 8.5 Representative Concentration Pathway is a greenhouse gas concentration trajectory for the "business as usual" climate future scenario.

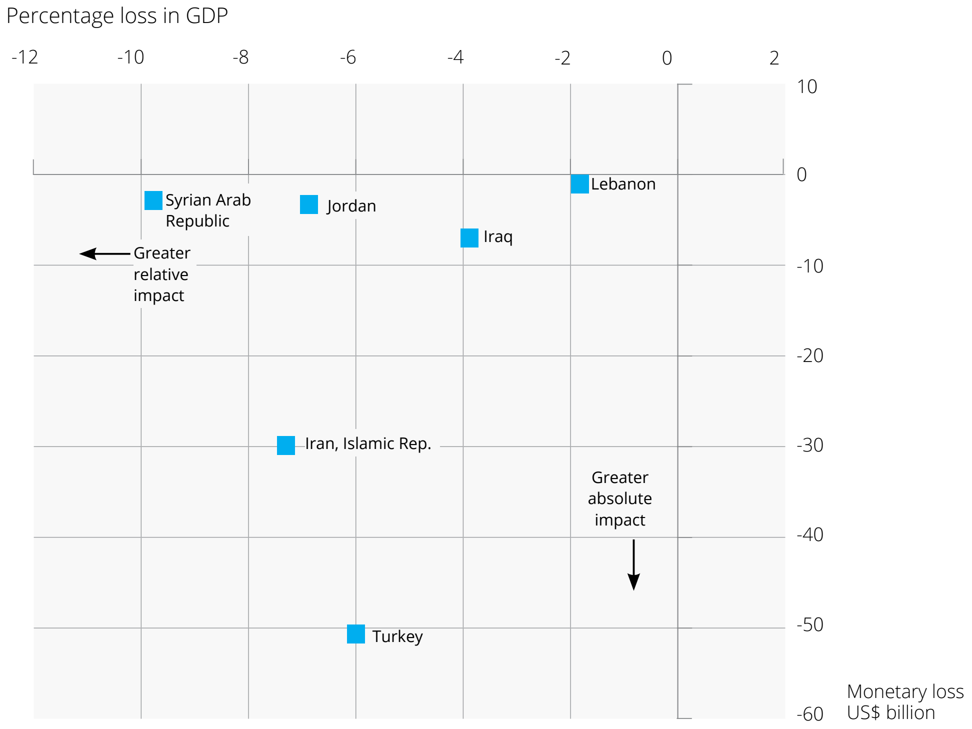
Source: FAO, 2021a

All the countries appear to suffer losses under increasing scarcity, but the most significant losses are expected in Iran and Turkey, countries with substantial agricultural sectors contributing 19.6% and 6.6% respectively to GDP. The 20% water loss scenario also indicates that Syria would experience the most significant fall in GDP. Agriculture is likely to suffer most under climate change, but other sectors of the economy will also be adversely affected (Figure 3.5). Although Jordan has only a small agricultural sector, the impact on GDP would be high as the opportunity cost for water is high due to other sector demands for water, such as mining, manufacturing, energy, and services. This study suggests increasing water scarcity may render capital idle in agriculture and other sectors, forcing a shift away from producing agricultural products.

In the agricultural sector, some irrigated land may revert to rainfed farming where there is sufficient rainfall to sustain cropping.

The study also suggests that increasing WUE is a key option to dealing with water scarcity. However, the authors use the WUE definition in SDG 6.4, which is not about the technicalities of water-saving; it is a means of decoupling economic growth from water use. SDG 6.4 defines WUE in monetary terms (US$ per unit of water used). Improving this WUE indicator implies significant and complex shifts in the way water is used in the economy, not just for producing crops. Economists take quite a different view of the meaning of WUE, and this takes the discussion well beyond the boundaries of this report.

Figure 3.4 Impacts of climate change-induced water scarcity and crop yield changes on GDP



Source: Taheripour *et al.*, 2020

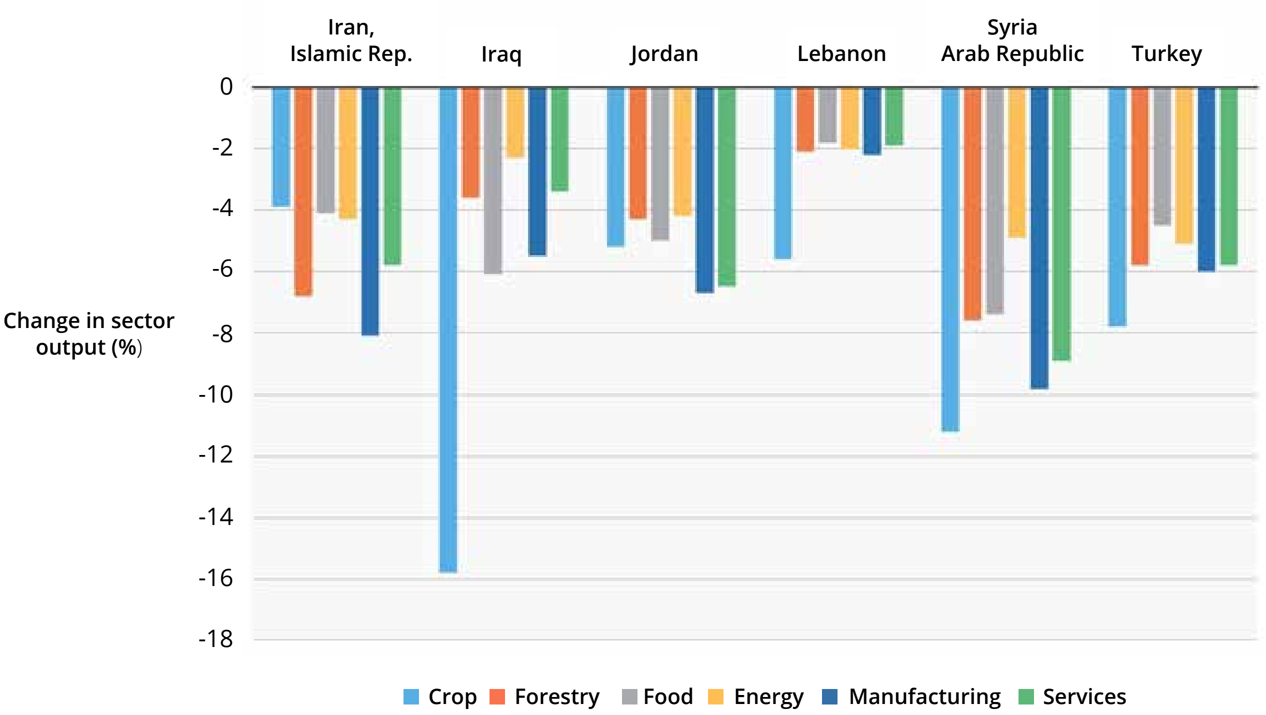
The broader impacts of climate change on agricultural production will increase risks for people in rural communities and affect food security and nutrition among rural and urban populations.

The effects on the poor are likely to be more severe because of their vulnerability. FAO suggests that disasters happen three times more often today than in the 1970s and 1980s, and agriculture absorbs a disproportionate 63% share of their impacts compared to other sectors (FAO, 2021a).

3.3 Water scarcity

Water has always been scarce and variable in the Middle East, primarily because of natural aridity but increasingly because of drought. Most countries have already exploited their available water resources. Many river basins have passed the sustainable level of water withdrawals and will experience major constraints in maintaining and expanding agricultural production in the future (Taheripour *et al.*, 2020).

Figure 3.5 Impacts of climate change-induced water scarcity and crop yield on sectoral outputs



Source: Taheripour *et al.*, 2020

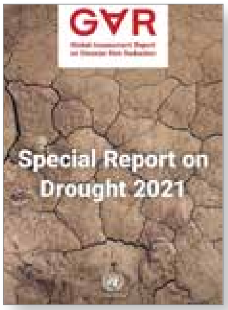
Groundwater use for irrigation is already in crisis in most countries, yet all the signs point to increasing use

Water scarcity is a persistent and worsening problem on a global scale, mainly where water resources are exploited for irrigation. Climate change predictions expect ET rates to increase with a knock-on effect on withdrawals and water stress. FAO predicts that by 2050 crop water requirements will rise by 17% under "business as usual" conditions and by almost 30% when accounting for climate change, including likely increases in areas irrigated. If the current ratio of crop water use to water withdrawals for irrigation remains at 50%, climate change could double withdrawals by 2050 (FAO, 2021a). In most countries, such increases are unsustainable, and the need to improve water productivity and reduce water wastage is present and urgent (Ungureanu *et al.*, 2020; Zamani *et al.*, 2021).

FAO also reports that 48% of some of the most productive irrigated cropland is at risk from salinity. The combination of water scarcity for irrigation and land degradation means that soil and water conservation must be a priority (FAO, 2021a). Although this is a global situation, the risks from salinity are highly relevant for counties in the Middle East.

Groundwater use for irrigation is already in crisis in most countries, yet all the signs point to increasing use for irrigation as farmers switch from reduced or regulated surface supplies (USGS, 2018). Groundwater is attractive for irrigators who are close to shallow aquifers. It offers a convenient, reliable, flexible, and primarily unregulated supply close to farms. Advantages for farmers are many, but they are outweighed by the more significant long-term problems of over-exploitation where there is no administrative control over the resource. Current patterns of exploitation present long-term risks for sustainable water supply and agricultural production. Poor water quality from saline intrusion and contamination from excess fertiliser applications also limit options to increase groundwater use in many accessible shallow aquifers (FAO, 2021a).

3.4 Droughts increase water scarcity



"Droughts are among the most complex and severe climate-related hazards encountered, with wide-ranging and cascading impacts across societies, ecosystems, and economies. They recur, can last from a few weeks to several years, and affect large areas and populations worldwide. Droughts have occurred throughout history, due to natural climate variability" (UNDRR, 2021).

Droughts are natural phenomena that threaten every country in both summer and winter. In developing countries, droughts can impact livelihoods and result in severe undernutrition and death from starvation. In the developed world, the impacts are mainly on economic growth, livelihoods, and the natural environment.

In the Middle East, which is primarily arid and semi-arid, it is essential to distinguish between drought and the 'normal' lack of rainfall that is a feature of aridity. In simple terms, drought can exacerbate water scarcity, but it is temporary and comes to an end. In contrast, aridity does not. It is a permanent state with little or no rainfall to support any vegetation. Planning to cope with aridity and drought has many facets in common, but there are also significant differences. Droughts are unpredictable, and most countries lack early warning systems, which often leads to crises requiring emergency intervention to provide essential water and food supplies.

Droughts are slow to develop and are not easily recognised at first but can cause severe long-term damage to societies, ecosystems, and economies

Droughts are temporary and come to an end. In contrast, aridity does not

(UNDRR, 2021). However, not all droughts cause problems. Much depends on where and when they occur. Climate change is anticipated to increase drought risk by changing the average climate conditions and climate variability. It can generate new threats in regions with little experience dealing with drought.

Meteorological drought is a common reference point describing rainfall less than the normal average (Figure 3.6). However, this has little meaning on its own and needs qualifying depending on the impact: what and who is suffering from drought? *Agricultural drought* is usually the first visible sign of problems. This can be short-lived, reduce crop yields and even destroy crops if prolonged. In rural areas, reduced crop production can affect farm incomes, increase food prices, unemployment, and migration. It can take many years for farmers to recover their income in some cases. *Hydrological drought* follows agricultural drought and adversely impacts aquatic ecosystems, wetlands, and river flows and leads to domestic water shortages. Finally, *socio-economic drought* affects most aspects of life, including public health and economic growth, with impacts lasting many months and even years, beyond when the meteorological drought is over and forgotten.

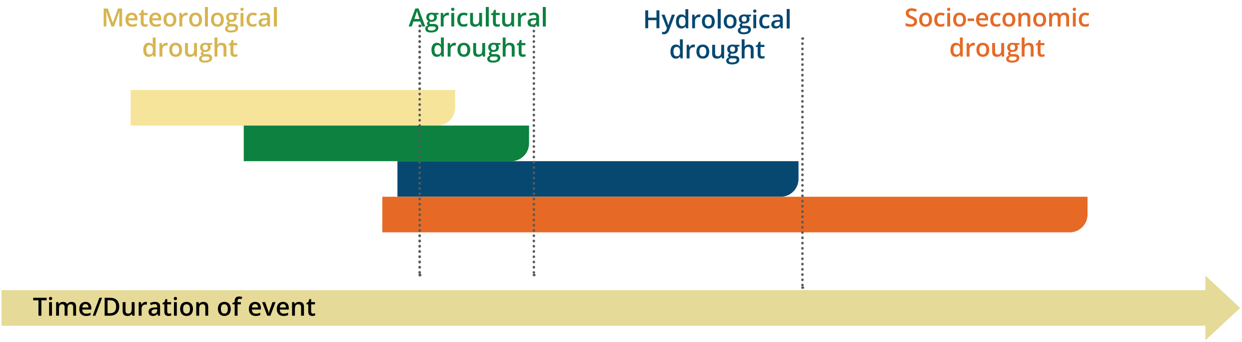
Dealing with drought is different to water scarcity. The unpredictable nature of drought means it tends to be dealt with as a crisis, like other natural events like flooding and earthquakes. However, approaching drought as a risk to be managed is a process that is gaining recognition internationally though very few countries have taken the steps needed to minimise drought impacts (WMO, 2013) (WMO; GWP, 2017) (Figure 3.7). Indeed, one of the biggest obstacles to effective drought planning is apathy. When there is good rainfall and stream flows, other problems take priority and drought is forgotten – until the next one comes along, which it surely will (Box 3.2).

Box 3.2 The "hydro-illogical cycle" of drought

The "hydro-illogical cycle" describes the pathway through a drought in much the same way as the more familiar "hydrological cycle" sets out the pathway of water. Drought slowly becomes visible and this leads to concern and then to panic. Rain usually brings relief and then apathy sets in as people relax and refocuses their attention on the many other pressing issues of the day. That is until the next drought…

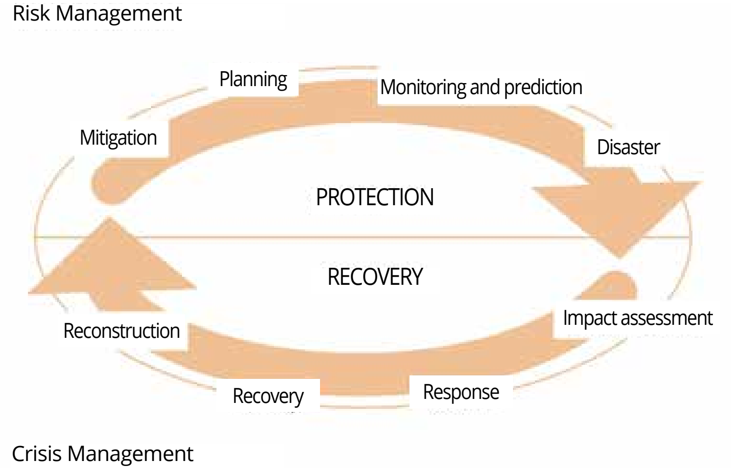
WMO; GWP, 2014

Figure 3.6 Characterising drought



Source: GWP CEE, 2019

Figure 3.7 From disaster management to risk management



Source: WMO; GWP, 2014

3.5 Shocks

Shocks, including severe floods and droughts, and pandemics such as COVID-19, for which most countries were unprepared, tend to divert attention away from long-term development priorities. COVID-19 notably exposed threats to global food systems. The World Bank estimates this has pushed many millions into extreme poverty (Lakner *et al.,* 2021). FAO's *The State of food security and nutrition 2021* report (FAO; IFAD; UNICEF; WHO, 2021) highlights food insecurity and estimates the effects will last for many years to come. Projections show the global number of undernourished people in 2030 will be around 660 million, in part due to the lasting effects of the COVID-19 pandemic on global food security. These events need to be part of future planning and investment to overcome the vulnerabilities they have exposed. Planning for future shocks and long-term development have many common features and offer win-win benefits.

3.6 Land and soil degradation

Healthy soils play a crucial role in improving water productivity and crop production. This is an obvious statement as soils are as essential as water to grow crops. However, increasing concerns worldwide about degrading soil resources and the desire to produce more with existing and limited resources is exhausting soils and impacting soil health.

According to the FAO report, *The Status of the World's Soil Resources Report* (FAO-ITPS, 2015), most of the world's soil resources are in poor or very poor condition; 33% are moderate to highly degraded and subject to ten main threats leading to soil degradation: soil erosion, organic carbon loss, nutrient imbalance, soil acidification, contamination, waterlogging, soil compaction, soil sealing, salinisation, and loss of soil biodiversity. Most of the problems are human-induced and potentially reversible, and as such, land degradation due to erosion, salinisation and pollution is high on the global agenda alongside water scarcity. Yet it is rarely addressed on the ground until cropland soils are degraded and compromise crop productivity.

Risks of soil salinisation have long been a problem in irrigation in arid and semi-arid areas, where salts build up in the surface soil through evaporation and reusing wastewater for irrigation (Sjoerd *et al.,* 2017).

Globally, more than 1 100 million ha are affected; 60% are saline, 26% are sodic, and 14% are saline-sodic. Estimates of irrigated salt-affected soils vary widely between 20% and 50% of irrigated land. The FAO Global Soils Partnership has prioritized soil salinity mapping to identify the scale of the problem in each region and the required investment in remedial measures (FAO, 2021a).

Photo Rubiconwater, Australia

4

Response options and actions when water is scarce

This report has briefly reviewed the status of irrigated agriculture in the study area, the risks to current and future production from shocks and natural variations in climate, human-induced pressures to increase agricultural production, and particularly the concerns over the need for good governance and management.

The challenges facing irrigation are multi-faceted, so there are no single-purpose solutions to the problems of inefficiency and low productivity. All the countries studied in this report have similar water scarcity problems, but each has its own unique set of natural resource endowments, socio-economic circumstances, and governance arrangements for investing and managing water resources. As such this chapter cannot offer specific solutions to the challenges facing irrigation, but it can highlight tried and tested options for decision-makers to select and package them to produce strategic actions that can enhance efficiency and productivity. In doing so, the overall aim is to contribute to a nation's food security and well-being while sustaining and protecting the natural environment on which future production depends.

Water scarcity radically changes many aspects of planning and management, including irrigation. In response, this chapter first describes how irrigation professionals are rethinking how they plan, design, and modernise irrigation systems, and the metrics they use to design, monitor and assess performance. Second, it offers a range of available technical and institutional options to improve the performance of both large irrigation systems and on-farm irrigation practices.

However, some options that impact irrigation performance and water use lie outside the farm, such as plant breeding and food losses and waste on farms and in the supply chains from "field to fork". These are briefly described to demonstrate that effects beyond the farm can also influence water use and water saving. This does not just concern those directly involved in freshwater abstraction for agriculture. It means every citizen being aware of their water use and how much they use. This is the advent of "water stewardship" and particularly for farmers, Water Stewardship in Agriculture (WSiA).

4.1 Is water use efficiency no longer fit for purpose?

Getting agricultural water right will be essential for sustainable and resilient food production. In the 1970s, the concept of WUE as a metric to guide designers and water managers served irrigation well. Water was plentiful, demand was low, and planning new schemes and withdrawals was done in silos, with little or no thought given to the impact on existing withdrawals in a river basin. Today, we face different circumstances. Planning new water projects and modernising old ones in isolation is no longer an option. Integrated approaches are needed to assess tradeoffs when sharing limited water resources among abstractors.

Water scarcity radically changes many aspects of planning and management

In such situations, the simple "classic approach" to measuring WUE[2] has limited value as a metric.

Irrigation professionals are turning towards more useful metrics that account for "real" water savings, improvements in water productivity (more crop per drop), increase crop production and nutrition in foods, how water contributes to food security and people's livelihoods, and sustains the aquatic environment.

4.1.1 Efficiency can be a useful concept but…

Why is classical WUE of limited value when water is scarce? Efficiency is a helpful concept for monitoring resource use such as energy, but it does not transfer well to water management and irrigated agriculture. Measuring WUE as a ratio of crop water use to the amount diverted from a river or groundwater is attractive in its simplicity. It is widely used, has long been accepted among irrigation professionals and practitioners, and is engrained in irrigation books, literature, and teaching. However, when water is scarce, such simplicity can lead to serious misunderstandings about how water is used and managed in agriculture and inappropriate decision-making with serious financial consequences. It may seem counter-intuitive, but there are a growing number of examples of investments in hi-tech solutions designed to 'improve WUE,' which have led to increased water use on farms rather than producing water savings for other purposes.

Many definitions of irrigation WUE have evolved over the past 50 years and are summarised in the SUEN publication *Improving irrigation water use efficiency: A synthesis of options to support capacity development* (SUEN, 2020) as part of the Blue Peace in the Middle East initiative. Definitions range from measuring on-farm efficiencies that assess adequacy and uniformity of applying water to fields to measuring the WUE of entire irrigation schemes. They all represent the "classic approach" to efficiency promoted and consolidated in a field study *On Irrigation Efficiencies* published by the University of Wageningen and the International Institute for Land Improvement in 1978 (Bos and Nugteren, 1978). There are so many different measures that they often confuse rather than clarify. The confusion begins on the farm and in the fields (Box 4.1).

4.1.2 Is low water use efficiency in irrigation a valid criticism?

Although this report initially reviews WUE as the main metric to assess the state of resources and the potential for improvements, its usefulness is limited under water scarcity conditions. The global average WUE is often quoted at 55%, with national figures ranging from 40-60% (Hoogeveen *et al.*, 2015) calculated as a ratio of crop water evapotranspiration to water withdrawal from rivers and groundwater for irrigation. This review of WUE also paints an equally gloomy picture. For Iran, Iraq, Syria, and Turkey, WUE lies between 35% and 50% (see chapter 2). At face value, these levels of WUE are unacceptable when water is scarce and when irrigated agriculture accounts for more than 70%, and as much as 90% in arid areas, of all freshwater withdrawals.

The implication is that much of the water diverted for irrigation never reaches the crops and is lost through seepage in canal systems and poor on-farm water management, creating further problems such as water-logging, salinity, and pollution. Irrigation textbooks and research literature over the past 50 years have taught that up to half the water withdrawn for irrigation is lost and that steps must be taken to reduce this appalling waste. However, water scarcity is driving irrigation professionals to ask the critical question: *where do the losses go*? Clearly, they do not just disappear. Some may be truly lost as water percolates into deep aquifers or drains into the desert or the sea. But much remains in the river basin, and frequently, others use this.

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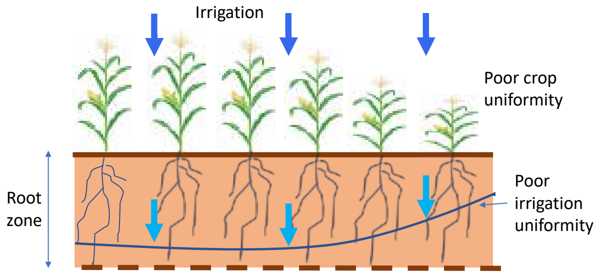
[2] Classical WUE is a ratio of crop water use (ET) to the amount of water withdrawn from a source.

Box 4.1 The problem of measuring WUE on-farms – 100%, 80% or 75%?

Three 'classic' measures demonstrate the complexity of deciding what WUE means for irrigation. Each measure provides information on a different perspective on the same irrigation application. Water application efficiency is 100% as there are no losses although the irrigation is clearly inadequate; water distribution efficiency is 80%, but this does not flag a serious deficiency at one end of the field; and water storage efficiency is 75%, demonstrating that the irrigation did not fill the crop root zone.

These data can be confusing, difficult to measure in practice, and difficult to interpret. A farmer who has intricate knowledge of their farm and irrigation method could spot these problems by field observations. For example, the crop is much smaller where the irrigation is poor, indicating poor water distribution, and crop height also indicates inadequate irrigation and the lack of water storage in the soil root zone. An added problem is that most farmers in developing countries do not have adequate control over their water supplies to fix these problems.

Figure. Three different ways of measuring efficiency: Water application efficiency = 100%; Water distribution efficiency = 80%; Water storage efficiency = 75%.



Modernisation can help resolve these problems by introducing flexible, adequate and timely irrigation supplies to enable farmers to take control of irrigation on their farms.

Source: SUEN, 2020

Most people are familiar with reusing sewage effluent for irrigation, so we should consider reusing the water lost from farms. Researchers and planners are learning that this is indeed what happens. Already farmers in the lower parts of a river basin are using water lost from farms in the upper parts of the basin. Thus, when water is scarce, irrigation managers need to account for this "reuse" often referred to as return flows. However, not all *return flows* are useful as they can be degraded by high levels of salinity and residues from fertilizer and pesticides (Box 4.2).

Box 4.2 Not all return flows are useful

A study of the 72 000 ha Moghan irrigation scheme in northwest Iran compared "classical" WUE, which assumes that all water not used by the crop is lost, and the 'neoclassical' approach which accounts for return flows. Not all return flows were usable and depended on the water quality, which can vary throughout the irrigation season particularly when additional water is usefully used for leaching purposes.

Using the classical approach, the irrigation WUE was only 37.9%. However, WUE, that included return flows and taking account of water quality, was 72% for the scheme. Over 91% of the return flows were usefully used in the study area.

Source: Kazem Attar *et al.*, 2020

We are familiar with reusing treated wastewater for irrigation, so why do we not reuse water lost from farms?

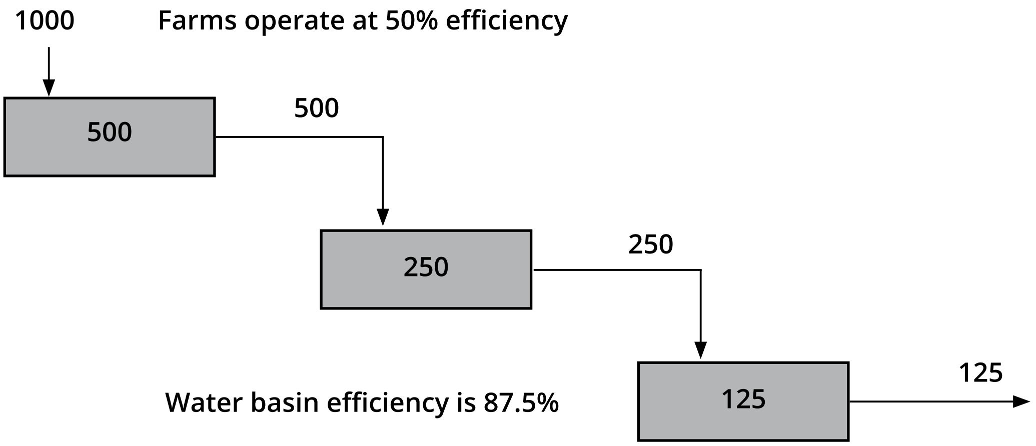
The implications of this are quite profound. It suggests that WUE can be low on individual farms, but taking a basin perspective, as planners must, the overall basin efficiency can be high when other users pick up return flows. Thus the 50% losses figure often quoted to highlight farm inefficiency may grossly overestimate what is truly "lost" to irrigation.

This concept of return flows is now receiving much attention. Analysis using innovative planning tools such as Water Accounting and Auditing (WA&A) can demonstrate "real" water savings when return flows are taken into account. Box 4.3 illustrates a simplified model of return flows and their impact on efficiency.

Box 4.3 Farm WUE vs basin WUE offer different perspectives on efficiency

A group of farmers take water from a river for irrigation. Each is operating a WUE of only 50% – so half the water that each farmer abstracts goes to waste. Assume the first farmer takes 1 000 units of water. He consumes 500 units and wastes 500, which run off into the drains and flows back into the river to become a source of supply for the next farmer downstream. He abstracts 500, uses 250 and because efficiency is again 50%, 250 units flow back into the river. The third farmer abstracts 250 and wastes 125 and so on. At this point, of the 1 000 units abstracted initially from the river, 875 units (500+250+125 units) are usefully consumed by the crops, albeit on different farms. Although each farmer operates at 50% WUE, taking a river basin approach, the overall WUE of the farmer group is much higher at 87.5%. Thus, individuals have low efficiency, but overall, very little water is wasted in the basin.

This example questions the value of farmers investing in WUE. If the first farm invests to increase WUE to 100%, practical experience from the field suggests the farmer would still take his 1,000 unit entitlement and use the water saved to grow more crops and increase his farm income. He is unlikely to offer 500 units back as a gift to the environment or other users unless forced to do so. So investing in farm WUE does not save water for others to use. Instead, the water is redistributed. It benefits the first farmer while others downstream suffer severe water shortages.



Source: Kay, 2017

4.1.3 Water management needs a common language

To add to the confusion over WUE, most people in the water sector views the term WUE differently. Decision-makers, water professionals, and farmers often use the same vocabulary to discuss water management issues, but each may have a different meaning that can lead to misunderstandings, and in some cases, expensive mistakes (Box 4.4).

A common language and understanding is essential for sensible decision-making and investment. Box 4.3 illustrates the importance of getting the correct terminology to discuss water issues (Perry, 2007). Myths about water that misrepresent facts and basic science are commonplace. There is even confusion in scientific publications and among water professionals about what water use means – is it consumptive or non-consumptive, can water be reused, or is it lost?

Box 4.4 How decision-makers, planners, managers, and farmers view WUE

At a global and national level: governments are concerned with meeting the SDGs set out in the UN 2030 Development Agenda, and in particular, SDG 6 – the "water goal" – which uses macro-indicators to monitor progress at regional and national levels for improving WUE across all water sectors including agriculture, environmental water stress, and how water scarcity affects people. WUE is measured as national economic output in US$ (*more US$ per drop*), which is a helpful indicator for governments to show where water is being used most effectively for sustainable economic growth. But it is of little value to an irrigation scheme manager or farmer who wishes to assess how water is withdrawn from rivers and used on an irrigation scheme or a farm. The average global efficiency measured in this way is US$15/m^3, but the range is significant, from US$2 to 1 000/m^3. Countries with high GDP and low water use fare much better than those with high water use, such as irrigation, and low production value (FAO, 2018d).

At a river basin level: water resources managers are more concerned with the efficiency of the river basin rather than individual schemes or farms (a ratio of water used in the basin and the renewable water resources available). They will use water accounting procedures to assess where water is used or consumed in the basin, how much water is still available in different parts of a basin, and whether the basin is still open for further water withdrawals. What happens on individual farms may be of little interest to them. Indeed, basin-level efficiency may be high even when the efficiency on individual farms is low.

At an irrigation system level: irrigation managers will be primarily concerned with the efficiency of their distribution system and farm irrigation efficiency (water consumed on farms vs freshwater withdrawals). Their main concern is to reduce water losses from seepage, evaporation, and *administrative* losses from poor water management in the distribution system and on farms.

At a farm level: Farmers will tend to measure efficiency in terms of water productivity (*more crop or US$ per drop*). Farmers receive incentives to increase nutrition rather than just yield (more nutrition per drop) in some countries. However, they are usually more concerned about saving money and increasing farm income than saving water. They may be willing to invest in WUE measures on their farm if this reduces water losses and increases farm income, particularly if the government subsidizes investments. They will be less interested if water managers claw back water savings to use elsewhere in the catchment.

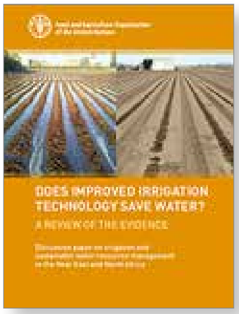
Irrigation engineers: tend to refer to WUE as the ratio of water consumed by a crop to the water applied or withdrawn from a water source. This works well for designing schemes, sizing canals and control structures to cope with maximum discharges so the system can cope with the most acute operating conditions that may arise.

Irrigation agronomists: tend to use WUE as a ratio of plant biomass or yield to transpiration.

Water engineers and hydrologists usually have a clear scientific understanding of how water is consumed in agriculture, used for domestic purposes with the possibility of re-use. However, engineers must be careful to consistently use language universally understood by the public, decision-makers, and those who formulate legislation and implement decisions to avoid misunderstandings that may lead to inappropriate decision-making.

4.1.4 Does switching to hi-tech make sense?

Improving WUE is usually the reason given for switching from surface irrigation to sprinkler and drip systems. However, water scarcity may challenge this reasoning.



DOES IMPROVED IRRIGATION TECHNOLOGY SAVE WATER?
A REVIEW OF THE EVIDENCE

In 2017 FAO published *Does Improved irrigation technology save water?* (Perry and Steduto, 2017). A quote from this publication: *"...introducing hi-tech irrigation [sprinkler and drip] in the absence of controls on water allocations will usually make the situation worse: [water] consumption per unit area increases, the area irrigated increases, and farmers will tend to pump more water from ever-deeper sources."* This statement seems counter-intuitive. However, experiences reported worldwide are showing this to be true. It is referred to as Jevon's paradox (Box 4.5).

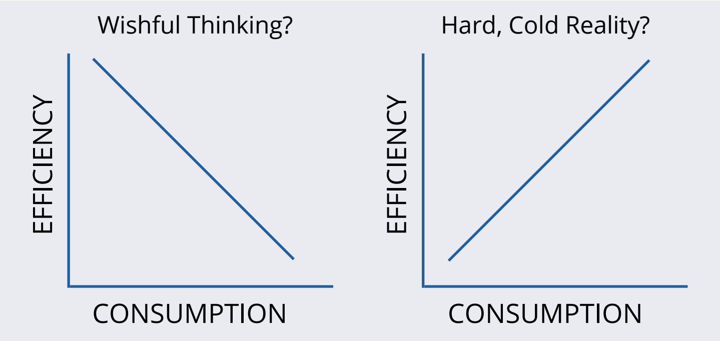
Box 4.5 Jevon's paradox applied to water resources management

Jevon's paradox first evolved around the use of coal to power steam engines in the 19th-century. Economists argued that as steam engines became more efficient, the demand for coal would reduce. However, Jevons suggested the opposite. He said that as efficiency increased, the need for energy would increase, and the demand for coal would also increase. This is precisely what happened.

Can this apply to irrigation? The conventional wisdom is that irrigation wastes water. If farmers used more efficient technologies, such as sprinklers and drip, water demand would fall, thus saving water for others to use. However, the opposite is happening. The demand for irrigation water rises worldwide, groundwater aquifers are over-pumped using deep-well technology, and river flows are reduced and polluted. As water resources become more valuable, the demand increases, and farmers want to retain as much water as possible on their farms. They view runoff and deep percolation as water losses. So they invest in hi-tech application methods to keep as much water as possible on the farm and use it to increase production and improve their water productivity.

But irrigating farms do not operate in isolation; they are connected across the river basin using the same resource. Those farm 'losses' initially returned to the basin and frequently became water sources for someone else downstream. Once upstream farmers began capturing their losses, it was usually to the detriment of downstream users.

The graphs illustrate the paradox. Interventions to improve WUE expect water consumption to decrease. The reality is that water consumption increases



Sources: Perry, 2020; Perry and Steduto, 2017

Research findings show that when farmers realise that water can be more productive and water is scarce, they will reduce losses as much as possible. Farmers become more willing to invest in hi-tech precision irrigation methods to reduce losses. However, they tend to use the extra water to increase their production and productivity rather than release it for others to use.

The main impact of investing in hi-tech is fewer return flows and less water available downstream. There are many examples where policymakers subsidise switching to hi-tech, expecting farmers to save water and release it for others to use, only to find those benefits do not materialise. In some cases, water consumption increases with little gain in water productivity (Yu *et al.,* 2021). See examples of this in Box 4.6.

Box 4.6 Investing in hi-tech on farms does not always produce water savings

In Montana and Wyoming in the USA, in 2012, a legal case in the US demonstrated the severe and unexpected impacts of increasing irrigation WUE to reduce water losses (return flows). The Yellowstone river basin in the US is nearly equally divided between Montana and Wyoming, and in 1950 the two states agreed to apportion the available water for irrigation and other purposes. However, following a severe drought between 2000 and 2006, Wyoming invested in sprinkler and drip irrigation to increase irrigation WUE to use their limited water allocation better. But Montana had long benefited from the inefficiencies (return flows) in Wyoming. The impact of increasing WUE was to reduce the return flows to the detriment of Montana. Montana alleged sprinklers increase WUE in Wyoming from 65% to 90%, reducing return flows from 35% to only 10%. Montana argued that Wyoming should have imposed administrative requirements to offset these adverse effects on Montana.

This was a complex legal case and dealt with the laws of the doctrine of recapture. Can farmers recapture their water losses by increasing their irrigation WUE when others downstream have long benefited from those losses? The court held that such improvements were permitted under the Yellowstone river agreement. This was a landmark ruling and a recognition of the importance of return flows in assessing water availability. However, this may not be the case for irrigation schemes in other parts of the world, where the legislation is unclear or non-existent.

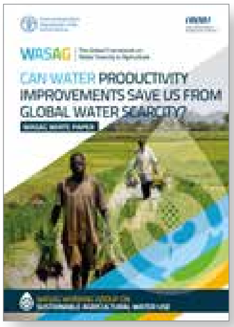
Source: MacDonnell, 2012

In India, the government promoted drip irrigation, including paying up to 75% of the costs, to conserve groundwater. In the absence of regulations to limit abstraction, farmers reacted by intensifying production, shortening fallow periods, and expanding the irrigated area between 40 – 67%. The result was an increase in abstraction rather than water saving.

Source: Birkenholtz, 2017

In Australia, the government embarked on costly and contentious intervention strategies to reduce water abstraction by increasing WUE to augment environmental flows for ecological and social benefits in the Murray-Darling river basin. The investment had the desired effect of increasing WUE but this had perverse outcomes. Researchers described farmers as receiving robust ‘gold plated’ irrigation infrastructure, who used the water ‘savings’ to increase their production rather than leaving flows in the river to augment environmental flows. Although farmers benefitted from this investment in hi-tech irrigation, at the basin level, there was little benefit as intended.

Source: Adamson and Loch, 2014



The message from these experiences (Box 4.6) is clear. Incentives for farmers to invest in hi-tech irrigation systems will likely benefit individual farmers, but water savings at the basin level are limited. Indeed water consumption may increase (Van Opstal *et al*., 2021). To avoid farmers grabbing the water savings, irrigation managers need to introduce and enforce strict control and limit access to water (Perry, 2020) to retain the "savings" in the system for reallocation (Box 4.7). This is not easily done. In situations where there are many thousands of smallholder farmers, not only is it costly to install all the equipment to control water quotas, it is also difficult and costly to monitor and administer and legally enforce the rules.

When water for irrigation is pumped using electrical energy, there are options to control water allocations by restricting the use of electricity. Shah explored several experiences of controlling and limiting groundwater abstraction (Shah, 2014). One example in Mexico, in 2002 the government reduced groundwater abstraction for irrigation by imposing electricity charges at commercial rates. Although successful, the impact was reduced in 2004 when the government offered subsidised night tariffs for groundwater pumping, and farmers switched to night-time irrigation.

Answering the question: *does switching to hi-tech make sense?*

Yes – farmers are likely to invest in hi-tech systems to reduce water losses when water is scarce, providing they can retain the water they save to increase their production.

No – when water is scarce, and government subsidises hi-tech investment on farms intending to claw back the saved water for others to use. Experience worldwide shows claw-back only happens when irrigation managers use flow measuring devices and legally enforceable farm quotas to limit abstraction. Such measures are unlikely to appeal to farmers who see little benefit in investing in hi-tech systems, even with subsidies. Farmers are usually more concerned about saving money and increasing farm income than saving water.

Although new ways of thinking about dealing with water scarcity are taking hold, change is slow. The classic metric of WUE persists among many professionals and those in decision-making positions (Box 4.8). However, when governments take difficult decisions to ensure that water supplies remain sustainable and renewable, farmers can be innovative in maintaining production and incomes. They adopt new crops and technologies that make commercial sense relative to the available water supply (Perry and Steduto, 2017).

Box 4.7 Strict water allocations produce real water savings

In Nebraska, USA, a shift from surface irrigation methods to centre-pivot irrigators was made to improve irrigation WUE. The key to reducing field water applications in three Natural Resources Districts was the introduction of regulatory quotas on pumping for irrigation which enabled water savings to be retained by the regulator for others to use.

Sources: Mekonnen *et al.,* 2020

To avoid farmers grabbing the water savings, irrigation managers need to introduce and enforce strict control and limit access to water

Box 4.8 Why does the idea of improving on-farm WUE persist as a means of achieving sustainable water use?

The problem lies with those involved in the process as each prefers the status quo:

- **Farmers** resist reductions in their water allocations
- **Governments** avoid unpopular decisions
- **Equipment manufacturers** want to sell irrigation systems
- **Donors** often like technology fixes to solve problems
- **Consultants** like to offer positive early outcomes from their proposals to improve efficiency
- **Researchers** like to report on solutions that are manageable with confined experiments.

Source: Perry and Steduto, 2017

4.1.5 From water use efficiency to water productivity

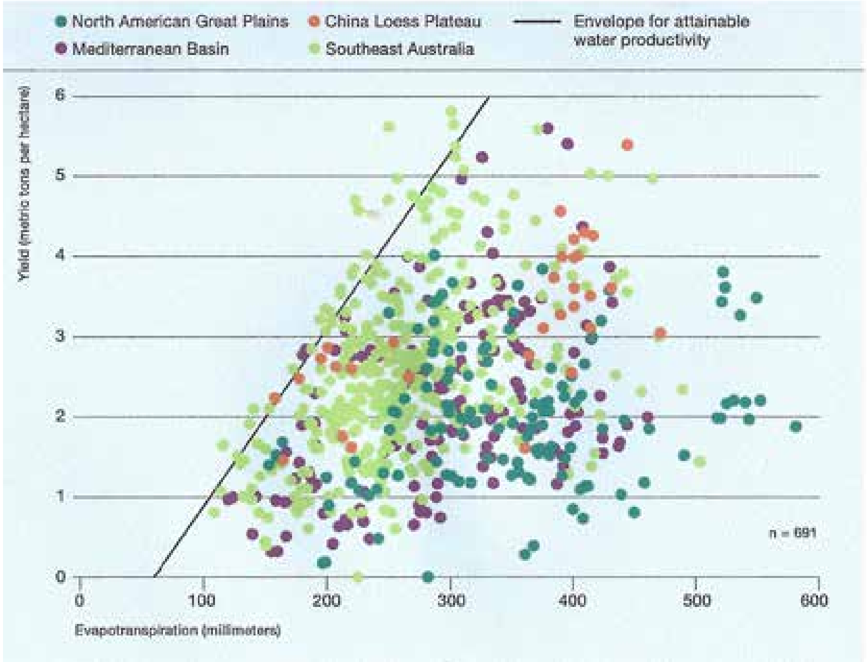
To avoid confusion surrounding WUE, water productivity offers a simple, direct and unambiguous link between water and the benefits that come from irrigation in terms of production, yield, economic value, and the connections with food security. The importance of water productivity depends on the context. Increasing it will be particularly important when a basin is closing (all the water in a basin is allocated). When a basin is still open (some water remains unallocated), other management objectives may take precedent, such as increasing supply to a sector or transferring water to another basin with more pressing needs (Van Opstal *et al.*, 2021).

Water productivity refers to the ratio of physical production (in terms of biomass or crop yield) or, in some instances, the economic value of production (gross or net value of the product) relative to water use (water withdrawn, applied, or consumed). This is expressed in kilograms per cubic metre (kg/m^3) or US dollars per cubic metre (US\$/m^3) and focuses attention on achieving *"more-crop-per-drop"*.
An alternative view from an ecological perspective is *"less-drop-per-crop"*.

Water productivity is not constant and open for comparison like WUE, as farmers often achieve substantially different yields for the same level of water input (ET). A common interpretation is that better water management could maintain crop yield by reducing water consumed by a crop. However, the well-established linear relationship between crop yield and water (crop ET) would suggest otherwise (Figure 4.1). Reducing ET would reduce production (in kg) but not productivity (kg/m^3) or bring about real water savings. Conversely, more water applied usually means a higher yield. Figure 4.1 illustrates both the linear relationship between yield and ET and the effects on yield and water when growing the same crop in different climates, agro-economic zones, and farming practices. In some cases, there is a five-fold increase in yield for the same level of ET. The water productivity data available from the countries in this study (Chapter 2) demonstrate the wide variety of results that are location specific.

The key elements to improve water productivity are (i) increase the marketable yield or value of the crop for each unit of water transpired; (ii) reduce all water losses (drainage, seepage, and percolation), including non-essential evaporative demand; and (iii) increase the effective use of rainfall, stored soil water, and water of marginal quality. The second and third principles impact individual farms and are components of a much broader Integrated Water Resource Management (IWRM) basin approach for water productivity improvement.

Figure 4.1 Variations in the water productivity of wheat (tonnes/ha/ET) in different regions



Source: Giordano *et al.,* 2017 adapted from Sadras and Angus, 2006.

4.2 Options to save water and increase productivity

Although the potential for increasing water productivity and water-saving appear significant, the conceptual and practical challenges of achieving this are also significant. In 1996, Seckler highlighted four basin-scale water management strategies to improve water productivity and achieve real water gains (Seckler, 1996). Seckler suggested the big issues include:

The following options help to put these broad strategies into practice:

- Reducing water lost to sinks (flows into the sea or deep aquifers) and unproductive ET
- Increasing productivity for each cubic meter of evaporated water
- Reducing the deterioration of water quality
- Switching from low to high-value crops to increase economic value.

- **Adopting Water Accounting and Auditing (WA&A)** enables water resources planners to understand better and quantify the significant water volumes that irrigated agriculture needs and allow decision-makers to allocate water volumes for irrigation and negotiate the tradeoffs needed to avoid conflict among water users.
- **Modernising irrigation schemes** can improve the overall performance of large schemes. It can give managers much greater control over water allocations and provide more reliable, timely, and adequate water services to farmers, including the options to limit supplies in times of shortage. An additional benefit is reduced water wastage in the distribution system.
- **Modernising irrigation on farms** can improve farm water management practices to make the best use of available water to increase water productivity, production, and, importantly, farm incomes. This may include hi-tech solutions, such as switching to sprinkler and drip irrigation and options to improve water control over surface irrigation methods (basin, border, and furrow irrigation).

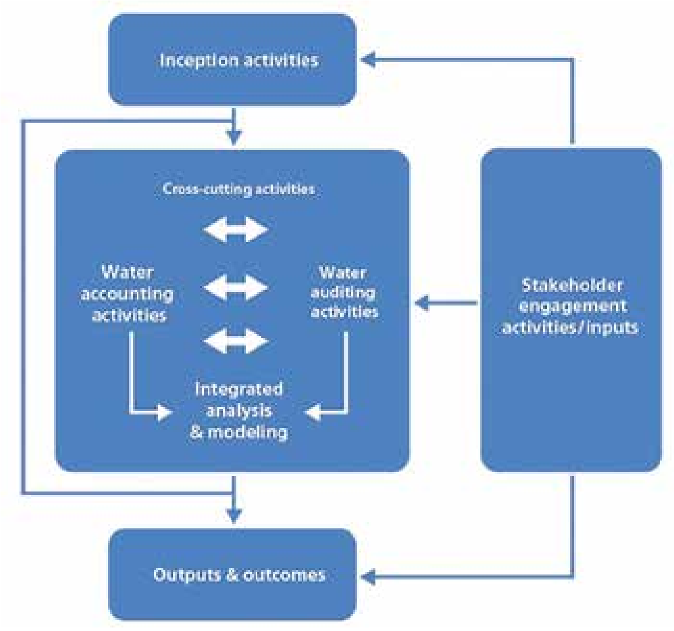
All these options are tried, tested, and available, but the essential element is good governance, without which the technologies are unlikely to succeed.

4.2.1 Water accounting and auditing

A growing number of international organisations are promoting WA&A as a tool for water resources planning and management when water is scarce and risks and uncertainties over water availability increase. When there is competition for water, any analysis must take in the broader hydrological context, and this requires a framework that enables proper comparison and assessment of the requirements of all water users. WA&A provides that framework (Figure 4.2).

Water accounting (WA) is similar to household accounting (FAO, 2018e) (FAO, 2016). Money is a precious and limited asset. It is vitally important to know how much is coming into the home and how much is spent. Budgets and bank accounts all help to keep track of income and expenditure. Businesses also need accounts and accountants to budget and monitor cash flows to ensure profitability and sustainability. Paradoxically, most water professionals do not give similar detailed attention and priority to accounting for water as a precious and limited resource.

Figure 4.2 Overall approach to water accounting and auditing



Source: FAO, undated

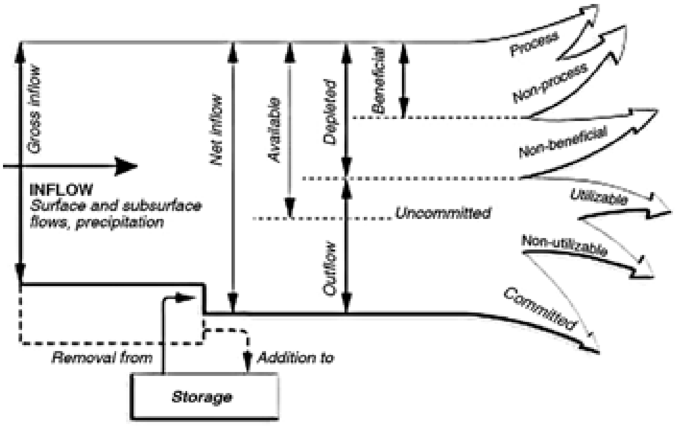
In its simplest form, WA is a hydrological water balance of inputs and outputs and can help make sense of how much is available and allocated to make sure the taps do not run dry. But WA is much more than this. It is essential to understand the hydrological cycle, but WA goes much further. It includes accounting for spatial and seasonal variations in rainfall and the less predictable extremes of floods and droughts. It must take account of medium and long-term changes in demand from all water users: communities, farming, energy, industry, and the environment, and inform water infrastructure investment for pumping, storage, and planning for climate change. It must distinguish between consumptive and non-consumptive use and beneficial and non-beneficial water uses (Figure 4.3). Water accounting is not just for hydrologists. It can help identify problems across different water and water-using sectors within river basins and help build resilience to climate change. This way, WA serves as part of ongoing monitoring and evaluation to improve and sustain water services delivery.

Equally important, WA can help create a common language to interpret and communicate water resources data to the many different people involved in managing water who come from different backgrounds, cultures, interests, and levels of education.

Water auditing provides the connection between WA and good water governance by providing sound evidence for decision-making. Water governance is widely accepted as the major weakness in water resource management in most developing countries. According to the World Bank, the uncertainty about the amount and quality of water available from year to year makes water governance particularly challenging. Like financial auditing, water auditing provides qualitative judgements to the water account. It is the means of placing findings, outputs, and recommendations of water accounting into the broader societal context of water management, water supply, and water services delivery (World Bank, 2006).

The FAO actively promotes WA&A as a water resources planning tool in countries where irrigation is a significant water user and where the challenges of producing more crop per drop are not always fully recognised or well understood by other water users.

Figure 4.3 Water accounting brings together all water flows



Source: FAO, 2018e; Karimi *et al.*, 2013; Adapted from Molden *et al.*, 2003

Water accounting and remote sensing

To plan water resources, agriculture needs to negotiate a fair share of the available resource and answer that critical question: *How much water does agriculture need, now and in the future?* This is a difficult question, but one that needs an answer for governments to plan for future food security. WA and remote sensing can help.

How much water does agriculture need now and in the future?

Most developing countries do not have a water management plan for agriculture even though it is the largest water user. Assessing agricultural water demand is fraught with difficulties because of the many technical and political uncertainties that affect water requirements for home food production.

Unlike domestic water demand, which is narrowly focused on predicting population growth, agricultural demand is a mix of changing drivers and pressures, including national food policy, population growth, lifestyle changes, dietary preferences that transform agricultural systems, and climate change. Within agriculture, the mix of rainfed and irrigated cropping and livestock farming adds to the challenges of planning and managing the pressures on natural resources management that can adversely affect the quality of rural and urban lives, the economy and the environment. Within irrigation, there is only limited monitoring of water withdrawals for irrigation.

Another critical issue is that most countries do not have the physical infrastructure nor the administrative systems to monitor water withdrawals on a volumetric basis. Even fewer, measure how much water crops consume and how much is non-consumptive and leaves the farms as potential return flows.

Most irrigation schemes allocate water on an area basis, (e.g., so many cubic metres per hectare) because the task of measuring water flows into many thousands of small farms and then collecting and using the data to monitor water use, raise invoices, and collect payments for water is not a practical nor a viable option. Simply put, most irrigation schemes have little idea of how much water they consume. If agriculture is to produce water management plans, an evidence base is needed to assess current water use and forecast demands to compete for water allocations at the basin level and manage limited allocations at a local level.

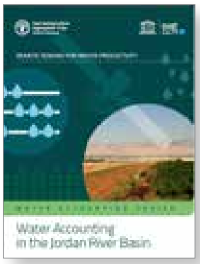
As most developing countries are unlikely to have the capacity to measure the amount of water used for irrigation in the foreseeable future, an alternative is to measure cropped areas and water use (ET) using RS methods (Karimi *et al.,* 2013). Together, WA and RS offer a solution to overcome many of the inadequacies of on-the-ground monitoring. Information derived from high-resolution satellite imagery combined with ground-data truthing has become a reliable source for accounting for crop water use. RS does not require extensive monitoring networks and field data collection. It can identify and map cropped areas, measure ET, and provide data on actual water consumed as an input into WA. The accuracy of RS data allows water consumption to be measured for river basins, irrigation schemes, and even individual farms within schemes.

RS can also monitor and measure the technical performance of irrigation schemes and provide operational and strategic decision support. It can also pinpoint significant differences in technical performance and where agricultural water productivity can be improved. Box 4.9 illustrates examples of WA combined with RS in the Middle East.

If agriculture is to produce water management plans, an evidence base is needed to assess current water use and forecast demands; WA and RS can help

Box 4.9 Water accounting with remote sensing in the Middle East

In Jordan



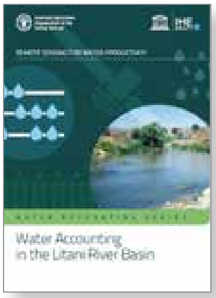
Water scarcity in the Jordan valley is managed using a crop-based quota system for allocating irrigation water. While the quotas are linked to crop water requirements based on three crop categories, the water allocation system lacks transparency and equity. Better estimates were needed to ensure that water was applied according to crop water needs.

To overcome the inadequate ground monitoring of water resources and water use, the Ministry of Water and Irrigation is adopting RS and geographic information systems (GIS) to improve water management at the country level, particularly for water budget calculations and for revising water management plans. The aim of the project is to develop and implement country-wide ET measurement, monitoring, and management system, using demonstrations in pilot areas in the Highlands. The program will provide MWI with estimates for irrigated areas, crop maps, water consumption (ET monitoring), and generate accurate and timely crop/irrigation/ET maps. MWI uses WA tools to calculate the national water balance and support research into optimising irrigation and water resources management.

The first project phase focused on technology transfer and capacity-building. In contrast, the second phase focuses on improving irrigation management activities at the farm-level (related to water consumption, pollution, tariffs). This innovation is expected to significantly strengthen the institutional and regulatory systems for allocating water in agriculture.

Source: FAO; IHE Delft, 2020

In Lebanon



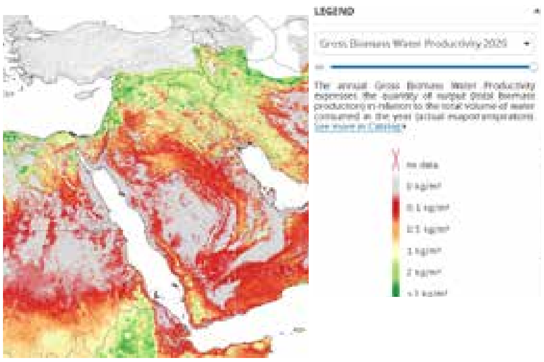
The Litani River basin is a key river basin and is experiencing water scarcity. The population has doubled since 2010 due to the Syrian refugee crisis to some 750 000, and water availability is now only 800 m^3/capita/yr. The growing population, climate change, and groundwater over-exploitation have put the available water resources in the basin under stress. WA systems are being used together with RS to overcome the limited availability of hydrological and meteorological data. This provides a reporting mechanism for water flows, fluxes, and stocks to improve water planning and management. From an irrigation perspective, the system measures irrigated cropped areas and water consumed by crops, thus providing a more realistic picture of water use rather than relying on water withdrawal data.

Source: FAO; IHE Delft, 2019

FAO water productivity open data portal

The FAO water productivity open data portal (WaPOR), uses RS to monitor and report on agricultural productivity over Africa and the Middle East to overcome limited data availability. The system measures irrigated crop areas and water consumed by crops, thus providing a more accurate picture of water use rather than relying on patchy water withdrawal data.

WaPOR also provides gross biomass data water productivity. The figure illustrates gross biomass water productivity for 2020.



Source: https://wapor.apps.fao.org/home/WAPOR_2/1

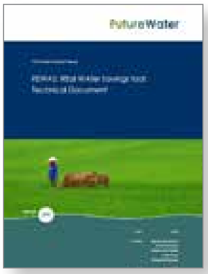
Assessing “real” water savings

The term “real” water savings has emerged from recognising return flows and that some water losses from farms are already being used downstream, but some may well be available for other uses. Real water savings can be assessed using FAO’s Real Water Savings (REWAS) tool developed as part of the FAO’s Water Scarcity Programme. The programme’s guiding principle is to *follow the water* (Kaune *et al.*, 2020). Box 4.10 is an example of the REWAS tool used to assess real water losses in a river basin in Nepal where research reported irrigation water losses of 75%. This study followed the classic definition of WUE and failed to allow for the return flows used downstream. The REWAS approach used WA methods to fully account for all the water flows (following the water) and found that 80% of the losses were recovered and used by irrigators downstream. Real water savings amounted to only 6% of water withdrawals. The rest were "paper" savings and, in practice, did not exist, thus negating the need for significant investment to save what at first appeared to be a much more substantial amount of water.

Operationalising water accounting

The World Bank has published an account of global experiences in operationalising WA from concept to implementation based on initiatives by the Asian Development Bank, FAO, and World Bank (World Bank, 2020). The authors observed that institutional and human capacity limits the adoption of WA and RS approaches. These included: (i) lack of knowledge and skills for using advanced technologies, such as, GIS, RS, and spatial hydrological modelling; (ii) insufficient commitments from country leadership, primarily due to a lack of awareness of the benefits the technology presents; (iii) shortage of financial resources necessary for implementation; and (iv) insufficient internal capacity to assemble, integrate, and share knowledge among relevant government agencies.

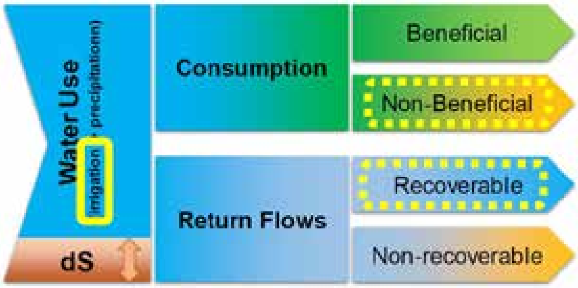
Box 4.10 Following the water for “real” water savings



Future Water as part of FAO’s Water Scarcity Programme developed the ‘Real water savings’ (REWAS) tool to assess “real” water savings in irrigation schemes based on the proven concepts of water accounting.

A river basin study in Nepal reported irrigation water savings of 75%. However, the study failed to “Follow the Water” principle as it assumed that all return flows were losses. Fully accounting for all the water flows, found that 80% of the ‘losses’ were return flows, which were recovered and used by irrigators downstream.

The original study focused only on the amount of water diverted for irrigation and the amount used by the crops. The REWAS analysis focused on the return flows and non-beneficial consumption (dotted yellow boxes) as these were recoverable and could be available for others to use. The results showed that real water saving in the river basin was only 6%.



Some definitions for WA:

Water use is the amount of water employed for a specific purpose (e.g., irrigation, energy, industrial process, domestic washing)

Water consumed can be beneficial (e.g. crop transpiration) or non-beneficial (e.g. soil evaporation).

Return flows are returned to the system and are either **recoverable** (e.g. returned to a river or an aquifer) or **non-recoverable** (flowing to the sea, polluted, or returned to economically unviable sinks).

Water saved is the amount of water resulting from a **reduction in consumption** and in the **non-recoverable** fraction of the return flows that can be made available for alternative uses.

Source: Kaune *et al.*, 2020; Droogers *et al.*, 2020

FAO in the Near East and North Africa region, in collaboration with IHE-Delft report they are taking steps to overcome these human capacity constraints by implementing WA&A capacity building in Algeria, Bahrain, Egypt, Iran, Iraq, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, Qatar, Saudi, Sudan, Syria, Tunisia, Emirates, Yemen, West Bank and Gaza (FAO, 2021b). Building capacity is a slow process (1-2 years to fully train professionals) and a complex endeavour involving training for multi-disciplinary groups typically used to working in silos.

World Bank also identified that most WB, FAO, and ADB task teams currently lack the technical guidance needed to support governments to embed WA in their institutional systems. WA outcomes also largely depend on the local capacity and institutions, though not every application requires advanced and sophisticated tools, such as RS. The key is matching the approach to local requirements and readiness to implement.

A recent World Bank publication: *Mainstreaming the Use of Remote Sensing Data and Applications in Operational Contexts,* offers a perspective on RS applications to World Bank projects and initiatives (World Bank Group, 2018).

4.2.2 Modernising large-scale irrigation systems

Modernizing large-scale irrigation systems can make real water savings, enable irrigation managers to gain much greater control over water allocations, and provide reliable, timely, and adequate water supplies to farmers, including the options to limit supplies in times of shortage. A quota-based system of water allocation among farmers is an option but will need infrastructure investments to provide control over supply and to improve service quality in terms of precise, timely, and reliable delivery.

Large-scale irrigation schemes exist in most Middle Eastern countries, and new systems are being planned and built. They are generally owned and operated by government agencies that supply water and services to individuals and groups of smallholder farmers. Over the past 50 years, large-scale canal irrigation has contributed to increasing food production, reducing hunger and poverty, increasing employment, and securing rural livelihoods. However, critics have suggested that planning and design have remained technically stagnant. Systems have proved challenging to manage, water supplies were often unreliable, and there is a strong disconnect between system managers and farmers unwilling to pay for unreliable services (Plusquellec, 2014). The SUEN publication *Improving irrigation water use efficiency: A synthesis of options to support capacity development (SUEN, 2020)* describes the history of the development and challenges facing large irrigation schemes.

Canal irrigation continues to suffer from poor flow regulation, and there have long been significant discrepancies between design assumptions and actual performance, hydraulically, economically, and socially. Water scarcity exacerbates this situation and is now the primary driver for improving performance by modernising existing schemes and designing new ones to overcome past problems.

Modernisation is not just about saving water and improving water control. FAO coined modernisation as *"a process of technical and managerial upgrading (as opposed to mere rehabilitation) of irrigation schemes combined with institutional reforms, to improve resource utilization (water, labour, economic, and environmental) and water delivery to farms".*

Implicit in modernisation is a shift from traditional supply-driven to demand-driven irrigation and introducing the concept of providing irrigation services to farmers

Implicit in modernisation is a shift from traditional supply-driven irrigation to demand-driven irrigation and introducing the concept of providing irrigation services to farmers." (FAO, 2007a). This is a complex process requiring major changes in scheme design and management.

Modernising irrigation is a means of rectifying past mistakes by taking a more holistic and coordinated approach to improving irrigation performance by upgrading and improving all aspects of an irrigation scheme to respond to modern farming requirements. It is driven partly by farmers who want more flexible and reliable water delivery and partly by governments concerned about making the best use of available water resources and the rising costs of scheme construction, operation, and maintenance.

Modernising irrigation involves two essential and complementary components. The first is upgrading technologies, the "hardware" that goes beyond rehabilitation, as this only replaces what is already there. This is the visible part of a system and involves installing networks and control structures, automation, lining canals, constructing reservoirs, and installing modern information systems to improve management and control. As more than 90% of irrigation in the region uses surface irrigation methods, most technology upgrading needs to simplify canal management and improve surface irrigation performance.

Modernising irrigation technology

Modernisation is often misunderstood and is associated only with high-tech solutions or costly automation. However, Horst argues that modernisation depends on local circumstances, and improvements can be achieved by using simple technologies as well as more sophisticated options. Both are worthy options to consider as they have the same objective in mind: to find technological solutions to replacing manually adjustable systems that have proved so difficult to manage (Horst, 1998).

However, there is one key difference: automation offers the option of *demand-oriented* water deliveries, that respond to farmer demands, whereas simplifying will remain essentially *supply-oriented*, which is 'top-down' and has all the inherent disadvantages associated with this approach.

Automation is attractive because it is seen as modern and up-to-date. Although many existing schemes still use hydraulic control structures and methods developed in the first half of the 20th century, technological advances in automation based on automatic and remote control, computer modelling, and advanced communication systems are already in use, mainly in Australia, France, and the USA. Automation significantly reduces the number of staff needed to operate and maintain systems, but at the same time, it changes the skills required. Passive automation uses float-operated gates that respond to farmer demands. Active automation relies on electronic systems to remotely operate adjustable gates and emulate the work usually undertaken manually by managers and gate operators. Such systems require instrumentation to measure the control variables such as water levels, gate openings and discharge; motors to change gate settings; and communication links to receive information from sensors and transmit instructions to change gate settings. Such systems include telephones, cabling, and remote signalling using radio or satellites. Telemetry requires power at the sensing point, and solar energy is increasingly used in remote locations. A challenge for remote control in developing countries is maintaining systems and the risk of theft.

A challenge for remote control in developing countries is maintaining systems and the risk of theft

In 2014 the American Society of Civil Engineers (ASCE) published the results of a Task Committee on recent advances in canal automation (Wahlin and Zimbelman, 2014). This Manual of Practice (No 131) is the most up-to-date publication on automation for canal systems.

Automation need not be sophisticated. Simple technologies can bring about significant improvements in performance. This includes proportional farm offtakes that reduce flows into farms in proportion to reduced flows in the canal system, on-off gates, and stepwise distributors like baffle (modular) distributors that deliver constant discharge irrespective of upstream water levels. Intermediate reservoirs are another option, as is converting canals to low-pressure pipe systems that can respond rapidly to changes in demand. Night storage reservoirs are helpful to balance supply and demand at farm level, and fixed broad weirs, rather than adjustable gates, can simplify water level and discharge control both in the system and on-farms (Horst, 1998).

Managers need to be able to control and measure water allocations. Clemmens commented that water measurement is a key component of water control (Clemmens, 2006). When water is in short supply, on the basis that you cannot manage what you cannot measure, a major challenge for irrigation managers is to measure water flows in canals and volumes of water delivered to farms. Engineering solutions have been tried in the past, such as installing flow measuring devices. On large schemes comprising a few large farms, this is a practical option. However, on schemes with many thousands of smallholder farms, this is unlikely to work well.

Reports suggest there was a dearth of dedicated trained canal operators to gather data and a lack of administrative structures and effective canal management to use the information for canal operation. Modern computing and RS is now offering a solution enabling irrigation managers to measure the volumes of water used by farmers.

Such tools are discussed in section 4.2.1 to plan water resource allocations across all water-using sectors. Such tools can also provide almost real-time data for monitoring water use to check that farmers are irrigating well and following the rules, and provide a means of charging for water on a volumetric basis.

Lining canals is an option for reducing seepage and improving water control, but care is needed to ensure that reducing seepage produces real water savings and is not just blocking return flows that others rely on for supply. Open canals are still the most common means of conveying irrigation water on schemes. They are usually constructed in natural soil and require regular maintenance. Some canals are lined with clay, concrete, or geotextiles to reduce seepage, improve canal performance, and reduce maintenance, though installation and maintenance costs can be high. Factors influencing conveyance efficiency include canal size, shape, and slope; water losses from seepage and evaporation; how well they are maintained to avoid erosion, siltation,

weed infestation; and the degree of control and automation used to control water flow. A strong reason for investing in canal lining is to improve flow control in canals. Canal lining also provides accurate geometry that aids automation. Precise canal shapes are vital to support the mathematical algorithms used in unsteady flow simulation models of canal systems.

Modernising irrigation management

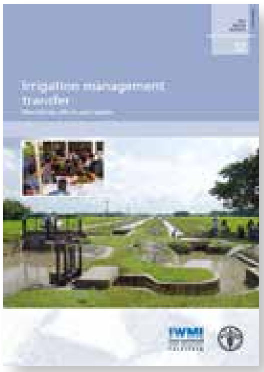
Modernising irrigation management is the "software" and is mostly invisible but is an essential complement to the "hardware" improvements in irrigation infrastructure. It involves upgrading irrigation management and the supporting institutional structures to ensure they have the capacity and capability to provide irrigation services appropriate to modern farming.

The concept of service is fundamental to modernising irrigation management. Irrigation agencies have often been deficient in defining and monitoring their service to farmers. Modernisation requires a major shift from the past when irrigation agencies traditionally adopted a *top-down* and a *supply-oriented* approach to irrigation management and operators told farmers how and when they would receive water, rather than listening and responding to the needs of farmers. The concept of irrigation service was introduced in the 1980s together with methods to evaluate service quality in terms of flexibility, reliability, and adequacy (Burt, 1996). In a modern irrigation scheme, farmers should expect a level of service that defines water quantity and quality and how reliable, timely, and flexible the irrigation water delivery should be from the source to farm. Flexibility is closely related to improvements in agricultural performance and is defined in terms of frequency, flow rate, and duration. There is a tacit assumption that providing farmers with a well-defined level of irrigation service will lead to increases in WUE and improve the overall performance of medium and large-scale irrigation schemes (Facon, 2005). The notion of service is important when farmers are expected to pay for water, particularly when in the past it was delivered free.

Participatory irrigation management (PIM) has been a prevalent theme in irrigation for over 40 years. Indeed, an international network on participatory irrigation management (INPIM) was established in the 1980s to promote PIM (though now disbanded). The participatory movement has long advocated that the size of government should be reduced and that people should participate more in governance, management, and financing development to promote sustainable and equitable development. Participation promotes the subsidiarity principle of making decisions at the lowest level possible and introduces the concept of self-reliance as a development strategy (FAO, 2007b).

PIM is about farmers engaging with the government in irrigation decision-making. Farmers can be involved in various management functions, including planning, design, operations, maintenance, rehabilitation, resource mobilisation, and conflict resolution. The involvement can be at multiple system levels from the field channel to the entire system (Svendsen *et al.,* 1997).

Today, the idea of farmer participation is now well accepted. It is almost unthinkable for irrigation planning, design, and significant changes to occur without some form of involvement that goes beyond mere consultation. Participation is a central feature within IWRM and is enshrined in Sustainable Development Goal (SDG 6) in the UN 2030 Development Agenda (Ortigara *et al.,* 2018).
PIM lies within IWRM, where irrigation water demands can no longer be dealt with in isolation and must be considered alongside domestic and industrial demands and water for the environment. Collaborative modelling is gaining momentum as a water resources planning approach that formally brings together water users and technical experts. Thus, developing models is not just an analytical process for computer programmers but one that builds consensus, trust and improves decision-making (GWP, 2017).



Irrigation management
transfer

IWMI

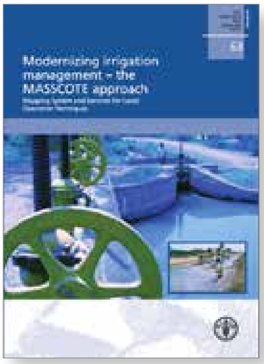
Irrigation management transfer (IMT) is a more specialised aspect of PIM and is distinct from farmers participating *with* irrigation agencies. It is a process of shifting irrigation management functions *away* from government and irrigation agencies to private sector entities, such as non-governmental organisations (NGOs), or more commonly, farmer groups like Water User Associations (WUAs) (Vermillion and Sagardoy, 1997). WUAs decide what services they need and are willing to pay for and negotiate with the irrigation agency to provide the services. The key to IMT is defining irrigation services and how the irrigation agency will provide them. IMT fits well with the concept of modernisation and is seen as an essential part of the reform process to improve irrigation management capacity.

The most comprehensive review of IMT in 42 countries, including Turkey, which introduced IMT in 1994, was undertaken by FAO in 2007 (FAO, 2007b).

Their conclusions are many and detailed, but overall, they found that:

- IMT does not necessarily lead to increases in cropping intensities or yields, though there were no cases where agricultural productivity decreased.
- IMT has led to improvements in communication between farmers and irrigation managers. There has been an increase in accountability and responsibility in providing irrigation services.

These changes need strong political support at the highest level and an enabling environment that provides farmers with incentives, manageable risks, and uninterrupted access to markets (FAO, 2007b).



The MASSCOTE approach (Mapping Systems and Services for Canal Operating Techniques) methodology, was designed by FAO to assist technical experts, irrigation professionals, and scheme managers in modernising schemes (FAO, 2007a). The entry point is canal operation, but the focus is on identifying targets, including finance and water use and meeting environmental requirements. Although mainly based on FAO experience in Asia, MASSCOTE is a generic methodology that applies to medium and large irrigation schemes elsewhere. The methodology seeks to stimulate a critical sense among scheme managers to diagnose and evaluate obstacles, constraints, and opportunities and develop a consistent modernisation strategy.
A step-by-step approach is offered to convert complex circumstances into simple elements that can be explored and improved. FAO is developing a similar methodology for pressurized systems, MASSPRES (Mapping System and Services for Pressurized Irrigation), to enable scheme managers to optimize sprinkler and drip systems designed to respond to irrigation on-demand.

Saving water is a priority for governments and irrigation scheme managers; it is not usually a priority for farmers

4.2.3 Modernising on-farm irrigation systems

Although saving water is a priority for governments and irrigation scheme managers, it is not usually a priority for irrigating farmers who are more concerned about saving money and maximising profits. Farmers are often more concerned about irrigation costs, the financial benefits of crop yield and quality, and resilience to water scarcity.
An indirect benefit of addressing these concerns is usually water savings which can benefit the river basin.

Modernisation also requires “hardware” improvements on farms, such as control systems that simplify canal management and provide farmers with flexible and reliable water supplies. Reliability creates confidence in managers and farmers, enabling them to switch off water supplies when irrigation ends. Where appropriate, farmers can also consider switching from gravity fed to pressurized sprinkler and drip irrigation to improve control over water application. Installing drainage can help to remove excess water and control salinity.

Famers need encouragement to adopt best practices, including ranking irrigation highly within farm management activities, understanding the interactions between soils, crops, and water, scheduling irrigation, using objective monitoring tools, and remaining open to new ideas, such as solar pumps for renewable energy. Benchmarking also helps farmers improve performance and, together with WUAs, can provide opportunities for farmers to work together to share ideas, compare performance, and transfer knowledge. Understanding and applying best practices can help to ensure that farmers become water stewards in agriculture.
(see section 4.4.1 Water stewardship in agriculture).

From a farmer perspective, there are many aspects of their irrigation system and farm management to consider, and the importance of each will depend on the local circumstances. Farmers should think about efficiency as a goal to be achieved by taking a holistic approach to improving all aspects of on-farm irrigation, rather than calculating a single number, which is often confusing and has little meaning in practice. This approach is the *pathway* to farm irrigation efficiency (Figure 4.4). Assessing performance in this way also makes the point that the pathway is not a one-off procedure or measurement. Instead, it is an ongoing process of iteration over the life of the farm irrigation system (Knox *et al.,* 2009).

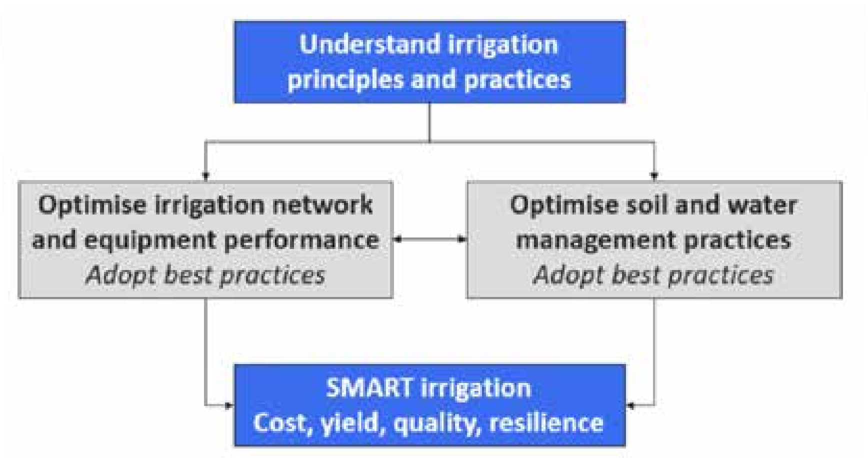
Optimising the various components of an on-farm system leads to SMART (Sustainable, Managed, Accountable, Responsible, and Trusted) irrigation and to an operating level that is practical and appropriate to local circumstances not just in terms of water use but also cost, crop yield, quality, and resilience.

Irrigation methods

Although there are many ways of applying irrigation water, there are essentially three main methods. They are described briefly here but in much more detail, including their advantages and disadvantages and methods of evaluating their effectiveness in the SUEN publication *Improving irrigation water use efficiency: A synthesis of options to support capacity development* (SUEN, 2020).

> Farmers should think about efficiency as a goal to be achieved by taking a holistic approach to improving all aspects of on-farm irrigation

Figure 4.4 A pathway to improving farm irrigation performance



Source: SUEN, 2020

Surface irrigation (basin, border and furrow irrigation) is the most widely used method and accounts for over 90% of the irrigated land area: Basin irrigation is the most common method, followed by furrow irrigation and then border irrigation. Understanding these different techniques is fundamental to ensuring adequate, uniform, and efficient irrigation.

Sprinkler irrigation comes in many shapes and sizes to match different crops, soils, climate, site conditions, nd different water, labour, and capital constraints. Basic components include a pump to pressurise the system, pipes to distribute water and sprinklers to spay water over the land under pressure.

Drip irrigation is increasingly adopted for use on many crops though globally, it only accounts for about 1% of the irrigated area. Applying small amounts of water slowly and frequently through emitters spaced along polyethene tape or tubing offers improved yield, more accurate and potentially more efficient irrigation. Best in places where water is scarce, soil conditions and water quality are poor, and labour is scarce or expensive.

Although there is growing interest in switching from surface methods to hi-tech sprinkler and drip methods, surface methods still dominate world agriculture, accounting for about 90% of the irrigated land area. Surface irrigation still dominates irrigation in Iran, Iraq, Syria, and Turkey and will continue to play a significant role in the future. Thus, it is incumbent on policymakers to ensure that irrigation managers and farmers follow pathways to improve surface irrigation methods. There are many ways of improving the performance of basins, borders, and furrows but much depends on local circumstances (SUEN, 2020). WUE can be increased through evaluating and improving methods on farms and also introducing hi-tech solutions, such as low-pressure pipe delivery systems and automatic regulators on canals (Figure 4.5). If farms are located in open basins, where there is still water to allocate or where farms downstream depend on return flows for their supply, investing in improving WUE to reduce losses, particularly on farms in the upper catchment, may not be beneficial. Nor indeed would switching to hi-tech irrigation because there would be little gain. Switching large areas to hi-tech will also be costly, and may not produce the water savings that are often the reason why switching occurs (see section 4.1.4).

Figure 4.5 Typical automatic gate and pipe systems to control water flow onto farms

Optimising soil and water management

Optimising soil and water management practices ensures that water applications are managed (scheduled) according to crop water requirements without unnecessary waste, avoiding over-irrigation and surface run-off. This requires a thorough knowledge of the water requirements of crops and the hydraulic properties of soils (Brouwer *et al.*,1985).

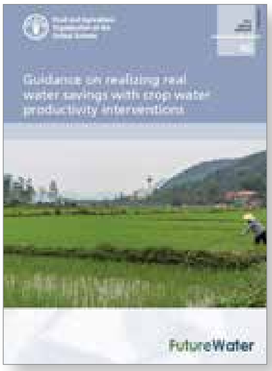
Scheduling irrigation is about putting the right amount of water into the soil in the right place at the right time (Brouwer, Prins and Heibloem, 1989), (Saskatchewan Government, 2016). Day-to-day irrigation management requires farmers to address *when to apply water and how much to apply?* The objective is to maintain an optimum soil water environment for crop growth. This may not necessarily mean for maximum yield; the aim may be the most economical yield, best crop quality, or the highest water productivity.

Scheduling irrigation can improve water use on farms using modern techniques, such as soil moisture measuring devices and weather station data. However such technologies are of little use on traditional large-scale irrigation schemes as there is insufficient control over water flow to farms and systems lack the flexibility to enable farmers to apply water as and when the crops need it.

Burt summarises this issue: *"There is absolutely no point in discussing modern irrigation scheduling, soil moisture measurement devices, and water measurement with farmers who receive water on a rotation basis or if the farmer does not have the ability to modify the duration of water delivery. The reason is simple; the farmer has no control over the topics (scheduling tools) being discussed. In other words, unless irrigation water is available 'on-demand' or true arranged schedule, these principles do not apply"* (Burt, 1999).

Improving water productivity

Most water productivity gains come from reducing losses on farms and switching to more appropriate technologies. But irrigation practices such as deficit irrigation can also increase water productivity. During crop growth, farmers can reduce the amount of water they apply and extend the interval between applications without unduly affecting the crop yield and quality. The effect is to increase water productivity. This technique relies on a good understanding of the relationship between water and crop yield and the more sensitive stages of crop growth when a lack of water can seriously affect yield (see also section 4.1.5). The relationship linking ET to yield has served farmers well for the past 40 years or so, but science has now developed a deeper understanding of how crops grow and respond to water and the lack of it, and so more sophisticated techniques, such as FAO's AquaCrop, are now available that enable farmers to provide the right amount of water at the right time for optimum yield and water productivity (Doorenbos and Kassam, 1979) (see Box 4.11). As with most farm irrigation practices, farmers need to have reliable access to water and full control of flow rates to take advantage of this technique.



FAO's *Guidance on realizing real water savings with crop water productivity interventions* (Van Opstal *et al.*, 2021) offers an intervention framework for water savings based on water management practices, soil and land management and agronomy, following an extensive search and analysis of available literature.

Most interventions for achieving higher water productivity will come from agronomic practices. These include improving soil water holding capacity, using mulches to reduce evaporation from moist soils, and between crop rows. Although not directly an irrigation matter, improved nutrient management and integrated weed and pest management can also increase water productivity.

Real water savings will come from selected agronomic and water management practices. Advances in crop science may lead to new crop varieties and breeds requiring fewer inputs per output unit. Similarly, agronomic practices such as mulching, zero-tillage, laser land-levelling, alternating wetting and drying, and deficit irrigation may require less applied water per unit output as non-beneficial evaporation is minimised.

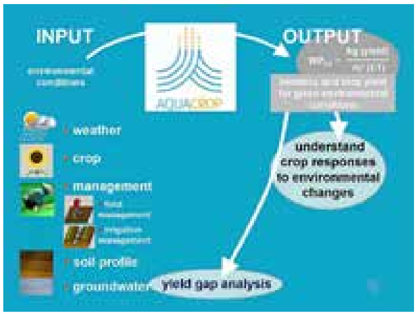
Should water productivity include water losses on the farm as consumption? When farmers are paying for water on a volumetric basis, then it would be of value to include losses as they represent a cost of production. Reducing losses would then reflect an increase in water productivity.

Expressing water productivity as farm income per cubic metre can also help farmers decide which crops to grow. In Jordan, for example, water productivity on farms varied from US\$0.3/m^3 for potatoes to US\$0.03/m^3 for wheat (FAO, 2003b).

Box 4.11 AquaCrop – linking soils, crops, and water to improve water productivity

The relationship between biomass production and water consumed through transpiration is well known and was adopted by FAO in 1979 when they first published information on the yield response of a wide range of irrigated crops (Doorenbos and Kassam, 1979). Water stress and reduced transpiration results in reduced biomass production that in turn normally reduces yields. The approach that linked a reduction in ET to a proportional reduction in yield, has served irrigators well for some 40 years but it suffers from drawbacks as a result of aggregating variables, i.e. it refers to the final yield rather than its components and ET rather than transpiration. As a result, the yield response factor has proved, in several cases, to be significantly variable.

In 2012 FAO published **AquaCrop**, which supersedes the 1979 version. This is centred around a crop growth model that simulates yield response to water of herbaceous crops and is particularly suited to address conditions where water is a key limiting factor in crop production. The model deals with complex biophysical processes linking water and crop growth but is designed to be simple to use yet accurate and robust. It relies on a relatively small number of explicit parameters and mostly intuitive input variables requiring simple methods for their determination. However, the calculation procedures are grounded on basic and often complex biophysical processes to guarantee an accurate simulation of the response of the crop in the plant-soil system. As a planning tool AquaCrop can provide a baseline for productivity analysis, taking into account major crops, irrigation regimes, and agricultural practices in the cropping season.



Source: Steduto *et al.*, 2012

4.2.4 Water storage

Water storage is an ideal asset for balancing supply and demand, managing uncertainties and variability, and building resilience to climate change. On irrigation schemes, overnight storage allows farmers to continuously take water from a canal system and irrigate their crops according to crop water needs rather than a fixed water schedule determined by scheme managers. Conjunctive use in irrigation using natural groundwater storage and built surface water storage is another example of balancing water supply with variable daily and seasonal irrigation demand.

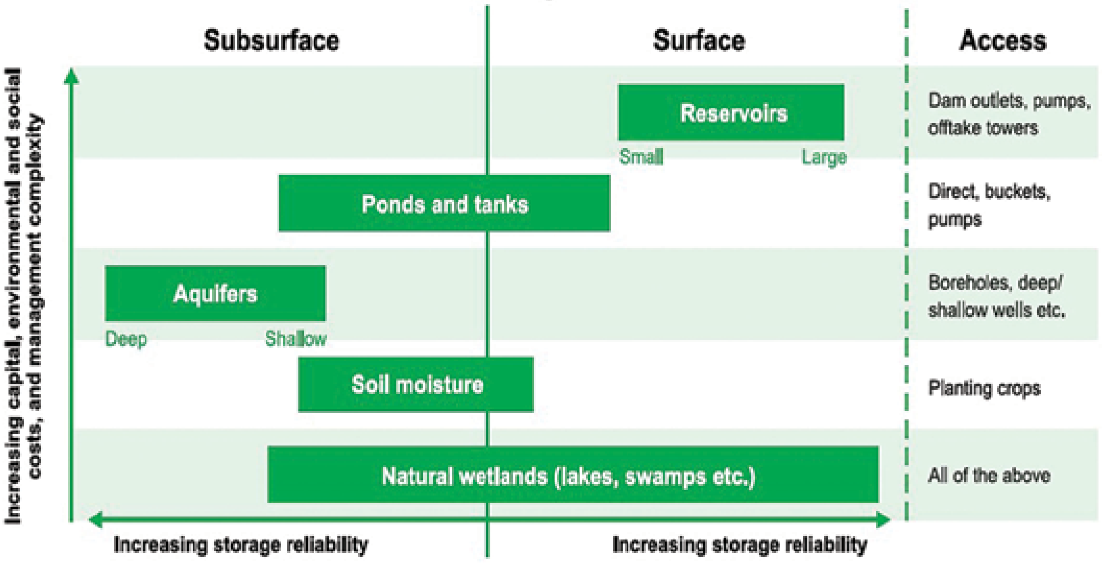
GWP and IWMI recommend that the current silo approach to storage needs rethinking and a more integrated approach adopted (Figure 4.6). There are many different kinds of storage, natural and built, that can come together to provide multiple socio-economic benefits (GWP; IWMI, 2021).

4.2.5 Water harvesting

Rainwater harvesting links rainfed agriculture and supplemental irrigation. It offers opportunities for improving water productivity in dry regions and can boost yields 2-3 fold over rainfed production, especially when combined with minimum-tillage methods that enhance water conservation (Oweis, 2016). Water harvesting can also augment irrigation water supplies and improve household access to water (Box 4.12).

"Water Harvesting – Guidelines to Good Practice" provides comprehensive and practical advice covering a wide range of flood, macro and micro catchment, and rooftop/courtyard water harvesting techniques (WOCAT, 2013).

Figure 4.6 The water storage continuum



Source: GWP; IMWI, 2021

Box 4.12 Rainwater harvesting in the Jordanian Badia

The main challenges facing livestock development in arid and semi-arid regions such as Jordan are overgrazing and degradation, low land productivity, soil erosion, low income for the rural communities and migration from the Badia to urban areas.

The IWRM programme techniques are effective tools in rangeland restoration and in improving land productivity. The general objective is to restore degraded rangeland and improve the production in Badia rangeland by more efficient use of rainfall through the proper and effective implementation of water harvesting.

Water harvesting can improve the control over surface runoff, increase soil moisture, conserve the soil, improve the natural plant cover, and improve vegetation production. Water harvesting can maximize the benefit from runoff to grow fodder shrubs. The most well-known plant species to suit drought and salinity conditions in the eastern Mediterranean arid land are *Atriplex*.

Source: Input by NARC, 2020

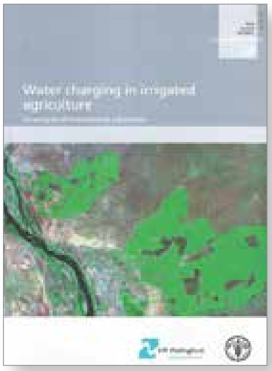
4.2.6 Sustainable soil management and soil health

Pressures and risk in chapter 3 raised the concerns over human-induced land and soil degradation due to erosion, salinisation and, pollution which are high alongside water scarcity on the global agenda. Healthy soils play a key role in improving water productivity and crop production.

Managing soil salinity involves reducing evaporation from the soil surface by controlling water applications to meet crop demand and providing a leaching fraction to maintain an acceptable salt balance in the soil. Excess water is leached through the soil profile into underground tile drains and open ditches for disposal. Plastic soil mulching can also improve water and salt balances, but this may have environmental impacts.

Some countries now accept saline drainage water and adopt biosaline agriculture with selected salt-tolerant crops and appropriate cropping patterns and management practices. If planned at the basin or landscape level, this adaptive approach can reduce environmental degradation and contribute to ecosystem restoration in drylands. A handbook for saline soil management (FAO, 2018f) provides innovative methods and technologies for ameliorating salt-affected soils.

4.2.7 Do water charges improve performance?



Economists see irrigation as an obvious case for introducing volumetric water pricing to reduce overconsumption and raise efficiency, but in reality, the issue is far from simple. A study commissioned by the FAO focused on applying charging tools and the practical lessons drawn from documented case study experience (FAO, 2004). The findings were designed to be of value to national policy-makers, donor agencies, and researchers who formulate or advise on irrigation policy.

Firstly, there is confusion over terminology. A wide range of terms is used to describe payments made for irrigation services and the costs incurred. Water charges include all the payments that a beneficiary makes for irrigation services, which may be fixed, volumetric or crop-based.

A water charging system embraces all the practicalities required to set a level of cost recovery and how the charge will be levied and collected. Water price is often synonymous with charges, but it means the payment per unit volume of water supplied to the farm. Most developing countries cannot monitor flows or volumes withdrawn by farmers, although this may be changing as RS offers a means of measuring crop water use. Charges are primarily area-based charges (US$/ha) with the tacit assumption of a fixed amount of water delivered to the farm. This is essentially a land payment rather than a water charge. But not everyone pays for water. It is unacceptable to charge for water in some cultures and political contexts. While in others, the practicality of metering, invoicing and collecting a relatively small amount of money from tens of thousands of smallholder farmers can become prohibitively expensive and a nightmare to administer.

The cost of water must be distinguished from the price, though they are the same for a farmer. Most common is to recover the costs of O&M – the direct expenses incurred in providing the irrigation service – though some argue that there should be an element or full cost recovery for the capital investment in irrigation schemes (GWP, 2000). Much theoretical work has been done on the economics of irrigation water pricing. However, there is still a considerable lack of understanding of what impacts can be realistically expected from water pricing policies in practice.

The FAO study concluded that the effect of volumetric water charging on water saving was minimal, as current prices tended to be well below the levels that farmers considered water saving was a significant financial consideration. Indeed, studies indicated that volumetric prices would need to be 10-20 times the price required for full supply cost recovery to affect demand. There are very few places where the price is the primary control method in irrigation. Studies indicated that the price would need to be at least 20% of net income to impact water use significantly. In many countries, the price paid may only be a few percentage points of net income.

Although the agriculture sector is seen as wasteful in its use of water, the available evidence suggests that pricing incentives do not always reduce losses.

No country relies on pricing alone to balance supply and demand

Firstly, individual farmers have no control over the losses in the canal system, which account for approximately half the losses in a scheme. Secondly, where farmers take excess water, return flows to the river or aquifer will mean that the overall level of water availability in the basin is not seriously affected, although the costs of service delivery may increase. If farmers are faced with increasing charges for water delivered, they may choose to improve on-farm efficiency, which perversely may increase consumption despite reducing demand for water deliveries.

FAO suggests that introducing a water charging policy is likely to be part of a larger package of measures designed to provide good irrigation services for which farmers are willing to pay. But FAO's study of water charges reviewed over 25 studies and found that physical sustainability was never achieved through water pricing alone. Broadly, two types of intervention can restrict and reduce water consumption – pricing and some form of constraint on demand through rationing or a quota system. No country relies on pricing alone to balance supply and demand (Perry, 2018).

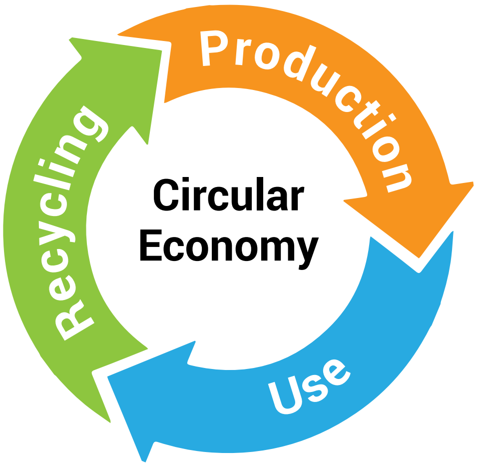
4.3 Options beyond the farm

Many activities beyond the farm also contribute the making wise use of limited water resources. Some are discussed briefly.

4.3.1 Circular economy

The benefits of a circular economy are just as applicable to agricultural water management as to the broader land-use and food systems. This approach creates opportunities to use non-conventional waters that might otherwise go to waste, such as saline and brackish water. Wastewater remains a largely untapped resource because the capacity to treat waste from cities is often inadequate. Most wastewater is discharged without treatment into the environment. It either runs to waste, or is diluted in the region's waterways and reused downstream in some countries to irrigate millions of hectares of cropland, often unintentionally posing serious risks to the health of farmers and consumers and the environment. Wastewater must be safe to reuse and is a requirement of SDG 6 to halve the proportion of untreated wastewater by 2030. One constraint is monitoring water quality, and a requirement is to increase and improve data collection.

In the Middle East and North Africa, the International Water Management Institute and the Middle East and North Africa ReWater programme (whose partners include FAO, the International Center for Advanced Mediterranean Agronomic Studies and the International Center for Agricultural Research in the Dry Areas) support capacity development on water reuse in agriculture, addressing barriers and promoting safe reuse practices that improve food safety, health and livelihoods (IWMI, undated).



4.3.2 Food losses and waste

Food loss and waste (FLW) is a function of marketing and distribution that ultimately influences land use. Reducing FLW is one measure to improve food security, lower production costs, reduce pressures on natural resources and improve environmental sustainability. The SDG Target 12.3 calls for halving per capita global food waste at the retail and consumer levels and reducing food losses along production and supply chains by 2030 (UN, 2015).

The *State of food and agriculture 2019* report distinguishes between food "loss", which occurs post-harvest, but not including the retail level, and food "waste", which refers to the decrease in the quantity or quality of food resulting from decisions and actions by retailers, food service providers and consumers (FAO, 2019). This aligns with the distinction implicit in SDG Target 12.3.

Food loss and waste represents an inefficient use of valuable agricultural resources and causes avoidable environmental degradation (HLPE, 2014). Globally, FLW accounts for 24% of total freshwater withdrawn for food crop production, 23% of cropland area and 23% of fertilizer use (Kummu *et al.*, 2012). Halving FLW would provide enough food for approximately 1 billion people. Alternatively, resources used to grow FLW could be redirected to higher-value use or support more environmentally sustainable agricultural production and consumption.

Globally, FLW accounts for 24% of total freshwater withdrawn for food crop production

4.3.3 Promoting sustainable diets and consumer options

Rapidly rising incomes and urbanisation are driving a global change in lifestyle and food consumption patterns, in which traditional diets are being replaced by diets higher in animal-based foods, in addition to refined sugar and fat (FAO; IFAD; UNICEF; WFP; WHO, 2018).

Dietary shifts have traditionally promoted health and well-being but are now linked to reducing the environmental impacts of food production including the impacts on water resources (Springmann *et al.,* 2018; IPCC, 2019). Dietary patterns with low environmental impacts can also be consistent with good health (Gonzalez Fischer and Garnett, 2016). However, researchers have not yet calculated the adjusted land and water resource requirements to service the change in crop production to substitute for animal protein.

4.3.4 Making use of ICT and big data

Opportunities are emerging from advances in ICT, and its application to agriculture can also help improve productivity, manage associated environmental risks, and ensure sustainable land and water management.

Recent advances in Information and Communication Technologies (ICTs), Big Data Science, Earth Observation Systems (EOS), Open-Access (OA), Artificial Intelligence (AI), Machine Learning (ML), and Cloud Computing Platforms (CCP), along with Smartphone-enabled Citizen Science (SCS), have increasingly made Big-Data analytics much smarter and more useful for agricultural planning and management. They have also created baseline information for better-informed decision-making and opened up opportunities to fill knowledge gaps at multiple levels (e.g., data, yield, ecology, economy, and resilience) and scales (e.g., space, time, and package) to target demand-driven interventions for sustainable land and water management.

4.4 Water governance

FAO defines governance as the formal and informal rules, organisations, and processes through which public and private actors articulate their interests and make and implement decisions. Governance issues arise in various public and private settings, from local communities, farms and cooperatives, business organisations, and large-scale enterprises, to local, regional, national, and international contexts.

Good water governance is essential for building capable and informed institutions and organisations that can respond to change and are open and transparent. However, achieving this with clear development objectives and commitment is still one of agriculture's most significant challenges for most developing countries (UN, 2018). Large irrigation schemes built last century, for example, paid little attention to governance and instead focused on supply-driven, infrastructure-led solutions that ignored the interconnections within a river basin as decision-makers devised responses to individual problems. Change is needed.

Many governance functions lie with the government and include formulating policy, developing legal frameworks, planning, coordination, funding and finance, capacity development, data acquisition and monitoring and regulation.

However, they increasingly cooperate with other stakeholders, including the private sector. Participation and multi-stakeholder engagement are now widely accepted as essential elements in formulating policy and planning, as is the need for neutral platforms that enable government, farmer groups and other citizen groups to engage in planning and decision-making to improve water services. Introducing Water Stewardship in Agriculture (WSiA) can encourage all those involved in irrigation and farming to become water stewards and appreciate and understand the importance of water to their livelihoods and their role in ensuring sustainability.

This report has described some of the myriad technological and management solutions emerging from research and practice to tackle the challenges of water scarcity and land degradation. However, these do not automatically lead to solutions to the problems. Solution packages will only succeed when there is a conducive and enabling environment, strong political will, sound policies and inclusive governance, and full participatory planning processes across all water and water-using sectors.

Good water governance is not just about agriculture. It will also be the key to putting IWRM into practice as the demand for greater cooperation across the water sector continues to grow.

FAO recommends integrating land and water governance and suggests several responses that promise effective transformation (FAO, 2021a).

Water stewardship

Water stewardship is the use of freshwater that is socially equitable, environmentally sustainable and economically beneficial, achieved through a stakeholder-inclusive process that involves site and catchment-based actions. Good water stewards understand their water use, catchment context and shared risk regarding water governance, water balance, water quality and important water-related areas.

Source: SAI, 2015.

They include developing coordinated and coherent policies and approaches, addressing emerging issues such as climate change, integrating land and water planning and management, devolving governance and addressing power differentials, and adopting adaptive governance to enable governments to resolve the challenges facing agriculture.

4.4.1 Water stewardship in agriculture

Water Stewardship in Agriculture (WSiA) is an integral part of good water governance. Farmers need encouragement to become water stewards and share joint responsibility for water resources rather than just be thought of as abstractors (World Bank, 2020). It is another step in collective stakeholder engagement that can bring a farming perspective to water resources planning and management and instil a sense of ownership among farmers for their actions as water users when pursuing objectives of increasing water productivity and profitability.

Water resource managers are driven by issues of sustainability at basin and national scales. However, farmers are not always well informed about the importance of saving water for the national good and often lack adequate means, incentives, and assistance to adopt better practices. They may be unaware of existing on-farm losses, unable to identify ways of saving water, and not see any financial benefits in changing their practices (Levidow *et al.,* 2014). Engaging farmers in water resources management will take time. At the heart of the process, there is a need for an engagement action plan that identifies stakeholders, their roles, relationships, and responsibilities.

From this engagement, agricultural water management and water service plans can be developed, defining water management objectives in agricultural zones that link to broader river basin management plans with agreed interventions at the farm, system, and basin level.

Providing farmers with opportunities to become water stewards can bring significant benefits. Yet, the public sector has been slow to recognize them and the benefits of collective action among agricultural water users. There is a gap between what is potentially a significant opportunity for public sector reforms and the enabling legal and institutional environment. Filling this gap will require strong leadership from national governments and greater decentralisation of responsibility (subsidiarity) for resource planning and management (Newborne and Dalton, 2016).

WSiA can benefit from the experiences in corporate water stewardship schemes that provide a framework for major water users to understand their water use and impacts and work collaboratively and transparently for sustainable water management within a catchment context (AWS, 2014).

4.4.2 Developing capacity

Good water governance is underpinned by strong formal and informal institutions and human resources.

Countries in the Middle East have a long tradition of irrigation and government organisations have a legacy of knowledge and experience of irrigated agriculture. Despite the conflicts in parts of the region over the past two decades it is anticipated that the corporate memory of these organisations is still strong. For some countries and regions, the questions focus on how to modernise existing systems and institutional structures and deliver changing services to farmers; while for others there may be urgent need to re-build capacity curtailed by years of turmoil. Thus, countries across the region will have different priorities and capacity needs.

In 2004 FAO highlighted a consensus among policy-makers in the developing world that a lack of capacity was constraining development in irrigation agriculture (Kay and Renault, 2004). This was not a new issue, but training was usually considered more of a bolt-on to infrastructure investment projects rather than a mainstream activity. However, in 2018, the UN review of SDG 6: the Water Goal (UN, 2018) (Ortigara, Kay and Uhlenbrook, 2018), suggested that little had changed and reported a lack of capacity in developing countries across the water sector and agriculture in particular and suggested that this was now a leading concern and constraint on water-related development. Governments and donor agencies had not helped this situation as they have often seemed more willing to invest in *hard* infrastructure rather than *soft* education and capacity development, which is much less visible and more difficult to measure. Thus, a lack of capacity development has been a worrying trend for decades and yet paradoxically we all know that we need people with knowledge and skills and organisations to make technologies work for us.

FAO also reported on confusion over the meaning of capacity development. It goes beyond the traditional education and training and building human resources to include the capacity of organisations that enable people to work effectively and an enabling environment in which irrigation and organisations can flourish. The issue of capacity development in irrigation is discussed in detail in SUEN publication *Improving irrigation water use efficiency: a synthesis of options to support capacity development* (SUEN, 2020).

4.5 An integrated approach

Although this study focuses on irrigation, it cannot ignore that irrigated farming is an integral part of water management within a river basin. Water scarcity is now driving water and water-using sectors to cooperate and take an integrated approach to basin water planning and management. This aligns with the call for integration in the UN Water Goal (SDG 6) (UN, 2018) in which agriculture and irrigation must play a significant role. However, agriculture as a sector has work to do in putting its own house in order. It is a highly fragmented industry, largely organised around commodities rather than resources and is a complex mix of rainfed and irrigated cropping. Irrigation also suffers from fragmentation as engineers have traditionally focused on infrastructure while agronomists have concentrated on cropping. A more enlightened approach is needed that builds links not just between engineering and agronomy but among the many disciplines that can influence improvements in WUE. It is hoped that this study will help develop those essential links for the benefit of all water users.

5

Conclusions and policy recommendations

"Business as usual" will not be an option as global freshwater withdrawals for irrigation, already more than 70% are predicted to double by 2050, creating unacceptable environmental disasters in many stressed river basins, increasing competition for resources, and causing new social challenges and conflicts over land and water. As the primary water user, it is incumbent on irrigated agriculture to use water resources wisely and contribute to reducing these problems. There is an urgent need to design a future for sustainable agriculture and food production that is coherent and inclusive, is climate-smart and protects the environment.

In summarising this report, there are five main areas for action recommended that would facilitate a transition towards efficient, reliable, and sustainable land and water management in irrigation.

Action area I: the need for good water governance is underpinned by strong formal and informal institutions and a workforce that is well informed on modern irrigation practices. Without this, technological and management innovations are unlikely to succeed. It requires a robust institutional framework to establish and implement good water policies, laws and regulations, and a strong administration to implement them.

Inclusive governance is also essential in recognising the symbiotic nature of water, land and soils and the need for coherent and integrated policies that bring land and water management objectives together, resources to be fairly distributed, and mechanisms agreed to avoid conflict over resource allocation. This extends to transboundary resources, where water use across national boundaries is a dominant issue.

Inclusive governance recognises the need for multi-stakeholder engagement at all levels and across disciplines that will be critical to achieving integrated land and water management, a central plank in achieving SDG 6 – the water goal. Holistic approaches to change will be essential to improve resource allocation and management, provide better control over water supplies and improve service quality in terms of precise, timely, and reliable water delivery. Introducing Water Stewardship in Agriculture is an integral part of good governance and could play a central role in helping irrigation agencies and individual farmers and farmer groups, such as Water User Associations to understand and adjust to the significant changes that quota-based irrigation brings.

Action area II: embracing innovative technologies and management to address water scarcity and drought and tackle problem soils. There are myriad options available. These include modernising large-scale irrigation schemes, automating canal systems, transitioning towards participatory irrigation management and transferring responsibilities to WUAs. New planning, design and evaluation technologies, such as water accounting and auditing, ICT and automation, are helping to modernize existing schemes and inform new designs. Attention is shifting from ill-defined metrics, such as WUE, and focusing on increasing water productivity, making real water savings and meeting farmer demand for more flexible and reliable water supplies.

Water storage offers a buffer for managing climate uncertainty and variability, addressing differences in supply and demand, and building resilience to climate change. A shift is taking place from conventional infrastructure-led storage to multi-purpose storage, integrating natural and built storage and exploiting conjunctive use of surface and groundwater. Modernising irrigation on farms will include surface irrigation which accounts for about 90% of the irrigated land area in the Middle East, and not just switching to hi-tech systems. The main objective must be to make real water savings that others can use productively.

Drought should no longer be considered an unexpected natural disaster requiring emergency assistance that wastes valuable resources and does not help build resilience. A risk-based approach can lessen drought impacts. This is a “three-pillar” approach that requires investment in monitoring and early warning systems, studies to assess vulnerability to drought and actions to reduce adverse impacts.

ICT and mobile phone technologies are spreading rapidly. Remote-sensing services, cloud-based computing and open access to data and information on crops, natural resources, climatic conditions, inputs and markets already benefit farmers by integrating them into digitally innovative agri-food systems. However, care is needed to avoid a “digital divide” among those with different levels of access to new technologies.

Options are also available beyond the farm that can contribute to making wise use of limited water resources. Circular economy principles, widely used in the food sector, are now being applied to agricultural water management and offer non-conventional waters that might otherwise go to waste, such as saline and brackish water, agricultural drainage, and domestic and industrial wastewater effluents.

Adapting crops to climate change will be vital as temperature and rainfall patterns shift cropping to new areas. Since 2000, progress in breeding crop varieties traits has been good. These are important to boost yields, tolerance to drought, waterlogging and salinity. Genetically modified crops offer many benefits but continue to be the subject of a long-running debate regarding risks to biodiversity, human and environmental health, and benefit-sharing.

The consequences of continued salinity build-up in soils in arid climates are worrying. However, options are available to deal with salinity issues, and drainage of salt-affected soils will be vital to future food security in arid and semi-arid environments.

Action area III: implementing integrated solutions at scale. Integrated approaches to resource use can help define critical resource thresholds and lead to beneficial outcomes when they are wrapped up in workable packages, including technical, institutional, governance, and financial support. Rigorous integrated planning for water and land resources is a crucial step involving all stakeholders rather than a traditional top-down approach. Water accounting will prove to be an invaluable tool to provide evidence for allocating water resources. Many examples are emerging of the success of this approach in terms of sustainable resource use, meeting food production targets while protecting valuable ecosystems on which everything else depends.

Action area IV: investing in long-term sustainability in the irrigation sector. Irrigation can be costly, but investment will need to be weighed against the cost of inaction and the impacts on water security, land and soil degradation and food insecurity.

Internationally, investment is shifting from infrastructure solutions towards sustaining productivity and improving governance, integrating systems at scale, innovations in technology and management and strengthening the capacities of organisations, including water-user and producer organisations.

By way of public-private partnership models, governments can encourage the private sector to complement public funding and investment from development banks and environmental funds. Farmers and local communities are also beginning to recognise the importance of investment. In situations where there is stable and good water governance, they too can become critical investors in sustaining their livelihoods and improving income levels.

Action area V: working together for common solutions. Working together has been the subject of much research by Elinor Ostrom (a Nobel prize winner) on governing common resources such as land and water in irrigation systems (Ostrom, 1993). She demonstrated that when people come together in a common cause, they can share and manage resources sustainably. She established the ingredients for effective collaboration, which included a shared dependence on irrigation, common threats, key individuals that can motivate group work, and people who have a long-term view of what needs to be done. The Blue Peace in the Middle East (BPME) is an excellent example of a platform that follows these principles to promote collaboration across the water sectors among BPME countries.

Why is regional collaboration needed? Conflicts, turmoil and migration in countries across the Middle East have profoundly affected all economic sectors, including agriculture and irrigation. This has created many problems, such as the destruction of irrigation infrastructure, weakened institutional capacity to provide effective governance, and a lack of human capacity to plan, build, operate, and maintain irrigation systems. Each country in this study must seek solutions to these challenges based on their natural resource base, environmental and socio-economic circumstances.

But they need not face some challenges alone as they have much in common. They are all concerned about the challenges of water scarcity, land and soil degradation, soil and water pollution, and sustainable food security as populations increase and climate change threatens resource availability. They also have much in common, including shared culture, customs and habits that can enable people to work together for common solutions and reap the benefits of scale. All these are essential ingredients that set the foundations for effective and mutually beneficial collaboration.

Experiences in collaboration within the European Union of funded joint research have shown significant benefits. They encourage collaboration among many young professionals working in different countries and environments across Europe. This is not just about building and sharing technical knowledge. It is also about building social capital (trust and friendship) among different nationalities and disciplines. This is the important but invisible benefit of collaboration and should prove a valuable asset from the BPME initiative. Collaboration takes time and resources and produces benefits that are not easily expressed in physical and monetary terms. However, they can be compared with the costs of non-cooperation and the benefits foregone, which are often greater.

This report has identified that much needs to be done to modernise technologies, improve and strengthen governance and management to improve irrigation system performance. Researchers and practitioners working together within and across national boundaries can undertake joint research to increase water productivity, the efficient use of soil and water resources, the development of new crop species and varieties, agronomic studies, and implement modern irrigation technologies. Many such projects require multi-disciplinary groups to resolve problems and not just scientists, engineers and agronomists working in silos. They must go beyond their laboratory and research centres to engage with government policy priorities and farmers who are often steeped in indigenous knowledge that can be of immense value when combined with modern science. Social scientists will be an essential ingredient in technological research to design projects that communicate with farmers and not just pursue the academic interests of the research community. Equally, scientists have a role in turning science into policy so that decision-making is evidence-based. This is not a linear process as most scientists think, but they can influence policy through access to networks, engaging with “champions” who are vital to catalysing change, and taking the time to maintain continuity of efforts and long term commitment.

Workshops and training also bring people together to exchange ideas and build social networks that can prove invaluable. Each country has specialities that can benefit others. Just two examples from this study: Turkey has unique experience in building Water User Associations from which others can benefit; Jordan and Lebanon have extensive knowledge of hi-tech precision irrigation. Many other in-country initiatives can benefit others through sharing and disseminating information.

Among its many achievements, the Blue Peace in the Middle East initiative has brought scientists and practitioners together to produce this publication. Opportunities exist for a future programme of continued fruitful cooperation. However, it must have the willingness, support and ownership of political leaders at the highest level to succeed.

BPME also aligns with the 2030 UN Development Agenda, which recognises the inter-relationships among all 17 SDGs and their 169 targets and the need for collaboration rather than silo thinking. Pursuing a water agenda, as in SDG 6, the “water goal” is a vital entry point. Indeed, the UN Deputy Secretary-General described SDG 6 as the "docking station" for all the SDGs and the 2030 Agenda (speech at Stockholm World Water Week 2018). Water flows through every aspect of development, and so it is essential to get it right.

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