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ADDRESSING THE WATER CHALLENGES IN THE AGRICULTURE SECTOR IN NEAR EAST AND NORTH AFRICA

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ADDRESSING THE WATER CHALLENGES IN THE AGRICULTURE SECTOR IN NEAR EAST AND NORTH AFRICA

State of Land and Water Resources for Food and Agriculture thematic paper

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Abbreviations and acronyms

AfDB African Development Bank

FAO Food and Agriculture Organization of the United Nations

GDP gross domestic product

IWRM Integrated Water Resources Management

NbS Nature-based Solutions

NDC Nationally Determined Contributions

NENA Near East and North Africa

SDG Sustainable Development Goals

UN United Nations

Introduction

The Near East and North Africa (NENA)[1] is considered one of the world's most arid regions. While rainfall levels and availability of water resources and arable land is indeed limited, over millennia, its population has learned to cope with this scarcity. In fact, archeological evidence suggests that the very first irrigation techniques and water storage infrastructures were developed here (Mithen, 2012). As a result, areas such as Mesopotamia and the Nile were the cradles of the first major global civilizations. Indeed, these areas were viewed as the breadbasket and the economic pillars for various ancient cultures beyond NENA boundaries.

Nonetheless, at present, the NENA region faces several additional challenges aside from aridity. For instance, its current population is expected to double, reaching around 700 million people by 2050. The growth will translate into increasing rates of urbanization, which in turn will lead to changes to lifestyle and dietary patterns. Furthermore, conflicts, civil unrest, and instability are significantly reshaping not just the regional economic expectations but also the social and political structures of individual countries. In fact, the NENA region is the only region globally in which extreme poverty has increased over the last decade. A total of around 15 million people are thought to be internally displaced, the region is host to over 12 million refugees, and the current global health crisis is already pushing over 10 million people into poverty (Sato, 2021). As a result, hunger and food insecurity have also risen over recent years.

Demand for land, water and food are only expected to rise over the coming years, thus placing additional pressure on the interlinked agricultural water sector. Added to this are the complexities of climate change: rising greenhouse gas emissions and the subsequent increase in global mean temperatures will have direct impacts on water availability and land scarcity. It will also impact regional infrastructure and economies, in terms of natural disasters, and may impact regional demographic characteristics. As such, climate change, along with social and political changes, will only serve to further aggravate the already challenging conditions in the NENA region's agricultural water sector.

[1] Consisting of the following countries: Algeria, Bahrain, , Egypt, Iraq, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, Palestine, Qatar, Saudi Arabia, Sudan, the Syrian Arab Republic, Tunisia, the United Arab Emirates. and Yemen.

The role of the agricultural water sector

The water and agricultural sectors align various physical, social, and economic drivers. For instance, food systems bring together the resources and inputs, production and transport, processing and manufacturing industries, and the retailing and consumption of food. Any impact on this chain inherently affects the environment, health, economic development, and society as a whole. Within this sphere, the water sector plays a natural and fundamental in crop production, livestock management, and aquaculture practices, and is also needed for consumption. Thus, its quality and safety is critical. At an institutional and societal level, the way in which water is distributed between economic, social, and environmental services drives the characteristics of the food supply system. Also, water may become a disruptive force for these processes. Floods, droughts, and water pollution have the power to break food systems with repercussions which may extend beyond the immediate water and food domains.

Hence taking actions in this interlinked sector is key, due to its natural role in the food and water security of the NENA region. As a first step, reaching water security is essential to fostering regional growth, reducing vulnerabilities to hydrological shocks, and indeed, minimizing social and political fragilities (World Bank, 2017a). Furthermore, the agricultural sector plays a key role in the regional economy, and is an engine of job creation. As of 2017, more than 20 percent of the labor force was employed in this sector, a share that increases to over 31 percent among women (Sato, 2021). Yet, about 70 percent of the region's impoverished population live in rural areas. The agricultural sector also typically accounts for over 10 percent of the NENA countries' GDPs (though in Gulf countries, this share is usually less than 5 percent). The sector is likewise essential for livelihoods and welfare in rural communities, which at present constitute over 40 percent of the regional population.

Addressing the agricultural water challenges in the NENA region would therefore make a positive impact well beyond improved agricultural outputs and water productivity. Indeed, if the agricultural water sector was prioritised, at least new 10 million jobs would be created in the region (Abaza *et al.,* 2011). Thus, the sector could become an important foundation for a COVID-19 recovery as well as a pillar for SDG1 for poverty eradication. Improving practices in the sector would also support the reduction of income volatility for farmers, thus providing them more stable finances. In fact, investing in better water resource management leads to economic benefit through an improvement in GDP per capita. Existing estimates show that the range of regional returns tend to be between 16 percent and 36 percent depending on the intervention or activity.

Investing in the sector would also show benefits at the societal and even political level. In Iraq, the return of displaced people and improvements in gross incomes and reduction in hunger have been associated with investments in agricultural water systems (FAO, 2018). This is crucial in a region that accounts for 14 percent of global international migrant flows and, in 2016, for 41 percent (over 16 million) of the global population of internally displaced persons. At the same time, low levels of food security are thought to be connected with social instability in the region (Maystadt and Ecker, 2014). In fact, a rise in food prices has been strongly associated with the social unrest and protests of the 2011 so-called 'Arab spring' in Egypt, the Syrian Arab Republic, and Morocco (Soffiantini, 2020).

The aim of this report is to propose strategies for the NENA region's water sector that will allow for sustainable food production practices while also accounting for future regional challenges. The first section of this report diagnoses the status of the agricultural water sector in the NENA region. It includes a diagnostic of the physical characteristics, usage patterns and sourcing of water, as well as policy, management, and data practice that together determine scarcity in the region. Future challenges that the sector will have to face are also reviewed, including climate change, population growth, and COVID-19 recovery. The report's second section provides a review of various strategies to support the NENA region's agricultural water sector. These vary from management improvements and rainwater harvesting to technological innovations. Lastly, some final reflections are shared in the third section.

This report also examines how the different aspects that shape the agricultural water sector align with the narrative set forth by the Sustainable Development Goals (SDGs), which seeks to lay the foundations for the design of regional urgent actions with a 2030 horizon. This narrative illustrates how the agricultural water sector could become a central pillar towards achieving food, water, climate, and overall development agendas.

PART I: THE STATUS OF WATER RESOURCES IN THE NENA REGION

This section provides an overview of the current and future status of the agricultural water sector in the NENA region. The first chapter examines the current situation, and presents a picture of water availability and scarcity in the region. In addition to physical constraints, this includes the characteristics of sources, withdrawals and uses, policy, data, and management practices, and others. The second chapter then reviews future challenges that may arise in the agricultural water sector in the region. These include climate change and disasters, population growth and human displacement, and COVID-driven constrains. These two chapters seek to provide an overview of the conditions and challenges which characterize the NENA region as a whole, yet it should be remarked that a view on national and sub-national characteristics would also be needed to describe the sector in greater depth.

Chapter 1: Status and trends of water resources for the agricultural sector in the NENA region

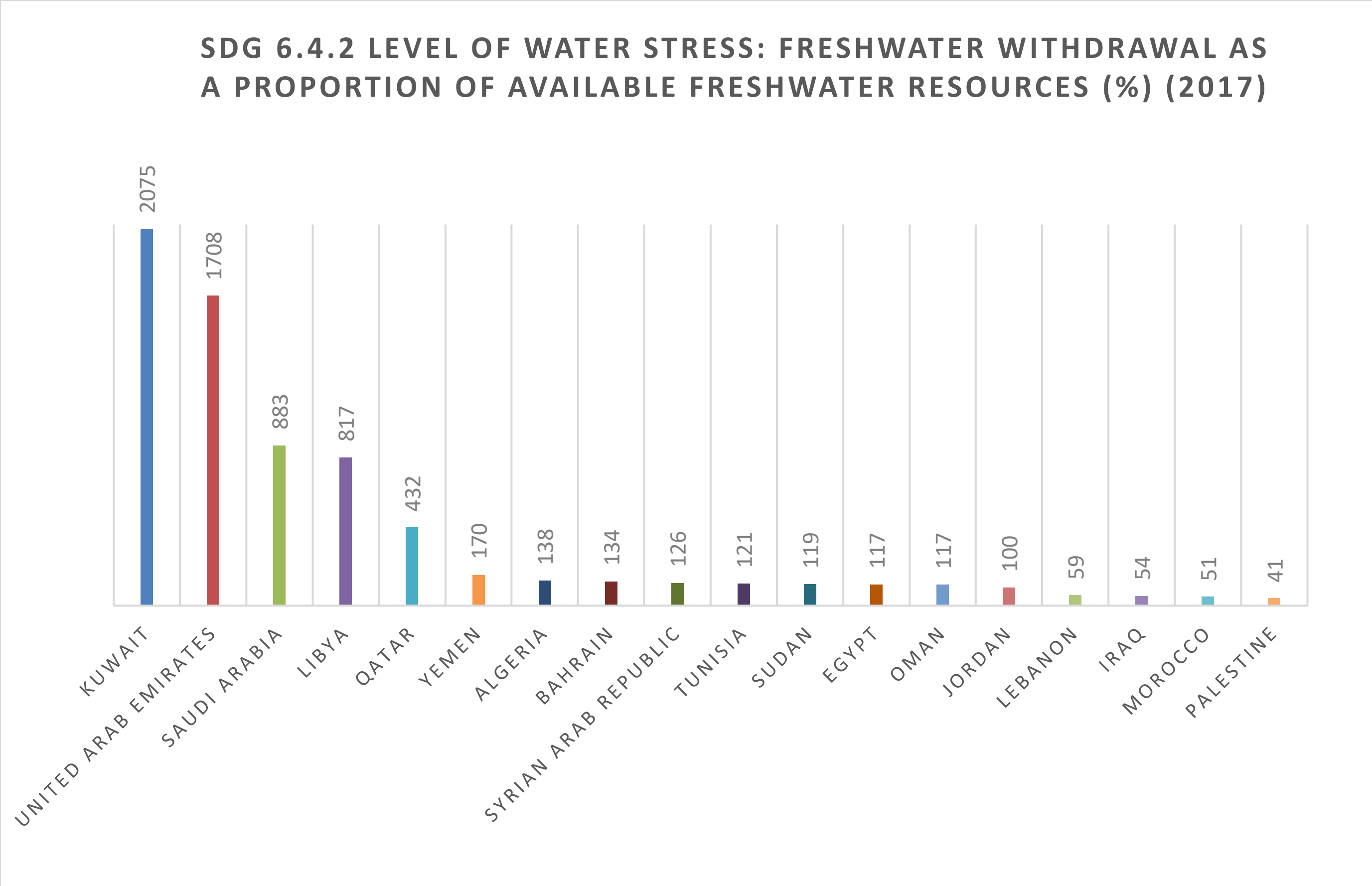
This first chapter provides an evaluation of the current characteristics determining the status of and challenges to the agricultural water sector in the NENA region. To start, we describe the physical constraints that determine regional water challenges in terms of availability and scarcity. From there, the main sources of water in the region – understood as groundwater, surface water, desalination and others – are reviewed. We then describe the current status of transboundary resources. This is followed by a description of the main water uses and agricultural patterns that describe the region. Next, this chapter reviews how the region copes with scarcity in terms of agricultural and water policies as well as market mechanisms (virtual water trade). Lastly, this chapter provides a description of the current status in data availability and a review of the regional status in terms of the relevant Sustainable Development Goals and international climatic agreements.

1.1. Physical status and trends of water resources: A region in physical stress

Precipitation in most of the Near East and North Africa (NENA) region does not typically exceed 500mm per year (Verner, 2012). In fact, apart from the Mediterranean zones in the north and subtropical areas in South Sudan, yearly precipitation rarely exceeds 200mm (idem.). As a result, the NENA region is the world's most water-scarce region (Tropp and Jagerskog, 2006; Droogers *et al.*, 2012). This scarcity derives from a combination of low availability of physical water resources and significant demand for water. In the NENA region, most countries are characterized by high and extremely high levels of water stress[2] (Figure 1.1).

[2] The Water Stress Score is a WRI-defined ratio between total water withdrawals to the available renewable groundwater and surface water. The indicator is expressed in score ranging from 0 (low risk) to 5 (Arid and low water use). Scores above 3 represent high risk, whereas those above 4, extreme high risk.

Figure 1.1 Levels of water stress in the NENA countries



Source: UN Water. 2021. *Summary Progress Update 2021 : SDG 6 — water and sanitation for all*, pp. 58. Geneva, Switzerland. https://www.unwater.org/app/uploads/2021/12/SDG-6-Summary-Progress-Update-2021_Version-July-2021a.pdf

The regional scarcity is evident when looking at Sustainable Development Goals (SDGs), specifically indicator 6.4.2[3] under Goal 6 which seeks to ensure safe drinking water and sanitation for all. For this indicator, which measures level of water stress, the North Africa and West Asia region scores 68 percent as of 2017[4]. This figure shows just a negligible improvement since 2015 when the score was 71 percent (UN-Water, 2021). Importantly, apart from Morocco, Iraq, Lebanon and Palestine, freshwater withdrawals levels as a proportion of available freshwater resources in the region are deemed critical. In fact, eight countries in the region (Kuwait, United Arab United Arab Emirates, Saudi Arabia, Libya, Qatar, Yemen, Algeria, and Bahrain) are in the top 10 for water stress levels globally. As a result, over 60 percent of the regional population and 70 percent of economic activity in the NENA region are located in areas characterized by high and very high levels of water stress[5] (World Bank,

[3] Indicator 6.4.2 tracks how much freshwater that is being withdrawn by all economic activities, compared to the total renewable freshwater resources available. It also takes into account environmental flow requirements. (UN Water SDG 6 portal)
[4] Retrieved from https://sdg6data.org/indicator/6.4.2 , data from FAO AQUASTAT
[5] Water Stress is a measure of the ratio of water withdrawals to renewable surface water supply. It should be noted that his metric does not account for the contribution of nonconventional water supplies or groundwater resources that may have been developed to relieve water stress.

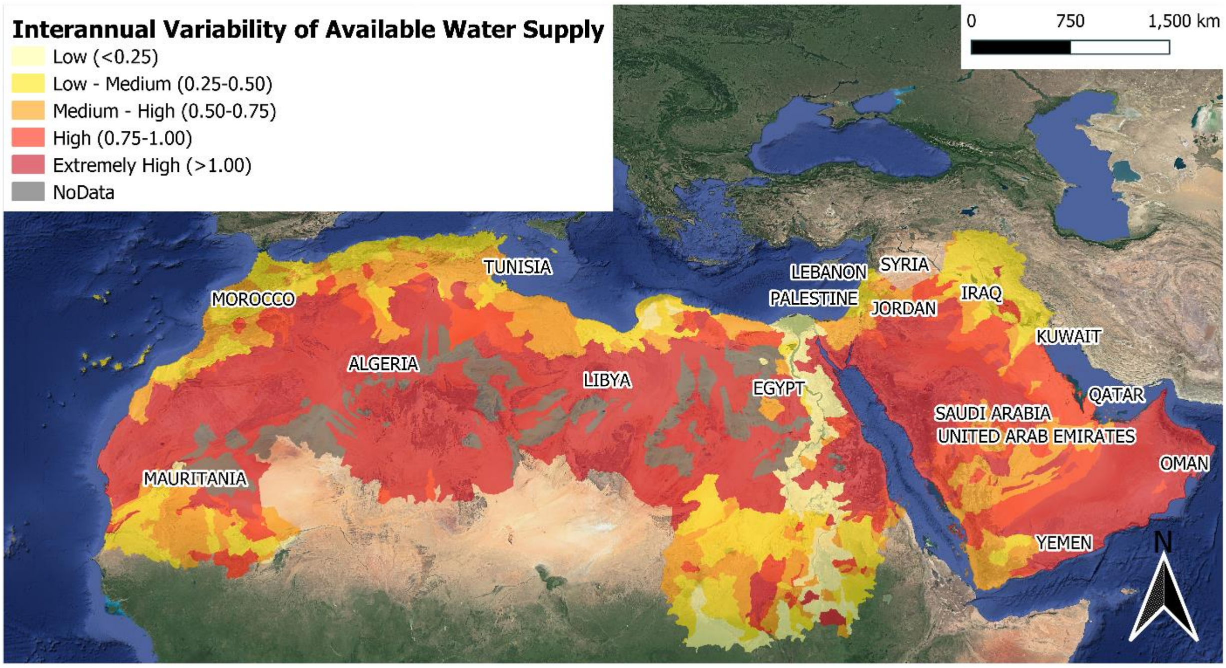
2017a). These estimates are about two to three times greater than global averages (Veolia Water, 2011).

This situation is more acute if, along with scarcity, variability is also accounted for. Water resources in the NENA region are believed to be the most variable in the world. Calculations suggest that year-to-year water variability (measured as the deviation from historical average annual surface water availability) is about 15 percent greater than the global average (Antonelli and Tamea, 2015; Borgomeo *et al*., 2020). In the Gulf countries, this variability may even surpass 75 percent (Figure 1.2) for surface water resources alone. Recent studies have also found changes in regional seasonal (multi-year) variability. For example, during the summer months, an overall decrease in precipitation of about 0.5 mm/day per decade has been detected (Dogar and Sato, 2018).

At the same time, high evaporation rates in the region, along with the overuse of resources, also increases the stress on surface water resources[6]. For example, surface water over-abstraction is believed to account for the fact that about one tenth of surface water consumption in the Mashreq and in the Nile region is unsustainable, or maintained at the expense of environmental flows (World Bank, 2017a). In fact, in countries such as Egypt, Iraq, and the Syrian Arab Republic, over-abstraction is believed to have already altered the flow regimes of key riverine systems (Shamout, 2015; Al-Mudaffar Fawzi *et al.*, 2016).

[6] Surface water bodies include, primarily, rivers, lakes, ponds, and reservoirs. Surface water is usually calculated as the total yearly river flow occurring in a country.

Figure 1.2 Inter-annual variability of available water supply in the NENA region



Data retrieved from: Hofste, R.W., Kuzma, S., Walker, S., Sutanudjaja, E. H. *et al*. 2019**.** Aqueduct 3.0: Updated Decision-Relevant Global Water Risk Indicators. *World Resources Institute.*

As a result of limited surface water resources, the NENA region relies significantly on the use of groundwater resources[7] (FAO, 2010). Yet, critical rates of withdrawal have led to overexploitation causing salt intrusions, groundwater pollution, a decline in piezometric levels, and overall groundwater stress (Goode *et al*., 2013; Al-Zyoud *et al*., 2015). Recent estimates suggest that the groundwater stress[8] levels in the region typically range from medium to extremely high (Gleeson *et al.*, 2012). For example, in Libya, groundwater abstraction rates are about eight times their natural recharge. In the Tigris and Euphrates basin, over 60 percent of water storage losses are linked to groundwater depletion (Voss *et al*., 2013; Joodaki *et al*., 2014). Added to this, the regional situation has deteriorated over time. The already significant groundwater abstraction rates have increased almost uniformly across the region between 1990 and 2010. For example, in the North-Western Sahara Aquifer –which spans three countries (Algeria, Libya, and Tunisia)– water abstractions have increased critically in the last few decades, from 0.6 to 2.5 km^3/year. In total, almost 10 000 water points have been located in this system (Steenbergen *et al*., 2010).

Overall, water resources in the NENA region are thought to have among the fastest global rates of decline. Over the last 40 years, they have decreased by about two thirds, and they are expected to fall over 50 percent by midcentury (FAO, 2010). However, it is also important

[7] Groundwater refers to the water found in aquifers underground in cracks and other spaces, and is estimated by calculating the aquifer recharge from infiltration.
[8] Groundwater stress is often calculated as a ratio of groundwater footprint (the area required to sustain groundwater use and groundwater-dependent ecosystem services) to aquifer area.

to note that in areas such as Iraq, the Mesopotamian marshes, or the Nile Delta, groundwater stress levels have improved (World Bank, 2017a). This may be due to social drivers such as population displacements (in the case of Iraq and Mesopotamia) or artificial recharge efforts. However, it is important to also highlight the scant understanding of regional groundwater processes, which does not allow for a comprehensive analysis of their status and trends.

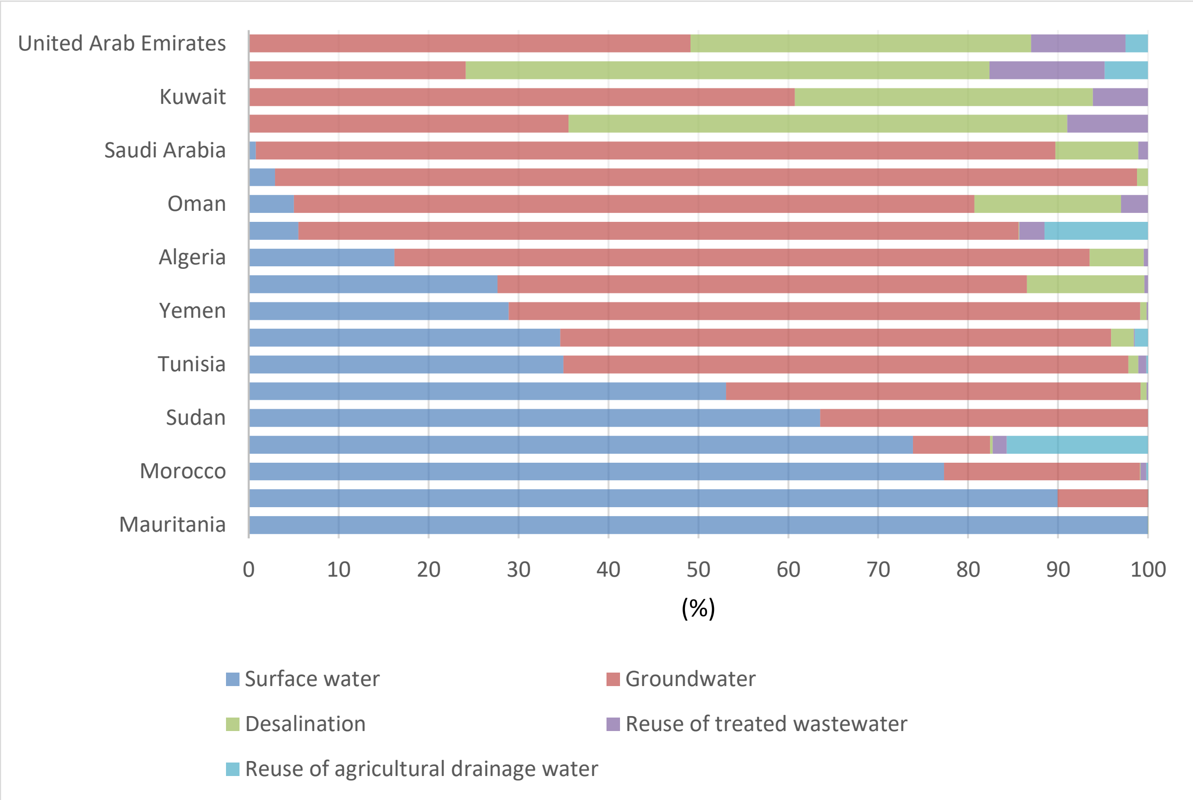
Water quality poses an additional challenge to water resources in the region. Apart from the Nile, all major regional water bodies are thought to have significant loads of nutrients and pollution, as well as a high potential for eutrophication (Garnier *et al*., 2010; Seitzinger *et al.*, 2010). The repercussions of this may be observed in algae blooms, losses in aquatic biodiversity, degradation of recreational opportunities, and others (Chislock *et al.*, 2013). While point-source discharges of nutrients are believed to play a major role, the constant stress of surface and groundwater resources often also result in poor water quality levels (Jasechko *et al*., 2017). For example, over-abstraction may lead to higher concentration of contaminants, as well as more saltwater intrusions into streams and aquifers. As a result, just Tunisia and Jordan report good quality in 80 percent of their water bodies and thus are on track to meet SDG 6.3.2 (*UN* Water, 2021). Unfortunately, the rest of the NENA countries do not have the data available to monitor this.

1.2. Sources of water withdrawals

Understanding the sources of water with drawal is also key to understanding water stress in the region (Figure 1.3). Overall, a combination of groundwater, surface water, and, to a lesser extent, of reuse of wastewater and desalination, dominate water withdrawal practices across the region. Water sources are nonetheless diverse within the region. In general, Maghreb countries use more surface water, while Mashreq and Gulf countries depend more on groundwater and other sources. For example, in countries such as Egypt or Morocco, the dependence on surface water may reach up to 80 percent, whereas in Libya, Yemen or Djibouti, the dependence on groundwater may even exceed 90 percent.

At the same time, desalination is particularly important given that about 50 percent of the world's desalination capacity is in the NENA region (World Bank, 2017a; Borgomeo *et al*., 2020). Yet these types of plants are mainly found in high-income countries in the Gulf that have been able to invest in desalination technologies. For example, in Qatar, Kuwait or Bahrain, desalination may account for more than 60 percent of their water withdrawals. The reliance on these technologies has thus also opened the floor for discussions about the water-energy-food nexus (See Box 1). At the same time, desalination practices are often associated with high energy and environmental costs.

Figure 1.3 Water withdrawals by source per total water withdrawal, NENA, 2015 and 2017



Source: AQUASTAT; AbuZeid, K., Wagdy, A. & Ibrahim, M. 2019. *3rd State of the Water Report for the Arab Region – 2015*, Cairo.

*Data for Jordan, Lebanon, Qatar and Tunisia are for 2017; data for the rest of NENA countries are for 2015.

Box 1 Desalination and the water-energy-food nexus

In the NENA region, desalinated water is used for human consumption and to produce food (see next section). The region accounts for about 50 percent of global desalination capacity. This high figure is partly due to technological developments and the subsidization of desalinated water supplies (via fiscal and pricing mechanisms). The energy cost of purification and distribution is still high, however. As an example, desalination accounts for 10 percent of total annual energy consumption in Saudi Arabia and 20 percent in the UAE (Commander *et al*., 2015). Also, NENA countries must understand the threat posed by desalination to conservation of the water-related ecosystem and to coastal zones in general.

Figure 1.4 Al-Khobar 1 Desalination plant in Saudi Arabia

Source: Commander, S., Nikoloski Z. & Vagliasindi M. 2015. *Estimating the size of external effects of energy subsidies in transport and agriculture*. World Bank Policy Research Working Paper 7227 and Jones *et al.,* 2018. *The state of desalination and brine production: A global outlook*. Science of The Total Environment. https://doi.org/10.1016/j.scitotenv.2018.12.076 0048-9697/© 2018 Elsevier B.V.

It is important to also note that about 45 percent of the wastewater generated in the NENA region is treated. This is a relatively high share compared to other developing regions globally. Yet, sub-regional characteristics should also be considered. Whilst in countries such as Kuwait or the United Arab Emirates, over 90 percent of domestic and industrial wastewater flow is safely treated, in others, such as Algeria, Iraq, Lebanon or Libya, this proportion falls to about 15 percent (*UN Water*, 2021). This highlights how current and effective wastewater management practices in the region could be expanded and promoted across the region. This would benefit not just the agricultural sector but would also work towards the achievement of SDG 6.3.1 which focuses on improving the proportion of wastewater flows treated.

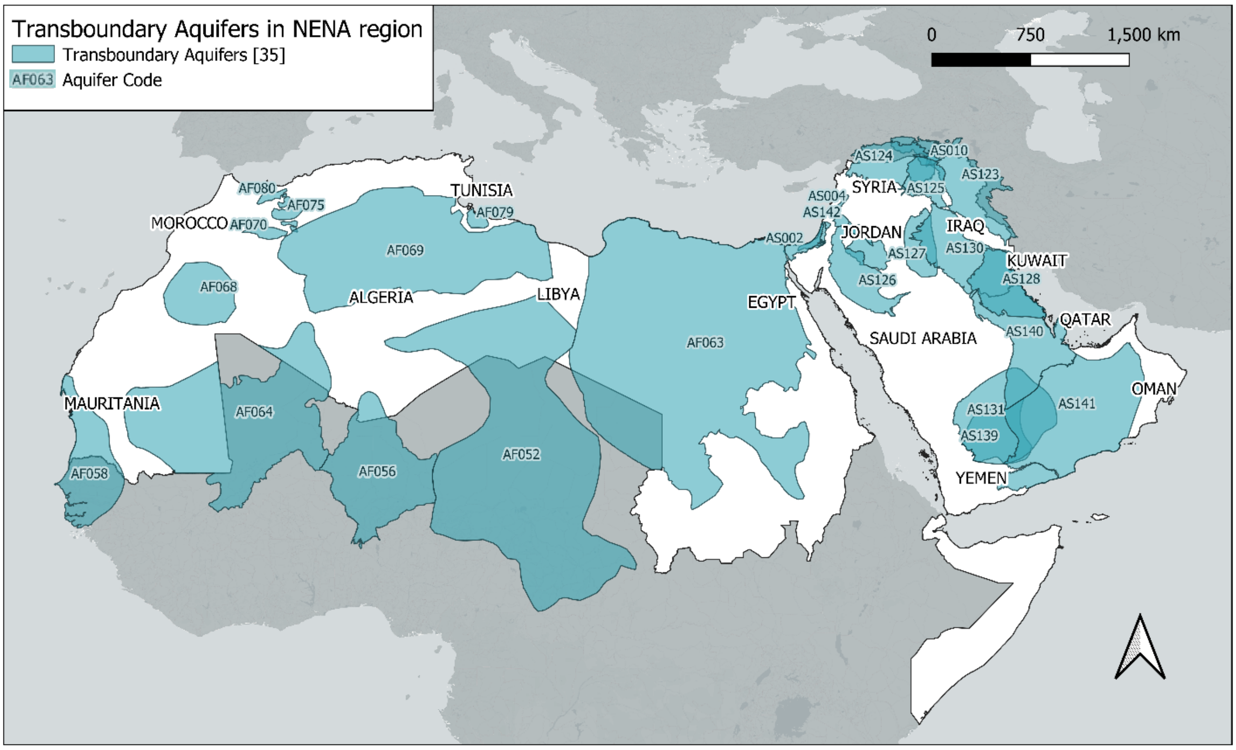
1.3. Transboundary water resources

Apart from the physical features described above, transboundary water resources also shape the regional characteristics of water availability. Importantly, about 60 percent of the total surface water in the region is shared across national borders, and all countries share at least one aquifer (Figure 1.5). In fact, the three main river systems of the region –the Nile, Tigris-Euphrates, and the Jordan-Yarmouk–, are shared with countries that in some cases are also outside the NENA region. Other shared rivers include the Shat Al Arab, Orontes, and Nahr el Kabir Rivers.

This situation is more critical for countries such as Egypt, Iraq, and the Syrian Arab Republic , which almost totally depend on other countries for surface water resources (FAO, 2010). Shared water systems are also relevant for groundwater resources. Indeed, several of the largest groundwater systems in the NENA region are transboundary. These include the Nubian Sandstone (Egypt, Libya, and Sudan), North Western Sahara (Algeria, Libyan Arab Jamahiriya and Tunisia), and Disi Aquifer (Jordan and Saudi Arabia) (FAO, 2010). Other minor groundwater systems also have significant effects on country-level water budgets. For instance, Bahrain and Kuwait have around a 97 percent dependence on groundwater flows from Saudi Arabia. As such, local-level water scarcity conditions may be attenuated or accentuated by the decision made upstream outside national borders.

These characteristics also have tremendous repercussions for the SDG agenda. SDG 5.2 remarks on the need for transboundary cooperation within arrangements stated in bilateral or multilateral treaties, conventions, agreements and other formal mechanisms. Yet Tunisia and Libya are the only countries in the NENA region which manage 80 percent of their transboundary basin area with operational agreements (UN Water, 2021). Critically, in countries such as Morocco, Qatar, and the United Arab United Arab Emirates, this proportion is zero. Also, alarmingly, in other countries such as Egypt, Algeria, the Syrian Arab Republic, and Iraq, data is not available to monitor the situation.

Figure 1.5 Map of transboundary aquifers in the NENA region

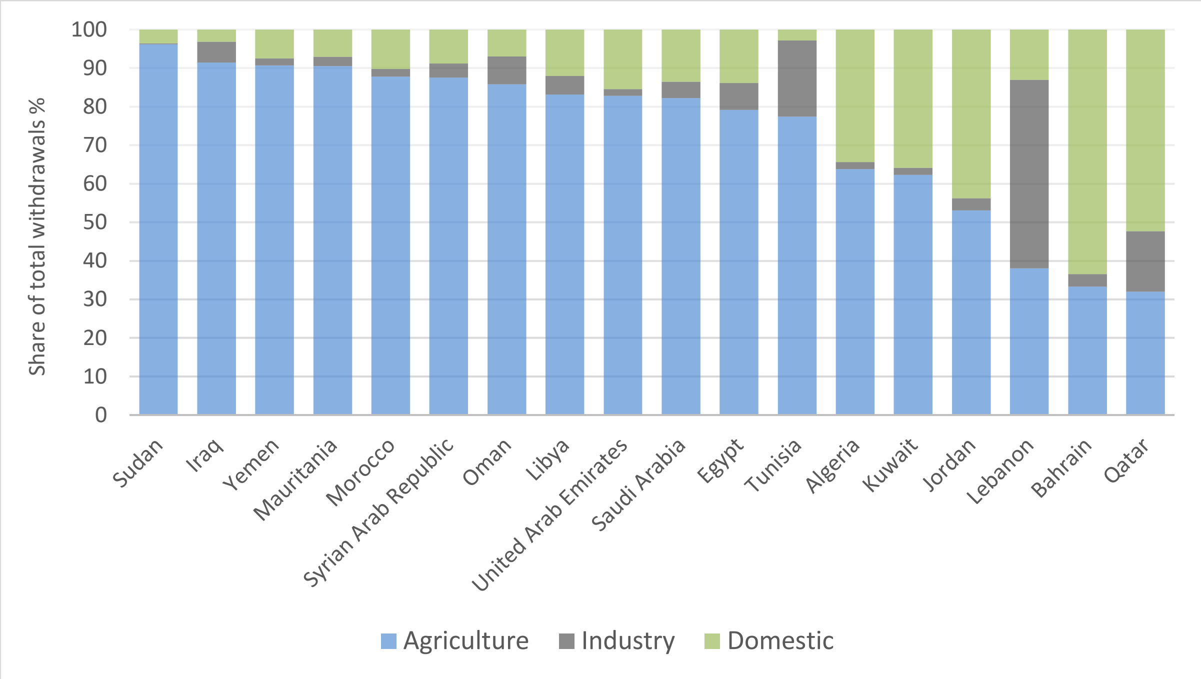


Source: IGRAC. 2020. International Groundwater Resources Assessment Center, Transboundary Aquifers of the World GIS data layer. https://www.un-igrac.org/ggis/transboundary-aquifers-world-map

1.4. Water uses

Historically, agriculture has been the largest source for water withdrawal in the NENA region. Overall, this sector accounts for nearly 85 percent of regional water use (almost 15 percent higher than the global average) in a given year (Figure 1.6) (Nin-Pratt *et al.*, 2017). In countries such as Yemen and Saudi Arabia this figure may be as high as 90 percent. Also, as may be expected, areas surrounding the major river systems such as the Nile and the Tigris-Euphrates are hotspots for agricultural water withdrawals (World Bank, 2017a). These figures may also change if groundwater that is essential for the agricultural sector is also considered. Yet, since groundwater resources are not well-monitored and regulated it is not possible to completely understand their role in the sector.

Figure 1.6 Water withdrawals by sector in NENA countries, 2017



Source: AQUASTAT, 2017

In contrast, regional industrial water use (about 5 percent) is just about a quarter of the global average (about 20 percent). Only in Qatar, Tunisia, and Lebanon does the industrial share approximate (or exceed, in the case of Lebanon) the global average. Also, domestic water withdrawals account for about 10 percent of total withdrawals (in Bahrain and Qatar, this figure may be higher than 50 percent). So, while agriculture is indeed the dominant source of water withdrawals in the region (apart from the four economies mentioned), these figures also show that this sector would face water competition if policies were oriented toward increased domestic and industrial water supply. This is for example, the case of Jordan, where priority is given to domestic use to meet minimum safety and hygiene requirements (Ministry of Water and Irrigation (Jordan), 2016). Then, each sector of the economy is given importance according to its contribution to national GDP. As a result, the agricultural sector in Jordan is limited in its withdrawal allocations and thus it can only be expanded when newly treated wastewater is used.

Moreover, water-use efficiencies also need to be considered when accounting for the region's physical constraints as well as its efforts to meet SDG 6.4.1. When examining water-use efficiencies in terms of economic return per volume of water, there are various significant differences across the region. Mainly, high-income Gulf countries present higher economic returns, since their economies are dominated by industries, manufacturing and other sectors with large monetary outputs (Borgomeo *et al.*, 2020). In these countries, particularly in Kuwait and Qatar, each cubic meter of water typically returns over USD 40 (UN Water, 2021). On the contrary, in the rest of the region where the agricultural sector provides less returns, efficiencies are seen to be low. This is particularly acute in countries such as Tunisia, Libya, Egypt, and Iraq where each cubic meter of water returns less than USD 4. Also, apart from Kuwait, Qatar, Bahrain, and Oman, the rest of the region has not made important progress towards adding more economic value to water and thus progressing towards SDG 6.4.1

However, these estimates have to be considered carefully. A monetary valuation does not capture other uses related to cultural, religious, landscape-related, and recreational uses of water. Unfortunately, the agricultural sector in the NENA region does not have additional data that allows losses and efficiencies to be comprehensively evaluated in the processes of water capture and storage, distribution, and irrigation.

1.5. Agricultural patterns and productivity

The region's high agricultural water withdrawal contrasts with its poor agricultural productivity. Since 1980 the region has ranked at the bottom of global agricultural productivity tables and at present, only the African sub-Saharan region has lower land productivity yields (gross agricultural production per ha of agricultural land) (FAO, 2017). In Yemen, for example, nearly 30 percent of the working population produced less than 5 percent of the national GDP (Sato, 2021). Just in Algeria and Jordan, GDP of the agricultural sector exceeds participation in the labor market. In fact, across the region the economic value added per agricultural worker typically remains below USD 10 000 (although in Saudi Arabia volume of production per labor unit exceeds USD 20 000[9]) (Roser and Ortiz-Ospina, 2018). Low productivity, in turn, compromises regional efforts to achieve SDG 2.3.1.

Low productivity is characterized by the dominance of cereals in the region, accounting for about 60 percent of the total harvested land, while contributing only to 15 percent of the total value of agricultural production (Nin-Pratt *et al*., 2017; OECD, 2018). On the other hand, horticultural products such as citrus, fruits, vegetables, tree nuts, and others, which have higher water productivity and economic values, occupy less than 20 percent of the NENA's harvested land (idem.). In general, around 40 percent of the value of agricultural production comes from horticultural products, compared to only 15 percent for cereals.

However, these conditions seem not to reconcile with the region's water scarcity characteristics (explained in the previous section). Just less than 5 percent of the land in the region is deemed as suitable for rain-fed crops, whereas 40 percent of crop-covered land requires irrigation (FAO, 2017; OECD, 2018). Also, other physical characteristics such as erosion and desertification pose a significant threat to soil and thus, to the sector. In fact, in over 75 percent of the region's countries, less than 5 percent of the land is arable, and about 75 percent of regional croplands are estimated to be degraded (idem.). More alarmingly, over recent years, land degradation in the NENA region is thought to have reduced the potential

[9] It is important to note that these estimates include classes of farming/pastoral/forestry enterprise size

productivity of soil by about a third (FAO, 2017). Indeed, economic losses due to land degradation amount to up to USD 9 billion per year and up to 7 percent of country-level GDPs.

Moreover, it should be noted that the agricultural sector in the NENA region is also characterized by a significant loss of water along the food supply chain. These losses result from poor agricultural processing, distribution, consumption, and disposal practices. Indeed, and alarmingly, in the NENA region, water losses average $86m^3$ per capita per year, when the global average is about $30m^3$ per capita per year (Kummu *et al.*, 2012). In various countries this figure may even reach up to $180m^3$ per capita per year.

Overall, these agricultural characteristics do not translate well into consistent progress towards SDG 2 on ending hunger, apart from the major regional efforts towards ending undernourishment in Iraq, Sudan, and Yemen (SDG 2.1.1) (Borgomeo and Santos, 2019). Also, apart from Sudan, NENA countries still make little effort towards tackling the prevalence of obesity in the region. And in countries such as Egypt, Sudan, Yemen and Iraq, the prevalence of stunting among children under 5 years of age still is over 20 percent (SDG 2.2.1) (Roser and Ortiz-Ospina, 2018). Also, it is important to note that the region in general lacks consistent record-keeping in the area of food security (SDG 2.1.2). In fact, Egypt is the only country that reports on current levels of food insecurity (about 35 percent).

1.6. Coping with scarcity: Agricultural water policy and management

In spite of investment and changes to regional agricultural systems, poor water conditions and low agricultural productivity persist in the region (Ghazouani *et al*., 2012; Borgomeo and Santos, 2019). Large scale irrigation systems and drainage expansion have been added since the 1960s. Yet, this infrastructure-based strategy stopped being feasible just a few decades after its implementation due to land and water constraints as well as to suboptimal operations and a lack of maintenance. Ultimately, a hydraulic and infrastructure-based policy were deemed insufficient to improve the sector's productivity.

Since the 1990s, agricultural water sector strategies have shifted towards a more integral approach (Borgomeo and Santos, 2019). Policies in the sector have looked to more decentralized and participatory-based approaches alongside more financially sustainable and cost-recovering strategies. These mechanisms have included policies that encourage internal and local management systems, expanded participation by farmers in the decision-making process, financial autonomy to lessen the burden on public finances, and the overall transfer of functions from the national level to local water associations and local farmers. This has also included a shift towards modernization, which in this case involves a new set of institutional reforms to reduce government intervention and promote better water delivery.

Whilst the application of this new set of policies has not been uniform, and indeed in various cases local authorities are trying to disengage from the management of irrigation systems, various regional experiences have shown promising results. For example, since 2002, Morocco has implemented a national programme (Plan Maroc Vert) for irrigation water savings that promotes wide implementation of drip irrigation (Oudra and Talks P., 2017).

Also, countries such as Egypt, Sudan, Jordan and Lebanon are at present maintaining their agricultural expansion policies. In fact, Sudan has a federal administration in charge of agricultural expansion which looks to engage local stakeholders, international organizations, governmental agencies, and others to increase productivity (Bello, 2014). As result, over the past decade, it was planned that total cultivated areas in the country would increase from 2.7 million to 4 million (African Development Bank (AfDB) Group, 2013).

At the same time, greenhouse farming has also been seen as a successful regional mechanism to manage scarcity. Indoor facilities reduce the exchange of air with the outside environment, thus facilitating the control of water and resources used in the agricultural process. In the NENA region, this approach increases yields in fruit and vegetable production while maintaining adequate water-efficiency rates. In the Algerian Sahara, for instance, over 130 000 greenhouses were put in place from 2000 to 2014 to support horticultural activities (Naouri *et al*., 2017).

As a result of these developments, the NENA region at present has an acceptable level of integrated water resources management (IWRM) implementation towards SDG 6.5.1.[10] The region has an IWRM implementation score of 60[11], performing slightly worse than other regions such as Eastern and South Asia, North America and Europe, and Australia and New Zealand. Yet within the NENA region, only Oman, Qatar, and Kuwait have high or very high levels of IWRM implementation. Other NENA countries show different results: Lebanon's levels are low and in countries such as Yemen, Egypt, and Iraq, and Sudan, these values are medium-low.

Hence, this emphasizes the issues that the region still needs to address. For instance, active strategies to tackle gender inequality are still lacking (Fisher and Reed, 2018). Currently, the design of policies and programmes do not typically include women's views, needs, or knowledge. There is also the issue of a lack of consultation and participation of local communities and users of the agricultural system. In fact, and worryingly, apart from Algeria

[10] SDG65.1.1 6.5.1 tracks the degree of integrated water resources management (IWRM) implementation, by assessing the four key dimensions: enabling environment, institutions and participation, management instruments and financing.
[11] The score measures the degree to which Integrated Water Resources Management (IWRM) is implemented, assessed by the four main dimensions of IWRM: enabling environment, institutions and participation, management instruments and financing. The degree of implementation is measured on a scale of zero to 100, using a self-assessed country questionnaire.

and the Syrian Arab Republic, all countries in the NENA region do not have any water subsectors with a high level of user and community participation (UN Water, 2021). This in turn is reflected in the low regional scores towards achieving SDG 6.b.1[12].

Operation and maintenance in the sector, as well as modernisation and the implementation of water-saving policies, still heavily rely on public finances (Toan, 2016). As a result, several NENA countries provide irrigation water for free or at a negligible cost. This means that the region spends about 2 percent of its GDP on subsidies for the sector (Kochhar, 2015). Specifically, the monitoring, enforcement, and legal frameworks and coordination of these public incentives are weak and insufficient (Bazza, 2003; Jeuland, 2015). Overall, these weak institutional arrangements and the lack of recognition of the real prices of irrigation water translate into a widespread undervaluing of water (World Bank, 2017a). This then results in a lack of incentives to efficiently manage water and indeed, a tendency to overexploit water sources even when new technologies are put in place. Simultaneously, public-private partnerships are still nascent in the region and their real benefits, while mixed, need to be evaluated (OECD, 2018).

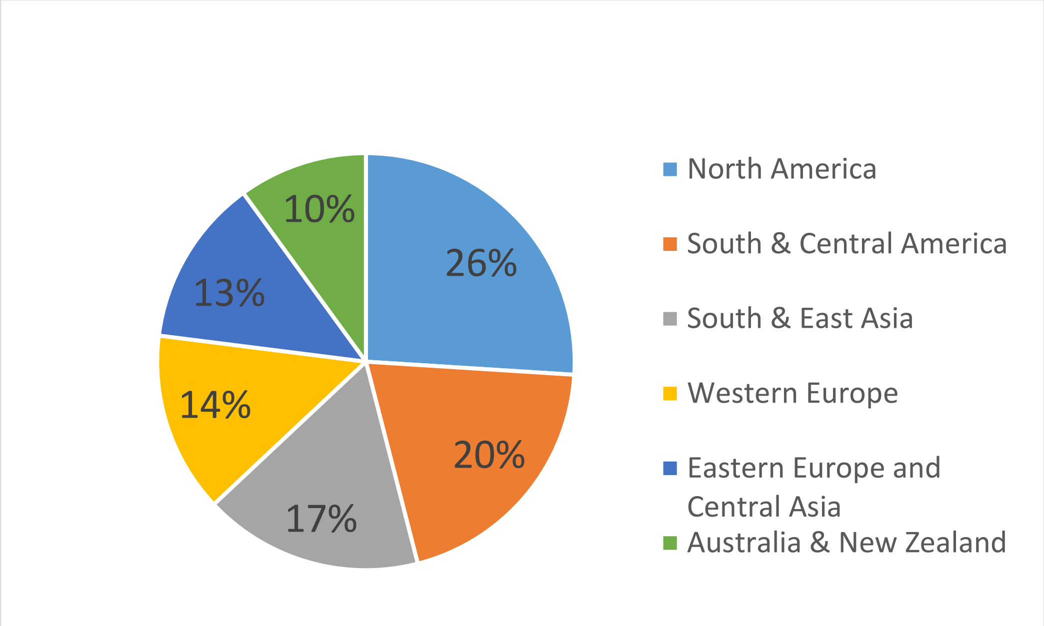
Also, at present, water conservation, wastewater reuse (as previously shown), rainfall harvesting, and the use of green water (water stored in the soil) are still not part of formal national strategies (Antonelli and Tamea, 2015). The potential that these types of strategies may have for regional water resources is often overlooked and underestimated (Rockström and Falkenmark, 2015; Borgomeo *et al*., 2020). As a result, these practices mainly rely on local and ancestral practices. The potential that these strategies may have for the region will be addressed in Chapters 3 and 4.

1.7. Virtual water trade

Another mechanism to *cope* with regional water stress is the artificial or virtual import of water embedded in commodities. The NENA region imports virtual water from practically all over the world and is the largest global food importer (Antonelli and Tameab, 2017; World Bank, 2017a; OECD, 2018). The United States, Brazil, and Argentina are the biggest virtual water exporters to the region. Altogether, in terms of water volumes, the Americas account for almost half of the NENA region's virtual water imports (Figure 1.7).

[12] SDG 6.b.1 looks to enhance participation of local communities in water and sanitation management

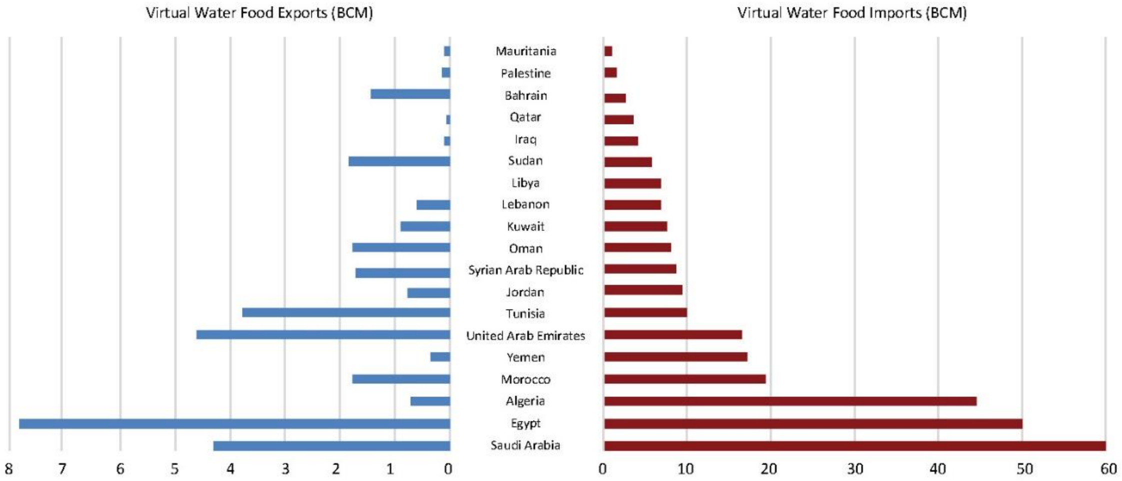
Figure 1.7 Percentage of net virtual water trade to the Middle East and North Africa, by world region in 2015



Source: World Bank, 2017a

The MENA region is the largest global importer of cereals and a significant importer of meats and fish, vegetable oils, oilseeds, sugar, and sweeteners (OECD, 2018). By 2019, the NENA region was receiving about a third of the international shipments of cereal, sheep meat, and whole grains, and about a fifth of sugar, poultry meat, and skimmed milk. Overall, the biggest food importers in region are Saudi Arabia, Morocco, Yemen, the United Arab Emirates, Egypt, and Algeria (Figure 1.8). In fact, the latter two countries alone account for 10 percent of global wheat imports and the region accounts for 40 percent of the global cereal imports. Yet it is worth noting that the region also has an advantage in that it is self-sufficient in terms of fruits, vegetables, and nuts.

Figure 1.8 Virtual water trade in the NENA region



Source: AbuZeid, K., Wagdy A. & Ibrahim, M. 2019. *3rd State of the Water Report for the Arab Region - 2015*. Cairo, CEDARE.

Since the situation is not expected to change in the next few years, it has become a relevant discussion point for decision-makers in the region. In just 25 years, between 1986 and 2010, water imports to the region increased by about 150 percent (Antonelli and Tameab, 2017; Antonelli *et al*., 2017). Naturally, it is politically challenging to be largely dependent on agricultural imports. Global food price shocks (such as that experienced in the 2007-2008 global food crisis), climate impacts on production countries, political tensions, conflicts and blockade, general supply chains disruptions, and others may in turn augment the regional vulnerability of the food and water sector (Breisinger *et al*., 2012). This could be particularly relevant in Saudi Arabia (20 percent) together with Egypt (17 percent) and Algeria (15 percent), which account for more than half of regional food imports (Anon, n.d.). A more detailed review of these potential sources of risk will be discussed in the following chapter.

It is likewise important to note that the region also plays an important role in water exports embedded in food. However, this corresponds to around a tenth of total water net imports (Anon, n.d.). Egypt, which accounts for nearly 25 percent of regional virtual water exports, is followed by the UAE, Saudi Arabia, and Tunisia (accounting for about 12 percent each) (Figure 6). Overall, over 50 percent of virtual water food exports constitute dairy and vegetable products, and sugar products account for about 15 percent. Still, food exporting countries may also be affected by local risks, which would in turn lead to impacts in export volumes and supply chains.

1.8. Status in data availability

The sources of data available for the NENA region typically include government websites, service provider websites, reports from international organizations, project documents, and other secondary sources (Mumssen and Triche, 2017). However, the availability of long-term consistent records of key hydrological variables such as precipitation and temperature, as well as other relevant physical information, such as environmental indicators or drought indices, is not constant across the region. The existence of comprehensive and longitudinal records is often linked to specific projects, such as irrigation, canals, reservoirs, or research. Indeed, in some locations, data may go back to the nineteenth century. Even specific locations, such as the Nile Delta, have attracted a number of climatological and natural reconstruction projects from the international academic community. These efforts offer time-series describing the evolution of climatic, fluvial, geomorphological, sedimentation, vegetation, and other variables over centennial and multi-millennial timescales (see for example the work of Crown, 1972; Nicholson, 1979; Revel *et al*., 2010; Zhao *et al*., 2012; Marriner *et al*., 2013; Anthony *et al*., 2014; Pennington *et al.,* 2017 in the Nile region and North Africa). Nonetheless, a gap remains between this generated historical physical knowledge and the design of current and future decisions in the region's agricultural water sector.

Moreover, within the region, the variance in number of stations and records differ across countries. For example, while Morocco has over 700 surface water gauging stations and over 130 groundwater monitoring wells, Lebanon has about 50 gauging stations and 13 monitoring wells (Fragaszy *et al*., 2020). This is aggravated due to the fact that efforts to reliably and systematically gather and process data at the regional scale appear to be non-existent. Also, the current challenges are not just related to data availability but also to real accessibility. Many institutions in the region do not have the data-sharing mechanisms in place to enrich the regional network of observations. At present, there are no regional data regulations and guidelines, nor frameworks to facilitate sharing. This is also true for other relevant and connected sectors such as food, infrastructure, environment, and others.

To overcome these limitations, the region has designed alternatives. A first mechanism includes access to global datasets. They include, among others, FAO-AQUASTAT[13], FAO Wapor[14] and Earth Map[15] and Hand-in-Hand geospatial platform[16], WRI-Aqueduct, World Bank Climate Change Knowledge Portal, World Meteorological Organization databases, precipitation reanalysis products[17] (e.g. CRU or GPCC, for a full review see (Sun *et al*. (2018))

[13] http://www.fao.org/aquastat/en/
[14] https://wapor.apps.fao.org/home/WAPOR_2/1
[15] https://earthmap.org/login
[16] http://www.fao.org/hih-geospatial-platform/
[17] Reanalysis refers to a commonly used climatological technique that provides a numerical description of the recent climate, produced by combining models with observations. The estimates are produced for all global

and others. Notable regional efforts to understand the impacts of climate change in agricultural, water, and other sectors include the Regional Initiative for Climate Change Impacts on Water Resources, RICCAR. This platform serves as a knowledge hub for decision makers, practitioners, and the overall public [18]. Other local-level sources include remote-sensor imagery derived from sensors such as GRACE, Landsat, MODIS, Sentinel, WAPOR, and other open or paid high-resolution satellites. Second, other various relevant local efforts exist to tackle these data limitations. For example, in Morocco, Tunisia, Lebanon, and Jordan, novel participatory frameworks have been put into place to enrich local physical observations and monitor drought conditions.

1.9. Evaluation from an SDG perspective

As reviewed over the last sections, the SDGs provide not just an agenda but also a mechanism to monitor the multidimensional progress of the sector with a 2030 horizon. Within them, and as mentioned, SDG 2 and SDG 6 are the two which are naturally connected to the agricultural water sector. Unfortunately, the reported progress in both SDGs, as discussed in the previous section, suggest that indeed, the NENA region is not on track to meet the SDG targets over the next 10 years.

Apart from the direct repercussions that this may have on water and food security, this may also be felt across other sectors. Particularly since these two sectors, and these two connected SDGs, provide the foundation from which to achieve the other 15 goals (Thacker *et al*., 2019). They include, among others, SDG 1 on ending poverty, SDG5 on gender equality, SDG11 on sustainable cities and communities, and SDG 15 on managing terrestrial ecosystems.

An overall failure to achieve these goals reflects the already-discussed problems within the region. For instance, apart from Morocco, Tunisia, Oman, Jordan, and the Syrian Arab Republic, the region does not report water and sanitation sub-sectors with clearly defined procedures in law or policy for the participation of local communities and users (UN Water, 2021). Also, worsening scarcity conditions along with over-exploitation of surface and groundwater resources in turn also affects the quality of water for human consumption and the health of ecosystems.

Moreover, the NENA region has also had the opportunity to be a global pillar for initiatives linking the agricultural water sector to global climatic efforts. A relevant mechanism for this

locations, and they span long time periods (multi-decadal or more). They produce long-term, coherent, and consistent climatological datasets at various scales.

[18] http://riccar.org

is the Paris Agreement[19] and its subsequent National Determined Contributions (NDCs). These are the country-level efforts to reduce greenhouse gas emissions. Here, the NENA region has the opportunity to promote clean energies and net-zero strategies throughout the water and food chains. The region also has the potential to link strategies for the reduction of land degradation and the promotion of economic diversification and gender equality with overall climate strategies (UNFCCC, 2020). However, further evaluation is still required at the country level to better understand how specific countries in the NENA region could better align economic sub-sectors towards the implementation of SDGs, while also accounting for food and water sustainability. The way in which policies and technologies could better be aligned to SGDs and international climate agendas will be discussed in Part II under Chapter 3 and 4.

[19] The Paris Agreement goal is to limit global warming to well below 2, and preferably to 1.5 degrees Celsius, compared to pre-industrial levels.

Chapter 2: Drivers of water use in the NENA region

The North Africa and Near East region is subject to several drivers that shape the agricultural water characteristics described in Chapter 1. These drivers are a product of both internal and external (or global) trends, and their nature is sometimes likewise uncertain. They mainly correspond to social and economic processes, changing dietary and lifestyle conditions, and climate change and environmental circumstances. The role of these relevant circumstances in the availability of water for agriculture is discussed below.

2.1. Social and economic drivers

By 2019, the NENA region had about 515 million inhabitants (United Nations, 2019). By 2030 the region is expected to add about 100 million more, and by 2050, is expected to reach an overall population of over 750 million. Naturally, such population growth poses additional pressures on already scarce water resources as well as on food demand in the region. For example, the demand for dairy products is expected to grow by 2.5 percent annually this decade, and production will have to increase in order to satisfy the needs of a growing population. At the same time, this population is likely to be largely concentrated in urban areas, since the rural population will continue to migrate to cities (Mirkin, 2013). As a result, urban consumers may shift towards preferences for more processed and sugary foods.

In line with this, migration and conflicts are also important factors affecting regional agricultural water processes. Conflicts in Iraq, the Syrian Arab Republic, and Yemen have led to waves of displaced people. By 2017, over 10 million people in the region were internally displaced, and about 6 million were considered refugees (UNHCR, 2017). About 20 percent of the current population in Lebanon and about 10 percent of that in Jordan are refugees (UNHCR, 2016). The repercussions from this are directly tied with the necessity for governments to address the food needs (as well as other services) of these unexpected populations. This thus translates into the need for more water (real and/or virtual) to satisfy such needs. Migration and displacement should also be carefully considered when evaluating water scarcity and stress trends in the countries of origin. For example, a recent decline in the trend of groundwater stress observed in southern Iraq is thought to be tied to decreasing water use resulting from population displacement (World Bank, 2017a).

The evolution of regional economic conditions also shapes the characteristics of the agricultural and water sectors. Firstly, the international energy market's volatility would play an important role in shaping the feasibility of desalination plant operation (Ghaffour *et al*., 2015). Fluctuations in energy prices would also impact subsidies for groundwater pumping, particularly in the Gulf countries (Commander *et al*., 2015). Secondly, it should be noted that changing incomes shift consumer preferences. At present in the NENA region, almost half of regional household incomes go towards food and beverages (OECD, 2018). Pre-COVID-19 estimates projected a modest income growth per capita during this decade (at 1.6 percent), which would not be likely to affect food consumption trends. Indeed it had been projected that over the next few years, economic growth and de-escalation of conflicts in some countries would lead to more investments in the water and agricultural sector, translating to a slight improvement in production growth (OECD, 2018).

Yet, as result of the global pandemic[20] and the subsequent lower oil and energy export revenues, in 2020 the region's economies contracted by 5.2 percent. By December 2020, macroeconomic losses had reached 7.5 percent of MENA's total GDP (World Bank Group, 2021). Critically, Lebanon in 2020 had expected losses equivalent to 23 percent of its 2019 GDP. This outlook translates into job losses and high rates of regional unemployment (which pre-pandemic was at 10 percent, making it the highest in the world, with a particular impact on young people) (World Economic Forum, 2012). At the same time, COVID-19 and volatility in commodity prices has also led to food prices rising to 20 percent in most of the region's countries (World Bank Group, 2021). Similarly, the current crisis may also be pushing consumer demand towards more vegetable-based diets and other diets that strengthen the immune system. The extent to which economic contraction and unemployment, rising food prices and increased consumption, and the future economic and societal consequences of COVID-19 will affect the region's interconnected water-food systems is not yet clear.

2.2. Dietary and lifestyle drivers

As mentioned in the previous chapter, diets in the region are mainly based on cereals and vegetables and this pattern is not expected to change significantly. In fact, by the end of the current decade, nearly 90 percent of calorie intake is estimated to come from these sources (a slight decrease compared to current intake) (OECD, 2018). The consumption of meat, fish, and dairy would increase by less than 1 percent. In rich Gulf countries, the share of these type of products in the dietary composition may reach up to 15 percent. Rice consumption would also increase in these countries, particularly among Asian migrants. The consumption of other oil and sugar-based products would continue to increase, raising their share of the regional dietary mix.

On the other hand, food production in the NENA region is not expected to keep pace with growing consumption (Borgomeo and Santos, 2019). For instance, by the end of the decade, regional net imports of wheat will be double that of regional production. Despite the modest increase in meat consumption[21], net imports would increase by 50 percent from their current

[20] As of April 2021, COVID-19 had caused about 85 000 confirmed deaths in the region. Source: https://ourworldindata.org/coronavirus

[21] Meat, fish and dairy products correspond to about 10 percent of the regional calorie intake. These sources also constitute about 35 percent of current region protein intake.

levels (OECD, 2018). Food imports from the Americas are also likely to continue. And because of the economic impacts of COVID-19 on purchasing power, NENA countries may see a decrease in meat consumption, and a sustained dominance of vegetables and cereal in local diets. As such, the region's dependence on cereal and vegetable imports will also grow.

2.3. Climate change and environmental drivers

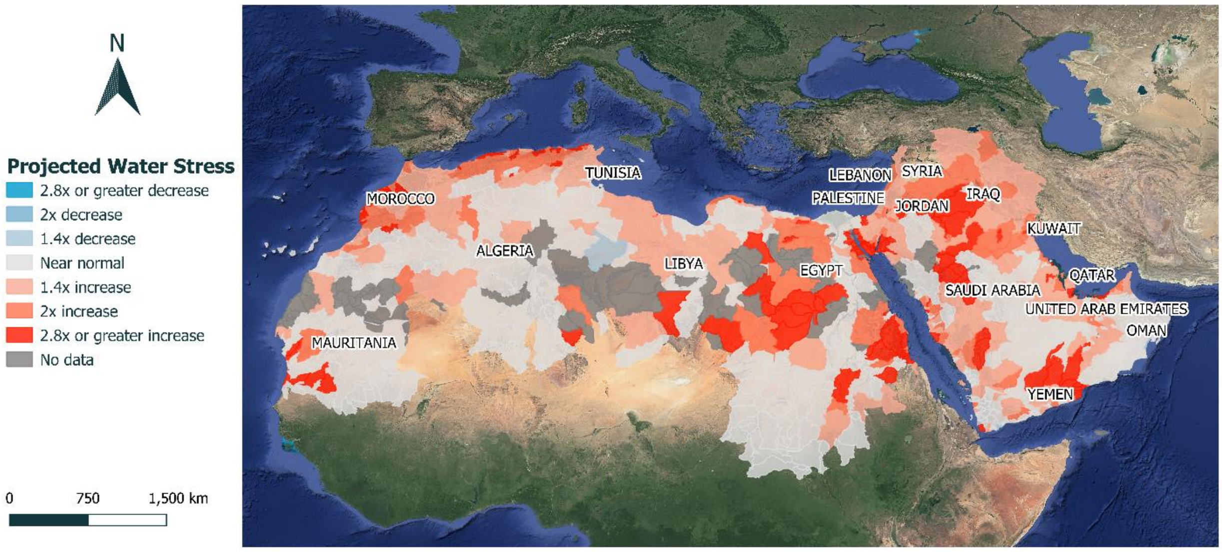
As in the rest of the world, in the NENA region, climate change has posed new challenges while exacerbating existing ones. Indeed, since the 1960s, temperatures in the region have increased by about 0.3°C per decade (Verner, 2012; Waha *et al*., 2017). As a result, the region has seen a decrease in the number of cool days, along with an increase in the number of hot days. Precipitation levels have also fallen, and the majority of countries in the region has got drier.

Considering that global temperatures are projected to increase this century, these trends may worsen (Hartmann *et al*., 2013; Dogar and Sato, 2018). In the NENA region, temperatures could increase by up to 4.8°C towards the end of the century under the most extreme climate scenario (United Nations Economic and Social Commission for Western Asia (ESCWA), 2017). The areas that would experience the highest rises in temperature would be Maghreb, the upper Nile River Valley, and the central and western parts of the Arabian Peninsula. Ultimately, this would translate into more evaporative losses as well as more heatwaves (Waha *et al*., 2017; Bucchignani *et al*., 2018).

Precipitation levels are also projected to fall in the NENA region, particularly in the al-Mashreq, al-Maghreb and Egypt (UNDP & GEF, 2018). For example, in a world 2.0°C warmer than pre-industrial levels, regional precipitation levels may decrease by about 25 percent (Paltan *et al*., 2018). In the Atlas Mountains, the RICCAR platform reports that most extreme climate projections estimate a reduction in mean annual precipitation of about 90mm, and a reduction of around 120mm in the coastal zones (United Nations Economic and Social Commission for Western Asia (ESCWA), 2017). These reductions may indeed translate into less available water. In the Jordan river for example, general precipitation decreases would lead to reductions in river flow and available water of up to 44 percent (Givati *et al*., 2019).

As a result, the NENA region is expected to become a global hotspot for droughts (Prudhomme *et al*., 2014; Cook *et al*., 2018; Driouech *et al*., 2020). This would, in turn, deeply aggravate the region's current water stress conditions. Indeed, under the most severe climatic scenario (RCP8.5), current water stress conditions would significantly increase in most of the region (Figure 2.1). This would be particularly acute in areas around the Mediterranean, the Nile region, and the Mashreq Region generally.

Figure 2.1 Change in water stress in 2030 under a RCP85 climate scenario and business-as-usual socio-economic conditions



Source: Hofste, R.W., Kuzma, S., Walker, S., Sutanudjaja, E. H. *et al.*, 2019. Aqueduct 3.0: Updated Decision-Relevant Global Water Risk Indicators. *World Resources Institute*.

Likewise, it is estimated that a regional spread of aridity would result in the deterioration of about a third of arable lands (Waha *et al*., 2017). Naturally, regional farming and food systems may be significantly undermined (Reyer *et al*., 2017; Waha *et al*., 2017; OECD, 2018). For example, irrigated farming systems would suffer from greater water stress, reduction in cropping intensities, and reduced yields. Pastoral activities would be severely affected by desertification and reductions in carrying capacities.

The situation becomes still more acute if variability and uncertainty are taken into consideration. Despite the general regional reduction in precipitation, the NENA region may see further occurrences of extreme events and flash floods. For instance, as global temperatures increase, extreme flows and floods are estimated to become more common in the Nile (Paltan *et al*., 2018). Also, in the Nahr el Kabir basin, in Lebanon and the Syrian Arab Republic, this century will be characterized by a tendency towards drier conditions, which will be accompanied by an increase in the magnitude of peak flows and flood frequencies (FAO, 2017). More common flooding would led to severe flood damages to key agricultural infrastructure, shifting groundwater recharge patterns, and losses in the soil's capacity to absorb water (World Bank, 2017a). Since 1970, floods in the region have caused more than 10 000 fatalities and annual economic losses of USD 200 million (Borgomeo *et al*., 2020). The countries that are traditionally most affected include Sudan, Somalia, and Yemen, which already experience conflicts. However, the full extent to which changes in the global climatic system translate into specific impacts in regional and local water, agricultural, and other systems is typically subject to various uncertainties and limitations in climate projections, models, and data, among other factors (Stainforth *et al*., 2007; Knutti and Sedláček, 2013; Harding *et al*., 2014; Heal and Millner, 2014).

As a whole, the NENA region will be at the forefront of global economic losses resulting from climate-related water scarcity (World Bank, 2017a). In fact, the region may lose between 6 and 14 percent of its GDP by 2050 as result of climate change. Critically, climate would also amplify various social and economic processes (described previously in section 2.1). As rural conditions worsen, the region would expect to see a major influx of rural migrants to urban areas (Waha *et al*., 2017). In Algeria for example, there has been a continuous migration from rural areas to mid-size cities due to water scarcity and general desertification processes (Gubert and Nordman, 2010). Shocks resulting from droughts in Yemen, Iraq, and the Syrian Arab Republic are also thought to have escalated already fragile conditions (Sadoff *et al*., 2017).

Climate change may also indirectly impact other conditions in the regional agricultural sector. For example, as temperatures increase, tropical diseases such as leishmaniasis would also spread. An expected increase in temperatures during the winter months in western North Africa would extend the period suitable for disease transmission (United Nations Economic and Social Commission for Western Asia (ESCWA), 2017). The broader spread of leishmaniasis would, in turn, present a major threat, particularly to women. In this region, women are the main livestock caretakers, which increases their exposure to sandfly bites. Climate can thus be seen as a driver that multiplies and fuels existing risks and aggravates institutional fragilities, conflict, conditions of violence, and displacement (Borgomeo *et al*., 2020). Taken together, these processes will in turn shape the NENA region's water and agricultural systems.

PART II: HOW CAN AGRICULTURAL PRODUCTION BE MAINTAINED IN THE FACE OF WATER CHALLENGES?

The NENA region requires novel transitions that allow countries to better align their agricultural water sectors to a Sustainable Development Goals (SDGs) horizon. Such transitions need to be centered around state-of-the-art paradigms, as well as management, policy, and technical innovations. The next two chapters present a review of these innovations (business as usual is a not an option anymore). In this part, the first chapter addresses the foundations for such a transition, including the required paradigm changes and shifts in policy responses in the region. The second chapter reviews the type of technological innovations and tools that could be offered to the sector to help it maintain its water needs to sustain agricultural production, while also achieving the SDG.

Chapter 3: Establishing the foundations of change in the agricultural sector

This chapter addresses the paradigms and strategic changes that the NENA region requires to address water and agricultural challenges and to cope with agricultural production needs, whilst also mainstreaming sustainability principles into its practices. They include management of already existing infrastructure to improve supply and demand practices; shifting towards resilience and circular economy paradigms; inclusion of the private sector and markets; acknowledgment of social and gender equality gaps; and general sustainable principles, including data and information monitoring and sharing. This chapter thus provides a broad overview of the principles and ideas required to facilitate the assimilation of a new set of policies for the sector. Inevitably, in order to be applied locally, the set of strategies outlined here requires context-level evaluations as well as direct involvement by stakeholders.

3.1. Managing supply and demand: A starting point

3.1.1. Managing supply

This first strategy corresponds to the improvement of existing water infrastructure without the need for significant extra investments in new systems[22]. The aim here is to rehabilitate, improve and upgrade storage, distribution, and operational infrastructure and practices so that the water system performance is maximised, or indeed modernised.

Under this strategy, the main actions for the NENA region include the rehabilitation of current intake structures and canals, dredging of drain canals to improve water-scheduling, introduction of automatic gauging stations and instruments for monitoring and delivery, and others. For example, Egypt is currently looking to rehabilitate and line 7 000km of canals by mid-2022 at an overall cost of over USD$ 1 billion (Daily News Egypt, 2020b). Overall, this would increase Egypt's water yields by 5 billion m^3 per year (currently losses in the system). The improvement of canal operations to distribute water between outlets at the right time would also make water use more efficient. For example, the potential of deploying smart and automated irrigation systems in the Jordan Valley area has previously been acknowledged as a mechanism to make canals more efficient (Massadeh, 2014).

In fact, recent estimates suggest that if the management of water storage and delivery infrastructure were improved in the NENA countries, regional economic benefits could range from USD 7 to USD 10 billion per year (Sadoff *et al.*, 2015). Estimates also suggest that these

[22] It should be noted that, in various cases, new investments and infrastructure projects may indeed be needed.

efforts would cost countries in the region between 0.08 and 0.16 of their GDPs (Rozenberg and Fay, 2019). This then highlights the potential financial feasibility of these strategies. Overall, this set of strategies then requires a basic level of institutional, managerial, and operational arrangements (Foster and Ait-Kadi, 2012).

3.1.2. Increasing water yields

Apart from improving infrastructure management practices, the region would benefit from an increase in water yields. Given the abundance of reservoirs and dams in the region as a result of regional policies in the last few decades, as reviewed in section 1.6, alternative ways of expanding water availability are required. This may initially include better rainfall capture and improved water harvesting through subsurface tanks. Rainwater capture and the use of green water (water stored as soil moisture) have been acknowledged as yet unexpanded options to increase water storage in the region (Borgomeo *et al*., 2020). Green water has yet to be included in regional national water budgets (Antonelli and Tamea, 2015). The productivity of rain-fed agriculture likewise remains below regional potential. In particular, rainfall harvesting via micro-catchment management has shown promising results in terms of water productivity for open crops in Egypt, Jordan, the Syrian Arab Republic, and North Africa (Borgomeo and Santos, 2019).

These strategies may to a large extent benefit from Nature-based Solutions (NbS)[23]. Examples of NbS include, but are not limited to, constructed wetlands, land and soil practices, the use of aquifers as natural storage infrastructures, and others. Water conservation practices could be improved if biodegradable soil and water absorbent materials are also used. NbS would also facilitate the regional reuse of wastewater for irrigation practices, which can satisfy 20-40 percent of irrigation needs in the region (more details and examples will be presented in section 3.3 on the circular economy). If implemented correctly, these actions may offer the chance to not only limit the social and environmental impacts of traditional grey infrastructure, but also to attain hydrological gains in terms of reduced evaporative losses and improvements in water quality performances (Gale, 2005). Applying NbS would serve as a catalyst to achieve at least 10 SDGs, among these SDG15, on promoting sustainable use of ecosystems, and others already being reviewed here (Martín *et al*., 2020).

Additional strategies include the expansion of desalination capacity and reuse of wastewater in the sector. The former, as reviewed, still brings significant energy costs to the region and environmental concerns that also can reduce plant efficiency (currently salinity in the Gulf is 45mg/l where negative impacts on a plant's efficiency occur at -40mg/l as per Amgad Elmahdi,

[23] The European commission defines Nature-based Solutions as '*solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience*' (*Anusheema Chakraborty*, 2020).

2019). So, its regional feasibility is dependent on technologies to improve plant energy efficiency, which also reduce environmental impacts. Wastewater reuse follows the principles of a circular economy, which are discussed in the next subsections.

3.1.3. Managing and reducing water demand

From here, a next set of strategies relates to the reduction of demand and the use of water by agricultural users, or an improvement in water efficiency. In the NENA region, appropriate pricing of water – that accurately reflects its scarcity– is deemed the first and most important step (World Bank, 2017a). Valuing water would in turn deter water waste and overexploitation of resources, while also providing financial means to water resources operators in the region. Other demand strategies include switching to crops that consume less water and produce higher economic yields. These crops include high-value horticulture or fruits and vegetables (Scheierling *et al*., 2006; OECD, 2018). Actions in this area include evaluating the potential of mixed cropping in the region to reduce soil degradation and water quality issues. For example, Saudi Arabia is moving to phase out domestic wheat production (in which the Kingdom was previously self-sufficient) and in its place, encouraging the production of high-value crops such as dates (Al-Shreed *et al*., 2012; Witt and Redding, 2014; OECD, 2018).

More efficient water consumption in the agricultural sector would also provide benefits to the overall water sector and to the general economy: a 30 percent reduction in agricultural water withdrawals in the region would translate to USD $68 billion in gains, or 2.5 percent of regional GDP (World Bank, 2017a). Better water use in the sector would also result in less competition for water resources with other sectors, such as the urban, industrial, or energy sectors, and would reduce regional water stress. That same 30 percent reduction in agricultural water withdrawals would reduce water stress for about 9 million people in the region.

On the whole, the agricultural water sector of the NENA region has the opportunity to put SDG 6.5[24] and *Integrated Sectorial Water Resources Management (ISWRM)* at the core of its practices. For the integrated agricultural water sectors, this could also relate to the establishment of long-term strategies that acknowledge the sustainable use of resources with other sectors (health, environment, drinking water supply, and other) that compete for this scarce resource, along with multi-sectorial benefits and tradeoffs of interventions. Indeed, ISWRM then supports and strengthens the recognition that in the NENA region, water has multiple uses and users (some even across national boundaries).

[24] SDG 6.5: *By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate.*

3.2. Acknowledging resilience

The paradigm of resilience, and its complementary metrics[25], relates to the idea of planning and preparing the sector so that it may adequately respond and recover in the face of series of uncertain and rapidly evolving threats and risks (Adger *et al*., 2011; Hall *et al*., 2019). This becomes critical for the NENA region given the various pressing, rapidly evolving, and even unpredictable challenges that the region faces (such as those derived from climate change, population growth, conflicts, and COVID-19, as reviewed in Chapter 2). For example, a district in the NENA region may have sufficient water supply reservoirs and good demand practices in place to manage the agricultural water sector. Yet water services in this district may be interrupted if the area is severely affected by unexpected floods which interrupt and contaminate irrigation canals or devastate crops. Additionally, unpredicted human displacement may change water consumption patterns, thus increasing stress.

So, resilience contemplates the water and agricultural systems' capacity to adapt, transform, and reinvent themselves to ensure *adequate performance* over time and in the face of stress conditions. For example, for the agricultural water sector, performance could be measured in terms of the time the water service is re-established for crop irrigation following a disaster, the number of hectares that have constant water access during dry months, and even water access and equity levels among farmers during periods of high-water competition.

As a result, resilience and the support of resilience could be used as an aid to improve SDG 13.1 on strengthening resilience and adaptive capacity to climate-related hazards and natural disasters in all countries, Also, actions to improve the performance of agricultural water systems may in turn serve as a catalyst for the achievement of SDG 9.1 on developing quality, reliable, sustainable, and resilient infrastructure.

At present, most of the efforts to address resilience in the NENA region seek to make crops and infrastructure more resistant to droughts or saline conditions. Box 2 shows academic suggestions in Qatar to improve the recovery capacity of desalination plants when dealing with failures. Yet, these and other suggestions around resilience still require the full consideration of governments, donors, and multi-lateral organizations. In Yemen, there are likewise important actions to improve the resilience of connected energy-irrigation systems when facing conflict and arid conditions. These initiatives will be addressed further in Section 4.1, when discussing technological innovations in the sector. In closing, we should highlight

[25] complementary metrics include reliability, vulnerability, and, in particular, robustness. Robustness estimates the number of potential scenarios (climatic, demographic, demand, geophysical, and other) at which the performance levels are maintained.

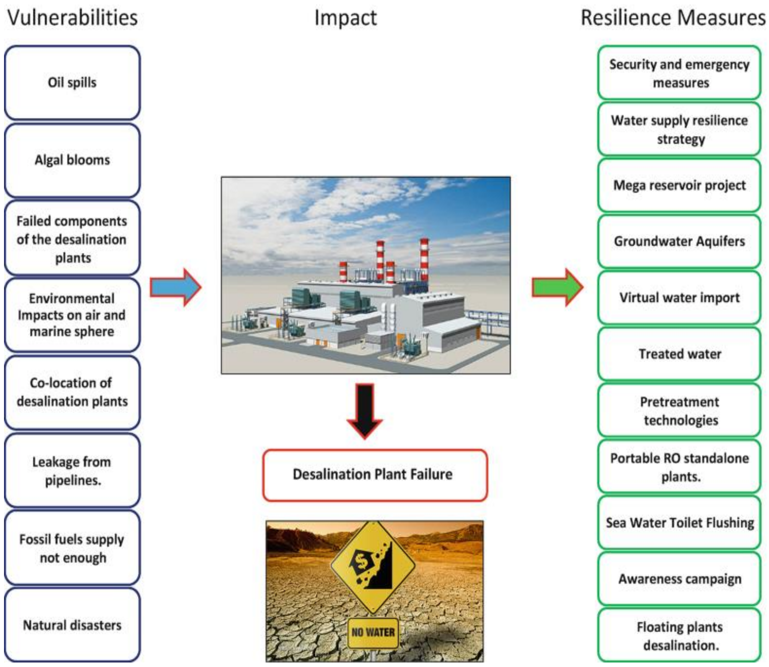
that there are no known projects in the NENA region where the resilience paradigm has been fully mainstreamed and applied for integral agricultural water systems[26].

Box 2 Resilience of desalination plants in Qatar

Qatar relies heavily on desalination for its water supply, not only for agriculture but for other sectors too. Yet, the structure of desalination plants in the country is vulnerable to various types of risks. Among others, these include adverse climate conditions, algae blooms, oil spills, co-location of plants (and the threat of a cascade and multiplication of risks if, for example, a power outage occurs), plant equipment failures, and others. Although some of these events may be unlikely, their repercussions would be felt widely, since the country only has a 48-hour emergency water supply for its 2.4 million people and for economic and industrial activities. The ability to quickly recover from emergencies is vital not only to this industry, but also to the country's overall food and water security.

To confront these threats, and indeed, increase recovery times should shocks hit these plants, researchers have mapped out vulnerabilities and proposed resilience measures, as shown below. Whilst this exercise provides a preliminary effort to promote technological diversification to maintain constant water supply without relying on fossil fuel-based desalination plants, additional steps are required. For instance, these measures still need to be evaluated against stakeholders' views while also designing implementation and financing roadmaps (Tahir *et al*., 2020).

Figure 3.1 Proposed desalination plant resilience strategy identifying vulnerabilities and adaptive measures



Adapted from: Tahir, F., Baloch, A.A.B. & Ali, H. 2020. *Resilience of Desalination Plants for Sustainable Water Supply in Middle East BT - Sustainability Perspectives: Science, Policy and Practice: A Global View of Theories, Policies and Practice in Sustainable Development*. P. A. Khaiter and M. G. Erechtchoukova eds.

[26] Countries where resilience and robustness principles have been applied to the agricultural water sector include projects by the World Bank in Kenya and Peru.

3.3. Towards a circular economy

A next step towards shifting the paradigm in the management of agricultural water practices in the NENA region is the need to redefine the potential role of wastewaters. The principles of a circular economy seek to shift the idea that water that has been used should be discarded or indeed, wasted (Toop *et al*., 2017; Korhonen *et al*., 2018). This paradigm offers an opportunity that strengthens links not just within the agricultural water sector, but also with other sectors, such as energy, environment, finance, and sanitation (Rodriguez *et al*., 2020). Overall, these principles would also facilitate the sector's alignment towards the achievement of SDGs. Here, the agricultural water sector of the NENA region could become a major contributor to SDG 6.3 towards reducing untreated wastewater and substantially increasing recycling and safe reuse.

At present, most wastewater in the NENA region remains untreated. It is believed that over 55 percent of the region still discharges untreated water into natural water bodies (World Bank, 2017a). However even when water is treated, it is still usually discharged directly into the sea. In fact, about 82 percent of regional water remains untreated or is not used following treatment. Under a circular economy paradigm, this wastewater (as well as the nutrients within it) could be exploited for the agricultural sector's benefit. Even treated wastewater could be used to recharge aquifers, thus maintaining a more balanced use of water resources for the agricultural sector (see Box 3 on the case of Oman).

Box 3 Oman groundwater management

The Sultanate of Oman is located in one of world's driest regions, where water resources are scarce. Groundwater is the main water resource utilised in Oman for domestic, industrial and agricultural purposes. To address this situation, the country has implemented many measures to efficiently use and preserve its resources to close the demand-supply gap. One of these includes artificial recharge for groundwater management. This is achieved through the construction of injection wells, recharge ponds and recharge dams.

Recharge dams are built across alluvial channels to store water during floods. The stored and clarified water is then released slowly, so that it can infiltrate thick alluvium downstream of the dam and in time be withdrawn for use. Oman has over 30 recharge dams with a total combined capacity of 88 million cubic meters. Existing evaluations suggest that recharge efficiency can be as high as 75 percent for these dams. Importantly, in the north of the country, groundwater recharge can be as twice as much as recharge under natural conditions. Altogether, it is estimated that this technique increases recharge by between 30 mcm/year and 50 mcm/year.

Artificial recharge has several other benefits. For instance, groundwater storage capacity surpasses that of most surface structures. The method is also cheaper and avoids silting difficulties. At the same time, water supplies are naturally purified for drinking purposes and evaporation losses are minimized. Similarly, in some regions of the country, injection wells are even undertaken to mitigate seawater intrusion into coastal aquifers.

However, to be successful, groundwater management strategies should be combined with several supplementary measures. For instance, a monitoring network is essential to measure the quantity of water intake, and when it occurs. Furthermore, proper safety measures and accurate decision-making on construction of new infrastructure is critical in dam operations. In Oman, all recharge dams are instrumented. The hydrological network of dams includes 47 rainfall stations, 18 falaj stations, 31 wadi flow stations and 264 monitoring wells. Data records show that, in an average year, the cumulative storage of all recharge dams in the Sultanate is slightly greater than their total combined capacity; presently this amounts to more than 84 million cubic meters. Most of this water recharges the aquifer – an amount similar to the annual production of the Al Ghubra sea water desalination plant. Naturally, this amount of data requires a level of institutional coordination and a capacity for sufficient decision-making.

Sources: Ministry of Region Municipalities & Water Resources. 2008. *Water Resources in Oman* & McDonnell, R. 2016. *Groundwater use and policies in Oman*. IWMI Project Report No.14

Other potential uses of treated water, which remains very limited in the region, include its injection in coastal aquifers to deter saltwater intrusion and its use by urban farmers to sustain local agriculture (Hettiarachchi and Ardakanian, 2016). As a result, NBSs also represent a major component of the circular economy. These alternatives could in turn increase the amount of water supply sources for the agricultural sector in the NENA region. Box 4 illustrates the example of the Nimr Water Treatment Plant (NWTP) in Oman, which uses wetlands to filter wastewater for later use in irrigation.

Box 4 Nimr water treatment plant, Oman

One of the largest manmade wetland systems in the world can be found at the Nimr oil field in Oman. In 2008, the state-owned oil firm initiated a project for the design, construction, ownership, operation and transfer (Bauer Nimr LLC, Muscat) of a constructed wetland system which supports the treatment of oil-contaminated wastewater. The treatment facility started its operation at the end of 2010, with an initial treatment capacity of 45 000 m^3/day. After three expansion phases (the last of which was completed in 2019), treatment capacity increased and today reaches about 175 000 m^3/day, a figure that represents more than 65 percent of the total oil-contaminated water generated at that oilfield. Chemical and biological processes occurring in wetland plants and soil treat oil-contaminated wastewater left over from oil production and exploration. The facility first separates the bulk of the oil using passive hydro-cyclone oil separators. The water produced is then discharged to the 360-hectare wetland and later to 500-hectare evaporation ponds, where the precipitated salt is processed into industrial grade salts. The treated effluent is used for irrigation of local salt-tolerant crops. In addition, the wetland provides a valuable habitat for migratory birds and other wildlife, with over 120 different bird species identified around the wetland. The plant alone contributes to 4.26 percent of Oman's overall Intended Nationally Determined Contributions to reduce emissions by 2 percent by 2030.

Furthermore, this method of treatment shows potential for application in irrigation systems. An initial research study was carried out in this wetland facility in Oman, where a research irrigation field of 22 hectares was established in which various salt tolerant plants with market value such as biofuel, cotton, forage grass, and others were tested. This research project provided significant information on the plant species that can survive under these specific harsh environmental conditions (water quality, climate) and yield a marketable product. In addition, a compost trial that was carried out using the reeds biomass from the wetland beds as the main substrate showed that locally produced compost could be used in the irrigation field, hence closing the waste materials cycle.

Another important aspect of this facility is the range of ecosystem services it provides. A study revealed for the first time that the presence of the Constructed Wetlands regulated the local microclimate; a 10-degree Celsius decrease in temperature was detected between the wetland body and the 1km radius around the wetland. These first findings clearly indicate the positive effect a constructed wetland system can have on its surrounding environment, especially when implemented in a hot and arid area. The reduced temperature and the increased humidity also modify the local biodiversity and can reduce the energy consumption for cooling.

Wetland facilities like this demonstrate not only the technical feasibility and the high treatment capacity of wetland technology under extreme climate conditions, but also prove their sustainability potential and present NBS options for a future transition to a circular water economy.

Sources: Breuer, R. 2017. Nimr water treatment plant. In *Produced Water Workshop* 2017, pp. 14 & Stefanakis, A., Stephane, P, & Breuer, R. 2020. Case Study 4– Nimr Water Treatment Plant (Oman). In *Wetland Technology: Practical Information on the Design and Application of Treatment Wetlands*, pp. 134-135. London, IWA Publishing.

Similarly, treated and reused wastewater can provide key nutrients to the agricultural sector. Extracted phosphorus could be used as a natural fertilizer for regional crops. In turn, this could make water use in irrigation areas more efficient, while supporting the overall transition to more sustainable food systems (Jurgilevich *et al.*, 2016). For example, the irrigated area of Ouardanine in Tunisia is deemed to be a successful model for treated wastewater reuse. In this area, farmers were able to install filtration devices at treatment plants. After the removal of sediments, effluents from 26 wastewater treatment plants are used for the irrigation of agricultural lands. This introduction of reused water in the area has resulted in a diversification of crops. While previously the area was exclusively used to grow olive trees, at present, a mixture of cereals, alfalfa, fruits, and olive trees are grown. The resulting biosolids have been used as fertilizers to rehabilitate the subsoil, which translates into financial savings as well as environmental benefits.

Water run-off from irrigated areas could also be captured in drainage ditches or similar systems, which could later be pumped back into irrigation systems (Tanji and Kielen, 2002; Qadir *et al*., 2007). This technique, called drainage water reuse, may also help to alleviate the final discharge volume of water disposals, and thus environmental concerns, such as aquifer contamination. As this water is of lower quality (typically with high salinity) it could be used in resilient and back-up strategies in scarcity conditions. This strategy has already been used by Egypt in the Nile Delta, which reuses over 13 billion m^3 of agricultural drainage water. This, in turn, reduces the demand for irrigated water by about 20 percent (Barnes, 2014; World Bank, 2017a). In particular, the Mahsama Water Reclamation Plant in Egypt provides a good example of this initiative (Box 5).

Yet, in spite of this and other promising initiatives, the NENA region still lacks regional strategies for wastewater reuse for the agricultural sector. Also, the region does not currently take steps to accurately measure the financial implications and overall gains of these strategies. A comprehensive examination of the regional and local-level opportunities (and challenges) for the agricultural water sector in the NENA region in the adoption of circular economy principles is still required.

Box 5 Al Mahsama water reclamation plant, Egypt

The Egyptian government has planned to settle more people in the arid Sinai Peninsula and to develop the farmland there. One of the most ambitious projects under this initiative is to build one of the world's largest water-reclamation plants on the eastern edge of the Suez Canal (Russell, 2020). The project is part of the Egyptian government's plan to address increasing water scarcity and growing food demands. The Al Mahsama plant aims to recycle agricultural wastewater to provide an alternative and sustainable solution for the irrigation of about 70 000 acres of land in Sinai, and to preserve the in El-Temsah lake (Moneim, 2020; Daily News Egypt, 2020a; State Information Service, 2020).

The new facility has a capacity of 1 million m^3/day and will treat and recycle mixed-use wastewater previously discarded into Lake Timsah to provide irrigation for up to 100 000 acres of agricultural land east of the Suez Canal. The project was built on an area of 150 feddan with a total cost of 3.5 billion Egyptian pounds. The plant consists of three main adjacent blocks, each 2 000 m^2, that host the main treatment units, two external blocks for flocculation and sedimentation, and one multistory central block for filtration and disinfection. The water is transferred to the plant from the Ismailia irrigation drainage canal, located west of Suez Canal, through two individual pump stations crossing underneath the Suez Canal into the Srabuim siphon, from which the water is further pumped through the plant's pump station using 8 vertical turbine type pumps – six working pumps and two on standby – with each pumping at a speed of 7 000m^3/hr.

Figure 3.2 Al Mahsama treatment plant

Source: A.Moneim, 2020. *Egypt's Al-Mahsama plant wins award for best world water recycling project in 2020*; Daily News Egypt, 2020a. *Egypt's Al Mahsama Water Reclamation Plant wins ENR Global Best Projects 2020*; *State Information Service*, 2020. *PM lauds 'Al Mahsama' wastewater treatment plant's winning of 2020 ENR best global project award*

3.4. Incorporating the private sector and market-based approaches

Market-based mechanisms may also strategically re-vitalize the agricultural water sector in the NENA region (Allan, 1997). An adequate implementation of strategies that involve the market, taking into account social protections, could not only improve water and food security in the region, but could also serve to create jobs and overall wealth engagement

(Borgomeo and Santos, 2019). These strategies could thus also tie in the regional agricultural water sector with SDG 8 on decent work and economic growth.

In this respect, national governments play a key role in facilitating reforms, which would attract a more active participation by private capital. This could be implemented by liberalizing various production chains, providing regulatory and social-dialogue frameworks to simplify this transition (while also guaranteeing sustainability and overall equity), as well as improving infrastructure and practices to support the private sector. These mechanisms also represent the enablement of public-private-partnerships across the region (PPPs) – which are often successful – to build, operate, and manage infrastructure, if adequate regulatory mechanisms are put in place. In Egypt alone, it is estimated that about USD 70 million could be saved if wheat infrastructure is managed and owned by the private sector (FAO, 2015). The private sector could also be an important ally in finding ways to reduce costs in the exploration of alternative water sources. This could support the lack of sufficient research and development and data gaps addressed in section 1.8. Box 6 presents a case study of an ongoing project in Jordan that follows a market systems approach to achieving savings and efficiencies in the water sector.

Box 6 Market based approach for water saving, Jordan

Jordan is one of the world's most water-scarce countries. Population and agricultural expansion pose a threat to water resource availability in the country. Over-abstraction also threatens aquifer levels and sustainability. The Water Innovation Technologies (WIT) project is a five-year initiative (2017-2022) that uses a market approach to mainstream the adoption of water-saving practices and technologies for households and agricultural uses with a target of 18 500 000 mm^3.

Stakeholders of this project include the US Agency for International Development (USAID), IWMI, the Government of Jordan, the Ministry of Water and Irrigation, the Ministry of Agriculture and the Ministry of Social Development, the Jordan Commercial Bank, and others. The total budget of the initiative is US$ 34.5 million.

The project envisages the adoption of several water-saving technologies, including improved irrigation management, technologies, and practices where the source of irrigation water is groundwater. The aim is to involve market players in the incentive structure. Agricultural savings come from two main groups: i) farmers who have adopted or will adopt water-saving technologies through suppliers who have signed investment agreements under the project that entail reduced technology prices or cost-sharing provisions, and ii) farmers who aim to adopt water saving technologies through suppliers who sign a water savings compensation agreement with the WIT project. Overall, this initiative compensates suppliers for each cubic meter of water saved after the adoption of technologies, instead of cost-sharing with the suppliers. Other interventions seek to use investment funds to request private sector ideas to tackle market constraints, offer irrigation technology suppliers result-based incentive packages, facilitate the development of irrigation-oriented loans from financial institutions, and support local authorities to enhance the type of information that farmers receive.

The water saved in February 2021 (Year 4 of implementation) was about 180 $000m^3$, of which savings from the agriculture sector were over 140 $000m^3$. In total, through March 21, water savings from adopted technologies and techniques amounted to 64 percent of the total target.

3.5. The role of virtual water

Virtual water trade may also positively impact water and agricultural productivity and the returns generated by the sector (FAO RNE, 2015; Borgomeo and Santos, 2019). This could be achieved by supporting exports of high-value crops (or other more productive water uses), which in turn provides revenues and cash flows. Such revenues could then be used to import low-value, or high water-demand, crops (thus influencing water productivity). This process can also contribute to job creation, dynamisation of additional sectors, or the generation of broader economic benefits, and can also support the region's countries to meet their food and water demand. Maximising crop values rather than focusing on trade deficits is a sensible strategy, which may not only provide high water returns, but also support development in other sectors. In fact, countries in the region, especially Morocco, Tunisia, and Jordan, have already made significant strides towards pursuing virtual water trade strategies.

Yet, this strategy should be taken with care. Food imports may favor more industrialized agricultural sectors and richer countries with higher purchasing power. In fact, the Gulf countries, which have the highest purchasing power, show higher food security regionally (Borgomeo *et al*., 2020). On the other hand, in middle and low-income countries where subsistence farming is extensive, these strategies may expand existing inequalities. If strategies are not optimally executed, cheap food imports may lead to a decline in the number of local agriculture jobs in the NENA region, or indeed weaken the control of communities over their local resources and food preferences (Vos and Boelens, 2016).

To protect vulnerable groups, appropriate protection measures, such as the expansion of social safety nets, targeted nutrition programs, and the reduction of food trade deficits should also accompany these efforts. Morocco, for example, reduced its food trade deficits by USD 1.3 billion between 2007 and 2009 by encouraging exports of high value-added products, such as fruits and vegetables (Borgomeo and Santos, 2019). Apart from these direct interventions, virtual water trade may serve as an opportunity to close the gender, environmental and social equity gaps discussed in sections 1.9 and 1.6. As an example, market reforms in Jordan, such as lifting price controls and the liberalisation of external trade to benefit agro-industrial transformations have gone hand-in-hand with the increasing participation of rural women in the sector (Figueroa *et al.*, 2018).

3.6. Trade of water rights

Another market-oriented innovation relates to the trading of water rights. This scheme allows established water owners to buy, sell, and transfer their rights, depending on their needs and circumstances. These mechanisms have proven efficient in managing water for agricultural use under conditions of scarcity in various global regions (Ann Wheeler and Garrick, 2020). This mechanism can also support a more cooperative and sustainable allocation in transboundary contexts (Borgomeo and Santos, 2019). In the NENA region, Morocco Tunisia, and Yemen already reallocate water through trade, providing the basis for the development of a broader water market (Richter, 2016). Nonetheless, is important to mention that the success –or failure– of market and trade strategies relies on clear and adequate legal, regulatory, and institutional frameworks. Indeed, in Morocco and Tunisia, unclear and weak regulatory frameworks are constraining the further progress of these strategies. In these countries, water rights and permits are still vaguely-defined, and are frequently tied to land ownership and transferred with property (Suárez-Varela *et al*., 2018).

3.7. Inclusiveness and equity

The management of the agricultural water sector in the NENA region can be additionally impactful if it also triggers inclusiveness and equity. This is particularly pertinent given the potential that the sector has to close the regional gender gap as well as to promote rural development. Failing to achieve these goals would in turn undermine the achievement of SDGs 10 and 16 on the reduction of inequalities, and peace and justice, respectively, as reviewed in section 1.9

It is suggested the following actions be prioritised in regional agricultural water strategies (Fortmann, 2009; World Bank, 2017b): i) expansion of women's access (including ownership) to land and rural finance; ii) inclusion of women agricultural value chains, from crop production to processing and marketing; iii) improvement of women's access to information, training, skills and general knowledge of techniques throughout value chains; iv) production and use of knowledge to guide and promote gender equality in the sector. With these overarching principles in mind, efforts in Sudan to engage women in wheat production provides an example of multi-stakeholder cooperation (Box 7).

Box 7 Engagement of Women in Wheat Production, Sudan

Sudan spends about USD 1 billion in food imports with wheat being the dominant crop. But despite agriculture being a dominant employer for 80 percent of women in rural areas, substantial gender gaps exist. This is evidenced in women's access to land, technologies, and information, and overall decision-making. To address these gender inequalities and deficits in wheat supply, the Sudanese government has been collaborating with the International Center of Agricultural Research in Dry Areas (ICARDA) and the Agricultural Research Corporation (ARC) on an African Development Bank (AfDB) funded project. This project initially worked with communities in the Gezira, River Nile and Northern regions of the country.

The engagement of women was achieved by stimulating activity in gender relations, through comprehensive involvement of project team members, and by addressing strategic gender needs. This also involved specific interventions in areas where women's workloads were deemed unfair. Interventions included mechanisation, clean planting seeds, pesticide use, gas ovens, and expedited value addition recipes. As a result, women involved in the project showed an increased ability to generate income and their workloads reduced. Also, several impacts at the institutional level were observed. They included flexibility in responding to differing gender roles and a focus on value addition, as well as involving women in hosting and generating technologies. The project also led to an increased awareness on gender roles and inequalities.

Agricultural water may also play a pivotal role in overall equity across the region. In particular, this corresponds to addressing the *who* and *when* of access to water for crops. In circumstances of inequality, the poorest might not be able to obtain fair access to water or land resources during conflict, disruption, or challenging times. Here, resilience frameworks could also support the integration of equity metrics to evaluate not only how *rapidly* an adequate level of service is re-established during crises, but also the way by which water is allocated and distributed across various types of users.

3.8. Towards the new generation of institutional and policy designs

The challenges, necessities, and strategies outlined in these sections require sets of policy reforms. This becomes more urgent since this decade is critical, not only for COVID recovery, but also in light of the established climatic agreements, and in order to meet the SDG 2030 agenda. The latter highlights the relevance of policy coherence, which in turn lays the foundation for linking the NENA region's agricultural water sector with other factors, such as gender equity, environment, trade and jobs, health, and others, as outlined here. In turn, policy coherence relates to efficient choices of policy instruments and investment options.

When designing and implementing policies, it is crucial to estimate the level at which water and agricultural policies end up affecting other SDGs. This requires country-level evaluations of how individual sets of reforms affect other SDGs that go beyond those directly connected with the sector (SDG 2 and SDG 6 on zero hunger and water, respectively). Naturally, this also requires an evaluation of whether policy actions and investments, which may appear beneficial to the agricultural water sector, may have negative collateral effects on any other SDGs.

3.8.1. Acknowledging the role of the sector within climate actions

The coherent application of agricultural water policy reforms in NENA countries also requires an alignment with international climate efforts. At present, the region lacks strong policy instruments to link the agricultural water sector with climate adaptation and mitigation. Various mechanisms offered by the Paris Agreement, translated into the National Determined Contributions (NDCs)[27], could offer opportunities for the sector to pursue the previously outlined actions. For instance, NENA countries often report efficient water resource management in their NDCs (Djoundourian, 2021); naturally, this aligns with several of the aforementioned SDGs. Climate and SDG cooperation thus becomes of supreme importance to meet the challenges of the coming decade. Here, regional actors, such as the League of Arab States, have been deemed crucial in the coordination of these strategic initiatives and efforts (Al-Sarihi and Luomi, 2019). At the same time, NENA countries must identify regional partners with common priorities, as well as international momentum that facilitates the implementation of the required set of policies.

3.8.2. Seizing global policy opportunities

One opportunity for the sector is to ride international momentum on tackling inadequate water valuation. For the NENA region, development partners collaborating with intergovernmental processes could support local decision-makers in rethinking the real value of water (quantity, quality and efficiency). Such novel pricing mechanisms are options that would allow the region's agricultural water sector to become financially sustainable while also promoting a more efficient use of this resource. For example, Morocco and Tunisia have begun to charge farmers for the amount of water used, rather than for areas cultivated. Naturally, modifications to water prices must be accompanied by improvements in service and a more efficient and resilient water supply, particularly during times of scarcity and crisis.

This new set of policies should also seek to accelerate several of the market-based strategies addressed in previous subsections. For example, in the coming years, NENA governments face

[27] NDCs embody efforts by each country to reduce national emissions and adapt to the impacts of climate change under the Paris Agreement.

the challenge of enabling competitive domestic markets by promoting regulatory and enforcement frameworks for food standards and quality, while also integrating food-trade partners. Along with this, the new generation of policies should establish frameworks to stimulate more efficient water use in the agricultural sector, while also penalizing food and water waste and encouraging more sustainable practices. The establishment of water allocation mechanisms in a transboundary context could also support progress towards achieving SDG 6.5.2 on proportioning transboundary basin areas with operational arrangements for water cooperation.

3.8.3. Closing the financial gap

To fill the investment gap, the public sector must increase its investment capacity and strengthen its role as the central enabler of sector financing. This could take the form of subsidies to technological innovations that make water usage more efficient (a review of these technologies is reviewed in the next section). For instance, Morocco heavily subsidises medium and small farms which form part of the Plan Maroc Vert programme. This initiative seeks to expand drip irrigation to over 50 percent of Moroccan agricultural land (Alonso *et al.*, 2019).

In this context, the private sector and PPPs must be recognized as novel and rapidly-evolving agents of support for funding in the region. Apart from closing the financial gap, they can be viewed as key players in the development of the regional agro-industrial sector, while also combining technological developments and innovations. For example, in Algeria, this scheme, via subsidies, has proven successful in developing business models for small and medium scale farmers who wish to invest in seeding machinery (Idoudi, 2020). The technification of this process reduces soil tillage and uses less energy and labor, while conserving water and soil nutrients. In post-conflict areas, PPPs may also represent a strategy to resume construction, maintenance, and operation of abandoned projects. Indeed, this model has been promising in Iraq, offsetting the government's lack of financial resources to take over a series of projects in the country (Khudhaire and Naji, 2021). In wealthier NENA countries, PPPs have also been used to secure arable lands, crops, and foods in other countries. For instance, in 2009, Kuwait offered Cambodia about USD 550 million in development loans to finance dams and infrastructure in return for long-term leases for rice production (Sowers *et al*., 2011).

Institutions with relevant activities in the region, such as the World Bank, the European Investment Bank, the African Development Bank, the Islamic Development Bank, and the International Monetary Fund may also step in to cover financial gaps. Other financial alternatives, at the local or catchment scale, include sustainable finance funds from agencies such as the European Union and various private fund managers.

Chapter 4: Innovation and technical strategies

This chapter addresses technological advances that could be adopted by the agricultural water sector in the NENA region. The chapter starts by reviewing the set of technologies that could be applied to current (and traditional) water practices to increase water yields and values. Then the advances that could improve agricultural productivity and make water use more efficient are addressed. Thirdly, this chapter addresses technological developments embedded within the fourth industrial, or digital, revolution. Lastly, the chapter discusses how the sector could use tools and technologies to better manage the challenges that will be faced by the NENA region in the future.

Beyond supporting the needs of the agricultural water sector in the NENA region, the innovations and tools to be discussed could form a bridge towards the achievement of SDGs. Investing in technology and innovation would facilitate the retrieval, storage, and management of water and agriculture data in localities with non-existent observations. This would, in turn, aid in the achievement of SDG 6, or support the monitoring of progress towards the reduction of hunger (SDG 2). At the same time, a constant monitoring of resources throughout the region would support SDGs 14 and 15 on maintaining and preserving life below water and on land respectively. Likewise, technical developments in the sector could support increased access to affordable and clean energy, since water irrigation systems also require energy sources (SDG 7). These techniques require training, which increases citizens' engagement in new technologies, thus supporting SDG 4.

4.1. Techniques to improve water yields

A series of novel technologies could be used in the sector to tackle water scarcity, as reviewed in section 1.1. Rainwater harvesting could be improved not just through management techniques (as reviewed in Chapter 3) but also with system upgrades. Mechanisms such as overspread implementation systems, which utilise terrace tanks and cisterns, have been deemed an ingenious form of capturing rainfall in a decentralized way (Steenbergen *et al*., 2010). Similarly, spate irrigation, or the diversion of floodwaters towards canals, often provides an alternative in rural areas, where aridity prevails (Bashir, 2020). However, if these are not accompanied by adequate policy and social frameworks, their real potential may be highly uncertain and difficult to reach. Here, the government of Jordan provides an example of acknowledging the potential of water harvesting as part of their national water strategy (Ministry of Water and Irrigation (Jordan), 2015).

Other novel approaches propose directly seizing and harvesting water from the atmosphere[28]. These include, for example, systems that absorb and release water with minimal energy costs using ambient sunlight (Kim *et al*., 2017). Other techniques also seek to distill water using compact solar-thermal membrane technologies, which are thought to be cost-effective and environmentally friendly (Xue *et al*., 2018). Yet, while these novel approaches promise a positive, potentially major impact in the sector, they have yet to be practically implemented on a large scale.

Renewable energy pumps would also improve water yields in the region whilst running on climate-friendly energy. Capitalising on the large solar potential in the region, this renewable source provides uninterrupted and free daytime *fuel*. In the NENA region, pilot project experiences in Saudi Arabia, Morocco, Egypt, and Yemen emphasize the cost-effectiveness and practicality of this alternative, increasing its attractiveness to governments and farmers across the region (Sahin and Rehman, 2012; Mahmoud *et al*., 2017; Borgomeo and Santos, 2019). Also, desalination practices could benefit from renewable sources, thus tackling the limitations of this water source as reviewed in section 1.2. Mechanisms such as membrane and multistage flash desalination[29] have also proven successful in the region and have shown promising results in terms of financial and environmental costs (Nair and Kumar, 2013). In Palestine, public authorities have led pilot studies that show how desalinated water could be beneficial for the agricultural sector in terms of water efficiency (FAO, 2019a).

However, if not monitored and governed accordingly, solar-powered irrigation systems or other renewable practices may also accelerate the depletion of groundwater resources (Shah *et al.*, 2018). If implemented accordingly, these initiatives may also pave the way for the sector to reach SDG7 on clean energy transition. Box 8 presents an example in Yemen, where solar photovoltaic water pumping systems have been implemented for irrigation.

[28] As an example, GEF recently approved a 33$M rainwater harvesting project in Jordan.
[29] Membrane desalination is the process by which salt and minerals are removed from water as it passes through a semipermeable membrane. Multistage flash desalination removes salt and minerals through multi-stage counter-current heat exchangers.

Box 8 Photovoltaic water pumping systems for resilient farming systems in Yemen

About 70 percent of Yemen's population lives in rural areas, meaning that agriculture constitutes the main source of economic activities and food sources. Arid conditions in the country already make water and agricultural activities challenging. On top of this, ongoing conflicts in the country have damaged water infrastructure and have disrupted fuel supplies, leading to soaring energy prices. Ultimately, this has affected farmers across the country who depend on groundwater for irrigation. Multilateral efforts, led by the FAO and the European Union, are supporting farmers in Yemen by providing solar photovoltaic water pumping stations, along with water-saving drip irrigation kits, to support and improve farming practices that are responsive in the face of difficult conditions.

The installation of these devices has aided in the delivery of about one million liters of water to about 55 000 people every day, while also promoting a sustainable source of energy. Likewise, this initiative has contributed to overall irrigation system resilience in the beneficiary areas, since groundwater and irrigation activities are less easily interrupted than diesel generators. This has resulted in an overall improvement in irrigation water, a reduction in operation and maintenance costs (of up to USD 1 350 a month per facility, when compared to diesel plants) and an increase in yields and crop diversification.

At the same time, by addressing local water sources, this initiative has contributed to more sustainable management of water resources by engaging local Water User Associations. This solution has also benefited other associated sectors, such as water, sanitation and health.

Source: Singh, N. & Brandolini G. 2019. *Enhancing Rural Resilience in Yemen - Joint Programme*. Final Evaluation Report [online]. UNDP. [Cited 30 November 2021].

4.2. Increasing agricultural water productivity and smart agriculture

One innovation in this area is the development of farming practices in controlled environments, or the use of hydroponic systems. With this technique, agriculture takes place in structures, such as greenhouses, where plants are grown using hydroponic systems, allowing plants and crops to receive a controlled amount of water. This controlled dripping may reduce water consumption by between 80 and 99 percent when compared to open field irrigation (Verner *et al*., 2017). At present, hydroponic systems are used in the region to grow tomatoes, cucumbers, peppers, and various herbs. This type of controlled-environment irrigation is regarded as an opportunity for people in the NENA region who lack access to land and traditional farming resources or tools, such as refugees (Somerville *et al*., 2014; Borgomeo and Santos, 2019). This technique can also be employed at small scale and in households. For example, as a response to the conflict in Gaza, the FAO encouraged a combination of hydroponics and fish farming within closed recirculating systems (Somerville *et al*., 2014). This resulted in an increased consumption of high-quality vegetables and protein from fish in rural and urban homes.

Aside from that, other innovations, such as smart and digital agricultural practices, may benefit the sector. Smart and digital, or precision agriculture can be understood as the enhancement of communication, information, and spatial analysis technologies which allow farmers to plan, monitor, and manage their activities throughout the value chain (Bolfe *et al*., 2020). Digitalisation includes the use of smart-pumps to remotely monitor groundwater resources (Thomson, 2021) or the use of big data management techniques to increase crop production, plant protection, and post-harvest management. These technologies in turn increase land efficiency and productivity while also enhancing revenues, water conservation, and citizen engagement levels in the sector (Trendov *et al*., 2019). It includes the use of mobile networks, phone apps, and data mining approaches to facilitate decision-making and infrastructure maintenance in real-time, as well as to connect farmers with suppliers and markets. Such flexibility and connectivity could also facilitate the better use of agricultural water resources in situations of shock or stress. Box 9 shows an example of the incorporation of climate smart agriculture practices in Palestine.

Box 9 Climate Smart Agriculture Practices, Palestine

Rain-fed systems dominate farming and agricultural systems in Palestine, with a coverage of 80 percent. Low soil fertility, water scarcity, degradation, and limited investment and financial resources are among the issues faced by the agricultural water sector in the country. Climate change will only serve to further aggravate these problems. In particularly, it will have a significant effect on olives, grapes, rainfed vegetables, citrus, and other fruit production.

As a response, the Palestinian Authority signed and ratified its compromise to the Paris Agreement. As part of these actions, in 2016, Palestine submitted their Initial National Communication Report and National Adaptation Plan, as well as a Nationally Determined Contribution and Roadmap. Within this plan, Palestine is developing community-level irrigation schemes: smart agriculture initiatives to improve water efficiencies and prepare the sector for disasters. It also includes initiatives to train and engage stakeholders and raise farmer awareness. The roadmap also sets out the establishment of a climate change centre for agriculture, which, apart from gathering and managing data, assists in capacity-building efforts. The work also includes the participation and collaboration of various local public and academic institutions, NGOs, and international organizations.

Source: FAO. 2019b. *Proceedings from the Regional Workshop on Climate-Smart Agriculture in the Near East and North Africa*. Cairo.

4.3. Improvement in mapping and data collection: the opportunity of the 4th industrial revolution

The 4th industrial revolution (4IR) relates to the recent digital changes underway at a global scale, consisting of remote sensing and drones, artificial intelligence (AI), machine learning (ML), blockchain technologies, and others[30]. Taken together, these technologies are proving useful as cost-effective options to improve mapping and data gathering for the sector and thus closing data gaps in the region. At the same time, these technologies could improve the financing and governance of the sector in the NENA region.

4.3.1. Remote sensing

A series of free and readily available datasets and portals could be used to assist with the mapping of resources in the NENA region and thus tackle the data gaps addressed in section 1.8. In the region, remotely managing drought has become a critical challenge for many countries. Among its actions to tackle drought, the Ministry of Agriculture, Fisheries, Rural Development, Water, and Forests (MAFRWF) in Morocco has published countrywide satellite-based drought maps online for the first time. The maps visually present satellite data on rainfall, land surface temperature, soil moisture, and vegetation health, which have been compiled into an easy-to-interpret enhanced Composite Drought Index (eCDI) (IWMI 2021).

Other global efforts such as the NASA's Earth Observatory[31] or the EU Copernicus Data and Information Access Services[32] platforms may be important allies in retrieving satellite information. This data would, importantly, support data collection and management in areas of the NENA region where data is typically scarce or unreliable. Ultimately this would pave the way for quantitatively estimating how the agricultural water sector enables (or constrains) the achievement of SDGs in the NENA region. For example, Box 10 shows a recent study that utilised Copernicus-satellite derived imagery to estimate salinization of agricultural lands in Algeria.

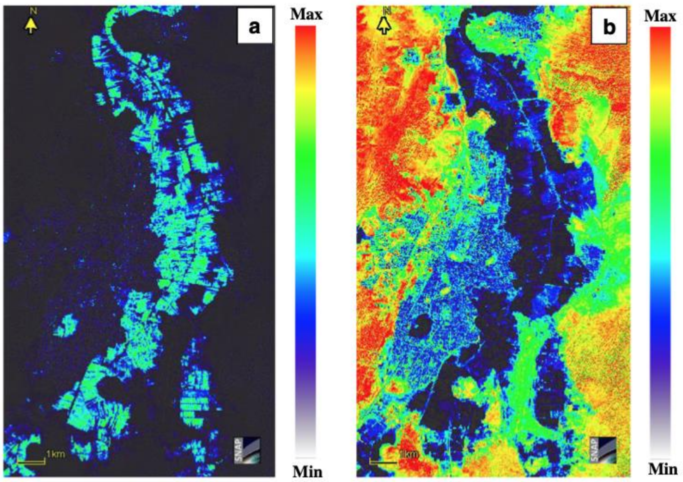
[30] More on the technological brink: https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/
[31] https://earthobservatory.nasa.gov
[32] https://scihub.copernicus.eu

Box 10 Satellite data to understand salinization in agricultural lands

The Algerian Sahara represents nearly 90 percent of the country's total surface area and is one of the driest and hottest regions in the world. Irrigation in the country is key to food security, and is mostly supplied from groundwater sources. The quality of this water is relatively poor, mainly due to high salinity levels. Evacuation of this salt water may also cause a rise in the water table, further affecting the country's water resources.
To understand agricultural land salinization, Sentinel-2 images were used in the southern part of the country. This exercise was carried out in the Touggourt, an ancient agricultural hotspot that remains active today. Multispectral imagery was obtained from the region to detect salt presence, extension, and effect, starting with the calculation of salinity and vegetation indices.

Results estimate that about a quarter of the region is dominated by salt zones. The imagery also revealed that, overall, vegetation in the region contains low concentrations of chlorophyll, evidencing the impact of salinization on local ecosystems.

Figure 4.1 Vegetation (a) and salinity (b) indexes in the Touggourt region in Algeria as detected by the Sentinel (Copernicus) satellite



Source: Touhami, M. K., Bouraoui, S. & Berguig, M.C. 2020. Contribution of Sentinel-2 multispectral satellite images to study salinization effect of the Touggourt agricultural region (Algeria). *Arabian Journal of Geoscience*, 13(13): 1–12.

Additional satellite platforms using high-resolution, thematic-specific sensors, and paid imagery would also support the agricultural water sector. For example, with a combination of satellite and airborne thermal remote sensing, coupled with field observations, researchers have been able to identify groundwater fluxes towards the Dead Sea in the river Jordan (Siebert *et al*., 2014). More recently, the use of drones has become popular to develop tailor-made studies at the farm scale. This would be of great benefit to farmers in remote areas that are not typically connected by primary road networks. Yet, in most countries in the region, the regulatory frameworks in place to control drone use (due to national security concerns) may limit their applicability.

4.3.2. Incorporating novel technologies

Novel 4IR technologies include the use of UAV (Unmanned Aerial Vehicles), digital maps, soil surveys, digital agriculture technologies (connected to AI), the internet of things (IoT), information and communications technology (ICT), and mobile phone applications. Taken together, these sensors could provide data on, for example, soil moisture characteristics, irrigation status, crop yields, pests, harvest times, and overall support better and faster decision-making at the farm level. Box 11 shows how ICT and mobile phone applications, along with remote sensing, offer opportunities for local farmers to improve agricultural practices through two models (with and without private sector involvement).

The data produced could also support farmers in examining social and market conditions. For example, farmers could access parameters on financial indicators, which estimate upcoming demand for certain types of commodities and products or prevent value chain disruptions due to social events. These tools would also facilitate accountability, transparency, and water-metering, and thus pricing and better governance and management. This potential could be maximised if the data generated are properly maintained, processed, and managed following big data protocols or cloud storage mechanisms. Naturally, this process would also require the building of local capacities; it thus provides good opportunities to engage with academic and research institutions.

Other 4IR innovations, such as blockchain technology and AI, have been combined to improve the management and policy dimensions of the water sector (*Dogo et al.*, 2019; *Hewa et al.*, 2021). For instance, blockchain technology and cryptocurrencies have been used in countries such as Australia to establish smart contracts in a secure, rapid and transparent way. This could support rapid transactions between peer-to-peer water rights holders and thus improve the development of water markets in the region and support the negotiation of water allocation in the regional transboundary catchments. This information also improves water accounting and could help support the development of national or regional-level accounting platforms. In turn, these tools could speed up water governance in the NENA region to improve sustainability and inform future investment decisions in supply and demand strategies. That said, these sets of technologies (which have proven successful in other regions), naturally would be highly dependent on the level of internet diffusion in rural areas and the IT education of local farmers and users.

Box 11 ICT to Enhance agricultural production

In 2017, together with the IWMI, FAO initiated a project focused on the use of ICT and remote sensing tools to improve water productivity in Lebanon and Egypt. A mobile phone application called *LARI-LEB* was developed in Lebanon. IWMI, in partnership with local institutes such as the Lebanese Agricultural Research Institute (LARI) upgraded the phone application, with the objective of providing farmers with information customized to their plots, weather conditions and crop types. The new app integrates geo-specific weather data (from the institute's 12 weather stations), extracts crop evapotranspiration values (for the main crops on the Bekaa plain) and translates this technical data into readable irrigation schedules. The app also specifies the amount of water required based on crop type, irrigation system and soil type. Furthermore, it provides farmers with information about how much irrigation is required over the next seven days, as well as details on crop evolution and health using FAO's open-access portal (WaPOR) for the monitoring water productivity.

The project also developed the 'Irrigation Water Information (IRWI) App in Egypt, initially to help farmers enhance their day-to-day irrigation practices and to inform them on crop health during the season. The app provides farmers with irrigation scheduling information, specifically regarding when to irrigate and for how long, based on ET estimations from satellite data (WAPOR). This information is tailored based on the farmer's geographic location and the characteristics of their farm and irrigation techniques.

Overall, this initiative has transformed the way new technologies are mainstreamed and used by government and research institutions as well as by NGOs and start-ups. For local farmers, this initiative has improved agricultural productivity by between 10 and 20 percent.

Source: Elmahdi, A., Nassif M.H. & Abi Saab M.T. 2020. Phone app gives opportunity to improve water productivity in Lebanon. *IWMI* [online]. [Cited 9 March 2021].

4.4. Managing the future

The technologies and innovation tools thus far proposed are helpful in understanding, diagnosing, and monitoring past, present, and future conditions. However, solid planning strategies for the agricultural water sector in the NENA region require an understanding of and ability to forecast future conditions. This specifically relates to the need to quantitatively diagnose the potential impacts of climate change on the sector.

4.4.1. Long-term climatic changes

Global Circulation Models (GCMs) and Regional Circulation Models (RCMs) are the main tools to detect multi-decadal changes in the main variables of interest for the agricultural and water sector: precipitation and temperature. They in turn could be used to address the future climatic challenges of the region as outlined in section 2.3. The results of such model outputs could be retrieved directly from global modelling groups. For example, the UN World Climate Research Programme offers these datasets[33]. Similarly, regional-level efforts, such as the Cordex Programme, provide higher resolution climatic maps specific to the NENA region[34].Yet, to download, manipulate and process these datasets requires computing resources as well as an expert-level understanding of climatological data analysis.

To overcome this limitation, several international organizations offer climate portals from which future climatological variables and indices can be retrieved. They include, among others, the World Bank's Climate Portal[35] and the Royal Netherlands Meteorological Institute (KNMI)[36]. At the NENA level, the Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR) also provides an 11-partner collaborative partnership to evaluate the implications of climate change in the region, while also providing a number of resources and local support. Other international platforms, such as the Aqueduct Global Flood Analyzer, offer flood risk diagnostics. Commercially, Fathom provides high resolution (90m) global flood maps[37].

Nonetheless, it is important to note that GCMs and RCMs often lack exhaustive regional validations to allow for a direct manipulation of outputs. This would translate into substantial uncertainties in terms of projecting future changes in precipitation and temperatures at the local scale. Here, the paradigm of resilience and robustness, discussed in the previous chapter, would be a valid strategy for planning under uncertain and diverse potential climatic scenarios.

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[33] https://www.wcrp-climate.org/wgcm-cmip/wgcm-cmip6
[34] For the NENA region see the Africa region: https://cordex.org/domains/region-5-africa/
[35] https://climateknowledgeportal.worldbank.org/region/africa/climate-data-historical
[36] https://climexp.knmi.nl/start.cgi
[37] https://www.deltares.nl/en/software/aqueduct-global-flood-analyzer/

4.4.2. Weather and seasonal forecasting

The NENA region also has the potential to incorporate tools for short and medium-term weather and seasonal forecasting. The former corresponds to the numerical forecasting of hydrometeorological events within a seven-day time period. These offer an opportunity to plan for and prevent flood damages, and even to view them as an opportunity for reservoir refilling or sustaining environmental flows. On the other hand, seasonal forecasting offers the opportunity to monitor weather conditions on multi-week or multi-month scales. In similarly arid regions, such as California, a joint effort between academia, public institutions, river basin authorities and others implemented a programme to inform reservoir operation based on forecasts[38] or via the use of drought forecasts to expand drought insurance mechanisms for crops.

These efforts also have potential for enhancement through partnerships with international meteorological institutes, such as the European Centre for Medium-Range Weather Forecasts[39], NASA's Global Modelling and Assimilation Office[40], and others. Other partnerships could include private companies and tech giants such as Google or Microsoft that use their advanced data and computing capabilities to develop AI and big data tools for forecasting disasters, or overall earth resource management[41].

By way of example, Box 12 highlights NASA's Hydrological forecast systems, specifically designed to support food and water security in Africa and the Middle East. This system also supports the IWMI's MENA Drought project to better predict, prepare for, and respond to the impacts of droughts in Morocco, Lebanon, and Jordan. Here, the Australia 2007 Water Act offers a good regional example on how these technologies can be connected within an institutional framework under the context of drought occurrence.

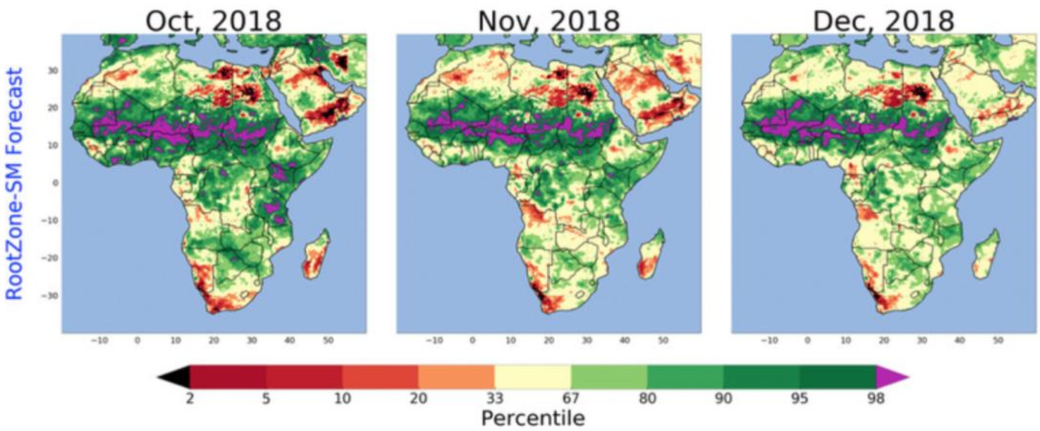
[38] See more: https://cw3e.ucsd.edu/firo/
[39] https://www.ecmwf.int/en/forecasts
[40] https://gmao.gsfc.nasa.gov/seasonal/
[41] See Microsoft AI for Earth: https://www.microsoft.com/en-us/ai/ai-for-earth. Google New Tools for Flood Forecasting: https://ai.googleblog.com/2020/01/using-machine-learning-to-nowcast.html?m=1

Box 12 NASA's Hydrological Forecast and Analysis System (NHyFAS) for Food and Water Security Applications.

Based on an increasing awareness of the need for governments, relief organizations, and citizens to be better prepared for hydrological extremes, in 2020 NASA developed frameworks to forecast drought conditions and flood potentials. Specifically, NASA improved their Famine Early Warning System Network (FEWS NET) with a module on Hydrological Forecast and Analysis System for Food and Water Security Applications (NHyFAS).

This system combines Land Information Systems along with satellite data and climate forecasts from NASA's atmospheric models. Running on sophisticated supercomputers, this system seeks to capture and predict hydrological and agricultural drought events. For the NENA region, seasonal forecasts are produced on a monthly basis. Among others, outputs include hydrological variables, such as soil moisture content, streamflow, terrestrial water storage (which could be used as proxy for groundwater status), drought indices, etc. Data is also shared with the US Agency for International Development's network for Famine Early Warning Systems Network (FEWSN). Ultimately, data from this platform could help to develop scenarios from which resilience or robustness strategies could be drawn.

Figure 4.2 Example of NASA seasonal hydrologic forecast of root-zone soil moisture percentile product



Source: Arsenault, K. R., Shukla S., Hazra A., Getirana A., McNally A., Kumar S.V., Koster R.D., Peters-Lidard C.D., Zaitchik B.F. & Badr H. 2020. The NASA hydrological forecast system for food and water security applications. *Bulletin of the American Meteorological Society*, 101(7): E1007–E1025.

PART III: CONCLUSIONS AND FINAL REFLECTIONS

Circumstances in the NENA region suggest that the difficulties currently facing the water sector with regards to maintaining food production will persist. The challenges of aridity, water variability, and inadequate practice will be further aggravated by uncertainties caused by the impacts of climate change in the region. In addition, the challenges presently posed by the COVID crisis, demographic pressures, and other factors will only serve to place greater strain on an already exhausted agricultural water sector.

Ultimately, these difficulties will not only aggravate regional food and water insecurity: they will also stall regional and local progress towards achieving SDGs. In fact, a review of the scant regional progress made in terms of improving water stress, quality, IWRM, efficiencies, and other factors suggests that NENA countries will most likely fail to meet SDG 6. If other SDGs related to the agricultural water sector (such as SDG 1, on ending poverty, or SDG 15, on life on earth) are also considered, we can observe that the region is off track and is thus unlikely to meet the 2030 agenda. Critically, poor practices associated with the overexploitation of surface water resources, groundwater depletion and inadequate governance practices of the agricultural water sector negatively impact other water-connected SDGs via ecosystem contamination, increased competition, and related factors.

The NENA region urgently requires a paradigm shift regarding the use of water in the agricultural sector. This change must be built and sustained around four interlinked pillars:

1. **Improvement in water supply efficiency**. This requires actions that make the use of scarce water in the region more efficient. Firstly, the *principles of agricultural water reuse and the circular economy* must become fundamental. An acknowledgement that water used by the sector, or by other, connected sectors, is important not only for agricultural as a whole but also in terms of financial yields, should remain at the forefront of new practices in the region. This must also be accompanied by an *improvement and modernisation* of extraction practices, maintenance, and operation of the existing water infrastructure in the region. Similarly, the *acknowledgment of alternative, yet unexplored, water sources* would also increase regional water efficiency. These alternatives range from rainwater capture, the use of green water (water stored as soil moisture), groundwater injection, use of wetlands and other green solutions.

2. **Improvement in agricultural practices.** Policies in the NENA region require the *promotion of water efficient crops* and the reduction of water consumption in the
3. agricultural sector. Countries need a comprehensive diagnostic of crops eligible for replacement to reduce water use, soil degradation, and water quality issues while at

the same time yielding higher economic returns. Similarly, the sector requires the implementation of modern irrigation techniques to avoid water waste.

4. **Resilience must be at the core** of planning, managing, and operating agricultural water systems. A series of existing frameworks and tools should be incorporated into the sector to diagnose how shocks and changing conditions in the region may affect integral agricultural water systems; based on this, roadmaps can be proposed to increase regional recovery capacities, flexibilities, and robustness. This is fundamental given the range of challenges –which are typically uncertain and difficult to predict– that the region will face over the coming years, and it will aid the region to better navigate times of climatic changes, human displacement and migratory waves, demographic changes, regional conflicts, public health emergencies and post-COVID recovery, amongst other challenges.

5. The **real value of water must be acknowledged**. This paradigm shift requires that the region develop collaborative and participative mechanisms to rethink the real value of water. Initially, this would lead to the adjustment of pricing mechanisms, which would support not only a more efficient use of water but would also benefit sector financing and investments. Similarly, this paradigm shift requires the examination of value beyond that of the monetary, but rather in terms of culture, conservation and environment, recreation, and others.

Apart from these main paradigm pillars, *additional actions benefitting the agricultural water sector* must also be examined in the NENA region. These actions necessitate *careful evaluation* of the extent of the mechanisms and benefits of, and roadmaps towards, implementation, as well as of limitations, *considering regional diversity* of income and economic conditions, political systems, and specific sub-sectorial strategies. These actions are as follows:

i. **Intra and inter-regional trade, including virtual water trading and water allocation reforms.** The extent to which this could play a major role in the NENA region requires further consideration and an acknowledgement of regional diversity. This initiative could support the region in coping with challenges and in meeting demands for water and food security, and it would not only benefit regional water and food productivity, but would also support job creation and bolster the economy in other ways.

ii. The NENA region must also evaluate the **enablement of additional financial and market mechanisms to promote water efficiency**. This requires that water practices which promote higher economic returns per water unit be encouraged. Fresh cash flows may, in turn, be used to import less economically attractive crops, promote additional industries, and support job creation. This necessitates a careful *promotion* *of the liberalisation of some of the components of the food production chain whilst also incentivising investments in technologies*, which attracts private capital investments in the sector.

iii. **Application and development of green and low-carbon approaches and practices in the sector**. This is particularly important for irrigation, pumping, and desalination technologies, where energy consumption is traditionally high. For instance, the region must look into a broad incorporation of solar-powered water pumps and desalination plants. Yet this also necessitates careful consideration of economic costs and technical feasibility studies, and more broadly, an examination of the differences between wealthier countries with greater experience in these approaches, and lower-income ones, where these technologies are nascent or may be restricted.

Nonetheless, the new sector paradigm (as well as the associated complementary actions) requires an enabling environment that would facilitate the shift in terms dictated by the sector. Such enabling conditions are as follows:

1. **Position the sector as a pillar of the 2030 SDG agenda**. **The *region thus uses the 2030 SDG Agenda as a backbone for the assessment of any impact*** that individual and local policies may have, not just on the sector, but across the SDG spectrum. This condition also includes the acknowledgment of Integrated Sectorial Water Resources Management (ISWRM) and other water-specific SDGs.

2. **Develop strong guidelines and instruments to link the agricultural water sector with international climate adaptation and mitigation efforts**. Various mechanisms offered by the Paris Agreement, translated into the National Determined Contributions (NDCs), could offer opportunities for the sector to pursue actions such as green bonds, climate funds, and carbon-friendly approaches, among others.

3. **Redefine strategies that take into account the participation of women and traditionally vulnerable groups** in the sector. This can include providing access to land and capital, as well as to information, data, and training, and more generally, encouraging the participation of these groups in policy design and the food production chain. Likewise,
   protection schemes must be carefully designed and targeted, especially when implementing the previously outlined market and water trade mechanisms.

4. **Development of coherent regional policy for wastewater reuse in the agricultural sector**. This policy instrument needs to be aligned both with guidelines for crop management and water reuse within food production, as well as with technical and institutional mechanisms that allow the agricultural sector to benefit from water,

nutrients, and energy generated as a product of wastewater from other interconnected sectors.

5. **Promotion of competitive domestic markets for food standards and quality.** This would lead to the penalisation of food and water waste whilst encouraging sustainable practices.

6. **Adoption of digital technological developments and 4IR tools for forecasting and for the optimisation of water and food production processes**. National and international agencies, private tech companies, and academic institutions must be recognised as key stakeholders in the sector. Acknowledging their role helps close the regional data gap while supporting the design of data-informed decisions to improve agricultural productivity. The use of data and technologies also relates to the integration of tools to forecast short-term and seasonal hydrological events, as well as platforms for long-range climate modelling. This requires *significant capacity building and training for local farmers and key stakeholders*.

7. Supportive **cooperation for inter-regional know-how**. Within the NENA region, some countries already have advanced data acquisition and management and technological capabilities. For example, some Gulf countries are leading the way when it comes to efficiency and sustainability in desalination plants. These countries could, in turn, guide the region in the use of better technological practice in this area.

8. **Seizing of financial opportunities for sectorial investment.** Apart from traditional multilateral and regional organisations, international efforts in terms of climate actions and commitments offer opportunities for the regional agricultural water sector. This would also help align the sector with the implementation of low-carbon technologies, resilience and risk management strategies, and other environmental and social benefits. Furthermore, fresh cash flows would be activated if the role of the private sector were reinforced via public-private partnerships or direct investments. This may also be accompanied by an acceleration of direct funding to the sector by national governments in the region.

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