Mar 1, 2021

Water in agriculture in three Maghreb countries

Status of water resources and opportunities in Algeria, Morocco and Tunisia

Final report

Ministry of Agriculture, Nature and Food Quality of the Netherlands

The Salt Doctors

ACACIA WATER

Netherlands Agricultural Network

Executive summary

The Maghreb countries are facing increasing water scarcity amplified by inefficient water use and overexploitation of water resources. There is evidence that surface water is diminishing and that ground water levels are lowering rapidly. The countries are affected by climate change as rainfall is more erratic and there are longer lasting and more severe periods of drought, alternated with severe rains and catastrophic flooding. The projected climate change impact on agriculture in the Maghreb will most likely increase further. This is accompanied by salinization of soils and ground water, even strengthened by over-fertilization of soils, combined with a general low productivity and misuse of water.
The Netherlands has world-renowned expertise when it comes to water management and agriculture, and finding sustainable and practical solutions for water use efficiency, quality improvement and circular agriculture. In order to link the Dutch experience and expertise to the issues at hand, an assessment of the current situation of water use and water problems in agriculture as well as the challenges for improvement was needed.

We report here on the assessment carried out to better understand the challenges for bilateral cooperation in the field of water in agriculture in three Maghreb countries: Morocco, Algeria and Tunisia. The assessment results will be used for making concrete recommendations on business and institutional cooperation between the Netherlands and the three individual Maghreb countries especially in those fields where the Dutch agribusiness, knowledge and technology institutions can make a significant improvement.
The assessment included a literature study combined with interviews with experts and stakeholders in governments, research institutes, companies, international organisations in The Netherlands, Morocco, Algeria and Tunisia. Reviewed were the:

- The status and trends of the available water resources in relation to water use and water use efficiency in agriculture.
- Important Government policies and development plans on water and agriculture including adaptation and mitigation policies for climate change impact.
- Governance in Water Resources for agriculture on water efficiency, water reuse and water allocation at a national level and in focus regions East/South East and Souss/Masa in Morocco; the coastal zones and Biskra-region in Algeria; Gabes-region in Tunisia.
- Development status and trends in water efficiency technologies, including use of drip irrigation, non-conventional water sources, sustainable energy for pumping, circular greenhouses, remote sensing and satellite data applications.
- Status and development of relevant water-agri knowledge needs in relation to available Dutch technologies and experience.

The outcome allowed a comparative overview of several key opportunities and specific technological developments and link these to Dutch knowledge and technology solutions available. For each of the countries we described most opportune cooperation opportunities shaped as business cases with the involvement of the local Government, Dutch and local private sector and knowledge organizations.

For centuries the countries have tried to overcome water stress and scarcity by improving water policy and strategy, infrastructure development, economy of water use, wastewater, and desalinization, among others. We report that the three countries have become more vulnerable and are severely threatened by water resources responses to the changing climate conditions. Current water scarcity will increase with growing demand for water resources due to demography, the growth of economic sectors in particular agriculture that consume water. With current climate change projections and water use trends the relevance of water development policies will become more relevant, given that agricultural performance and economic growth of the three Maghreb countries is closely related to water resources and contributes strongly to the socioeconomic balance, regional stability, and gross domestic product.
The need to mainstream this change into development plans is more recognized; the new constitutions have adopted the sustainable development concept, which opens opportunities for technological and practical improvements for the sustainable use and protection of the land and water resources.

Colophon

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Abbreviations

3R	Recharge, Retention and Reuse
ABH	Agence du bassin hydraulique
ASR	Aquifer Storage and Recovery
BCM	Billion Cubic Metre
BGS	British Geological Survey
CI	Continental intercalaire (Intercalary continental)
CT	Complexe terminal (Terminal complex)
DRPE	Direction de la Recherche et de la Planification de l'Eau
EC	Electric Conductivity, in dS/m^{-1}
EKN	the Embassy of the Kingdom in the Netherlands
GDAs	Groupement de Développement Agricole (Agricultural Development Groups)
GDP	Gross domestic product
LNV	The Dutch Ministry of Agriculture, Nature and Food Quality
MAR	Managed Aquifer Recharge
NWSAS	North Western Sahara Aquifer System
SDG	Sustainable Development Goal
SLM	Sustainable Land Management
RVO	Netherlands Enterprise Agency
TDS	Total Dissolved Solids
WB	World Bank
WF	Water footprint
WWT	Wastewater Treatment
WWTPs	Wastewater Treatment plants

Units

1 MCM = 1×10^6 m^3 = million m^3
1 BCM = 1×10^9 m^3 = billion m^3

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Content

1 Introduction

1.1 Introduction

This desk study provides an overview of the current situation, challenges and opportunities of water and agriculture of three Maghreb countries: Algeria, Morocco and Tunisia. This report provides background and a framework on which multilateral cooperation between the three countries and The Netherlands can be promoted and fostered. This study is commissioned by the Agricultural Offices of the Dutch Embassies in Algiers and Rabat; and financed by the Dutch ministry of LNV.

Algeria, Morocco and Tunisia rely, to different degrees, on agriculture for their sustainability and development. Their geographic location with respect to Europe provides them with excellent trading opportunities, however their production capacity is limited by the increasing water scarcity and the overexploitation of water resources.

The Maghreb region is one of the most affected by severe water shortages, as currently between 54 and 68% of the population in Algeria, Morocco and Tunisia are living in water scarce areas (Water Scarcity Clock). This means that a large part of the population has less than 1700 m^3/capita/year and experiences water stress. With quantities lower than 500 m^3/capita/year, absolute scarcity is experienced by the population. The severity of water shortages is expected to increase due to climate change as a result of more erratic rains, longer drought periods and more extreme floods. This, together with the increased pressure on the water resources due to population growth, calls for efficient water use, improved water management and the use of non-conventional water resources. Previous studies (OSS, 2004; Alterra, 2012; Faysse *et al.*, 2011; Hamed *et al.*, 2018) have shown groundwater depletion and salinization in the region linked to overexploitation and inefficient irrigation systems. This report maps the challenges that these countries face regarding their water resources for agricultural production and links them to possible solutions and opportunities that were developed in the Netherlands and have been proven to work in arid countries.

The Dutch expertise in integrated water management, climate smart and circular agriculture can provide a great opportunity for cooperation and collaboration that would result in more sustainable growth in efficient agricultural systems. The collaboration between the Maghreb countries and the Netherlands through fruitful structures can support the adaptation to the new climatic and demographic reality.

This report is a background document for Dutch-Maghreb partnerships, focusing on:

1.. Use of water resources (groundwater, phreatic nappe and reservoirs) and non-conventional resources.
2.. Government policies on water and agriculture and climate change adaptation.

3.. Water use and governance efficiency in agriculture in Algeria, Morocco and Tunisia. In each country, a special focus is put on one or two specific regions. These regions are:
   - East/South East and Souss/Masa in Morocco
   - Coastal zones and Biskra-region in Algeria
   - Gabes-region in Tunisia

4.. Potential of water efficiency technologies for agriculture (including circular agriculture) and monitoring.

5.. Potential for Dutch expertise.

The information in this report was gathered from existing literature, reports and datasets and updated and supplemented with the information gathered during interviews performed in 2020 and 2021 with stakeholders and experts in governments, research institutes, the private sector and international organisations of Morocco, Algeria, Tunisia and the Netherlands. Interviews and data collection was carried out by the team of consultants and three local experts: Prof. Dr. Redouane Choukr-Allah (Morocco), Dr. Tarik Hartani (Algeria) & Prof. Dr. Mohamed Hachicha (Tunisia). Interviews were carried out abroad and, in the Netherlands (see annex 1 for a list of participants).

Figure 1-1. Farms in Oualidia, very close to the Moroccan coast (photo credit: The Salt Doctors)

This report contains a lot of information. For readers interested in the key challenges & opportunities, we recommend reading Chapter 6. The identified opportunities for the Dutch business sector per country are described in chapters 7 and 8. Readers interested in country specific information can read chapter 3, 4, or 5 respectively for Algeria, Morocco, or Tunisia.

This report has the following structure:

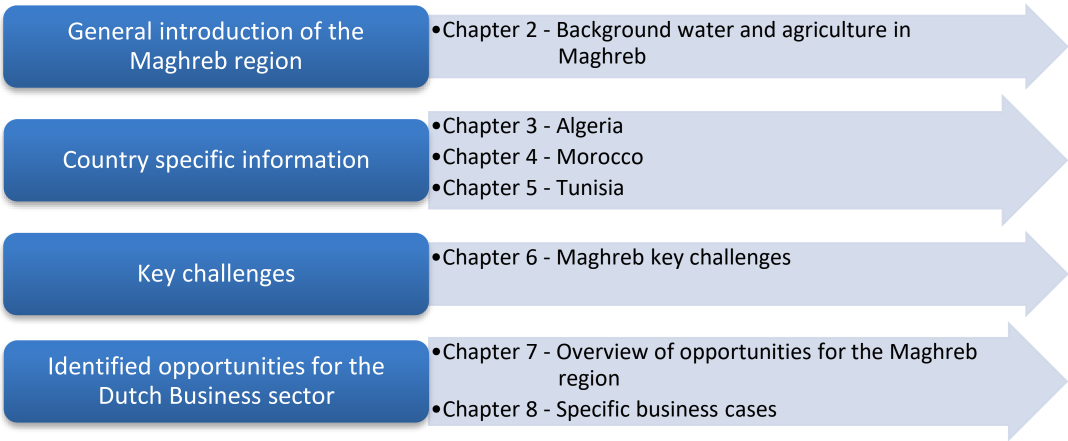


Figure 1-2. Readers guide

2 Background water and agriculture in Maghreb

2.1 Natural resources, population and climate

Maghreb (meaning "land of the sunset") is the Northwest region of Africa (Figure 2-1) that includes Mauritania, Morocco, Algeria, Tunisia and Libya, all members of the Arab Maghreb Union, and Ceuta and Melilla (Spanish) (Molle *et al.*, 2019). The Arab Maghreb Union was founded in 1989 to strengthen the ties between the five Northwest African Arab countries and to promote sustainable growth through harmonizing policies and more flexible flows of persons, services, and goods (Finaish, 1994). This African region is the closest to Europe and acts as a bridge with Europe and the Middle East (Hassan, 2014).

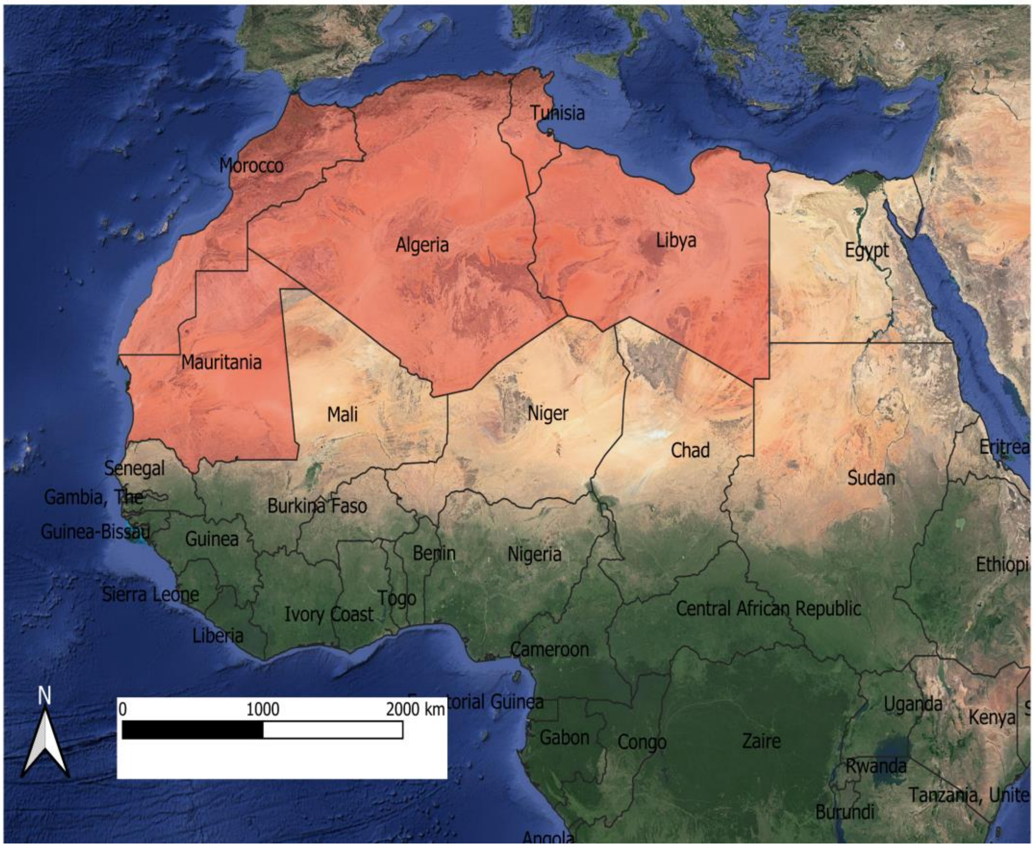


Figure 2-1. Overview of the Maghreb region, indicated in red.

The total population in the Maghreb countries Algeria, Libya, Mauritania, Morocco and Tunisia was ca. 100 million inhabitants in 2018 (Figure 2-2). There has been a steady growth since. Currently, the growth rate is low (around 1 to 2 percent) in Algeria, Tunisia and Morocco, the three focus countries of this report (World Bank, 2020). A large part of the population is dependent on agricultural activities for their income. Table 2-1 shows that for Morocco and Tunisia a large part of the country is cultivated (>20%). In Algeria, mainly the coastal zone is cultivated. The ratio of arable land areas and permanent crop differs per country. Tunisia, for example, has a relatively large part in use for permanent crops.

Table 2-1. Landuse data Maghreb, area in 1000x ha (source: Aquastat, 2016)

Country	Total area of the country (excl. coastal waters) (1000 ha)	Arable land area (1000 ha)	Permanent crops area (1000 ha)	Cultivated area (arable land + permanent crops) (1000 ha)	% of total country area cultivated (%)
Algeria	238174	7404	1013	8417	3,53
Morocco	44655	8130	1462	9592	21,48
Tunisia	16361	2900	2332	5232	31,98

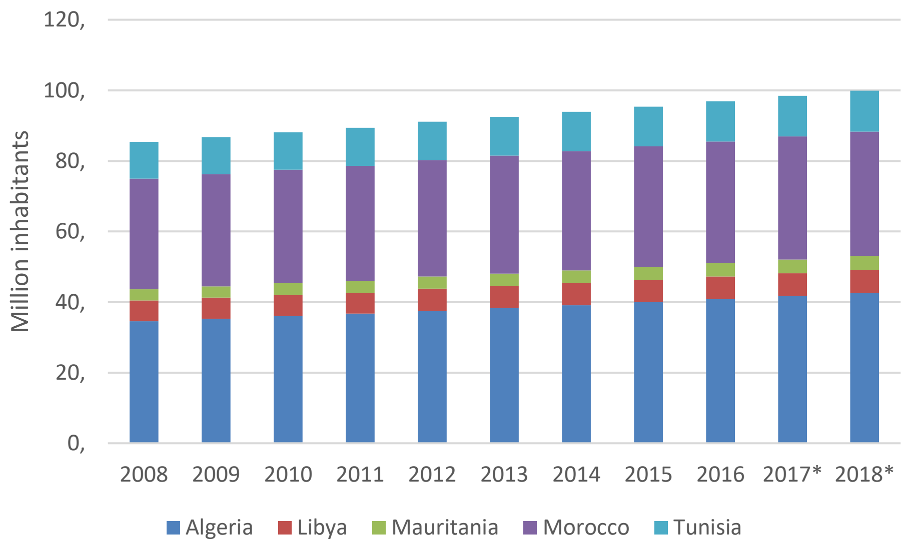


Figure 2-2 Total population of the Maghreb countries from 2008 to 2018. Source: IMF. World Economic Outlook Database October 2019.

The estimated gross domestic product (GDP) of all Maghreb countries, amounted to approximately 1,210 billion international dollars in 2019 (Figure 2-3).

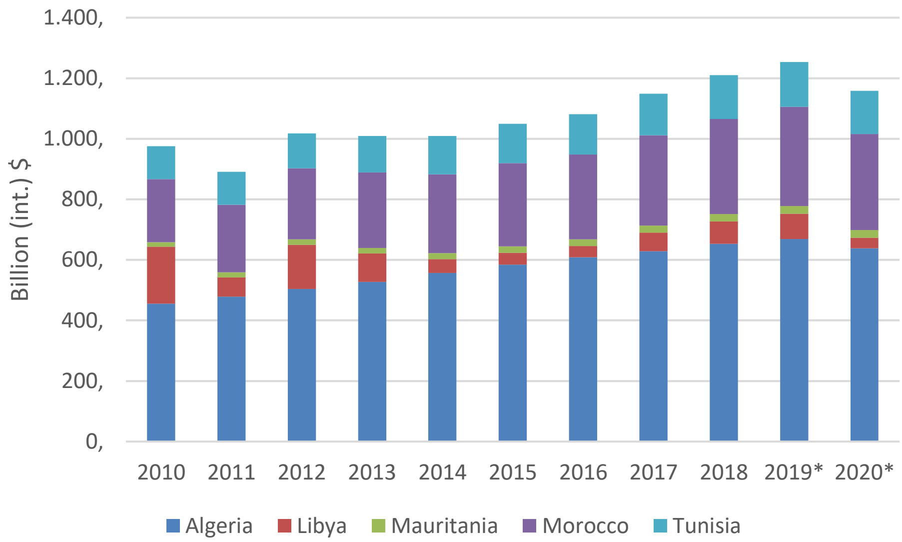


Figure 2-3. Gross domestic product of the Maghreb countries from 2010 to 2018 with projections up until 2020. Source: IMF. World Economic Outlook Database April 2020.

Water for nature and ecosystems

The Maghreb ecosystems are diverse, containing both fresh water and saltwater systems. There are wetlands along the coast, important for birds, that are sometimes designated as a Ramsar site (Wetland of International Importance; see Figure 2-4). The inland areas can be characterized as desertic areas and can be categorised into three main types: the agrosystems comprising the oases and the modern irrigated perimeters, the pastoral ecosystems extending from degraded forest formations to desert and freshwater wetlands (e.g., marshes), and salt water (e.g., chotts – salt lakes). These fragile and vulnerable ecosystems are under pressure (UNECE, 2020). As water scarcity is becoming more urgent and plans are made for sustainable water management in the Maghreb region, attention should be paid to the preservation of groundwater dependent ecosystems. For example, oasis, biodiversity hotspots, are groundwater dependent ecosystems that suffer from lowering groundwater tables.

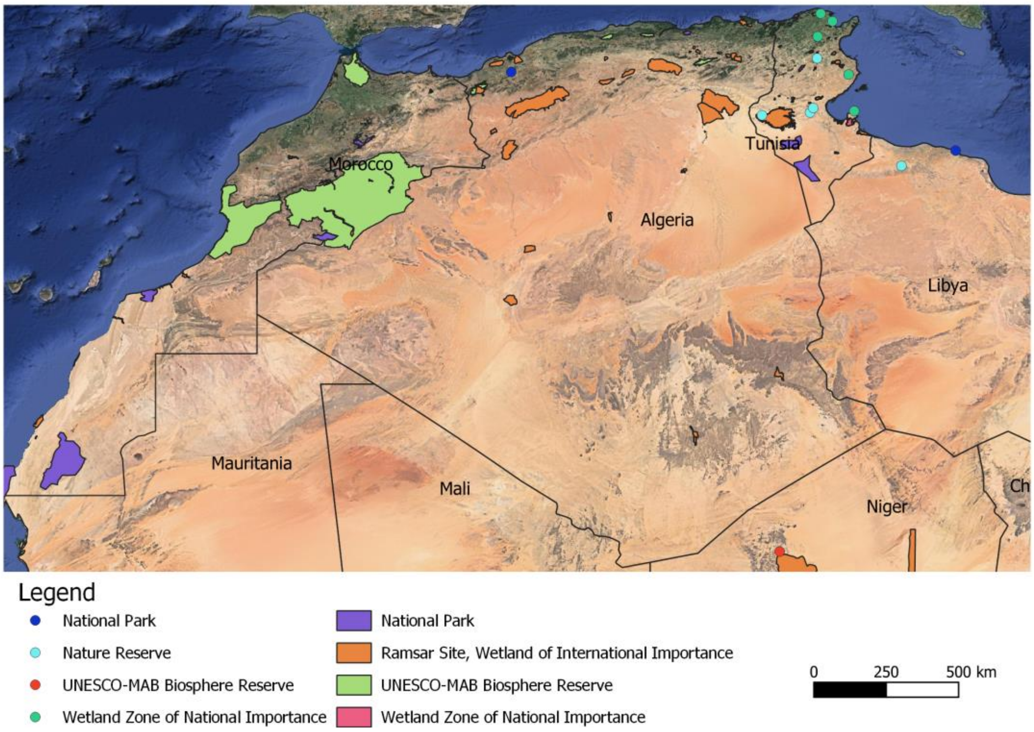


Figure 2-4. National parks and Nature reserves in the Maghreb region.

Climate

Climate varies highly in the Maghreb (Figure 2-5), and the region is divided in a Mediterranean (temperate) climate region in the north, and the arid Sahara in the south. The Atlas Mountains in Morocco are regarded as one of the Water Towers of Africa, and receive more rainfall than their lower surroundings) (UNEP, 2010). The Sahara Desert in the south receives little or no rainfall. With extreme variations in geographic features, proximity to the coast, etc, precipitation in the Maghreb is highly variable both in space and time. The largest rainfall variation is seen in Morocco. With amounts of more than 800 mm in the northern mountain areas (resulting in a rainfall surplus compared to evapotranspiration) to less than 300 mm in the south (rainfall deficit compared to evapotranspiration). Rainfall occurs mainly in wintertime (WMO, 2020).

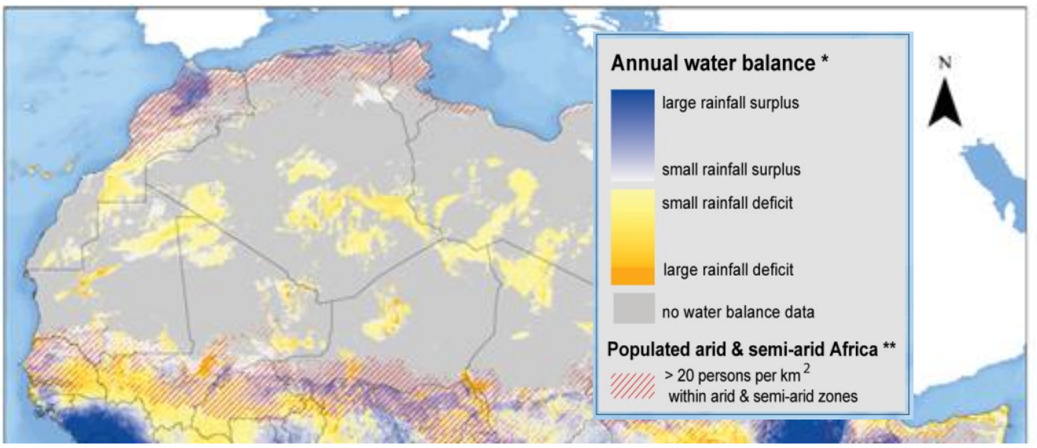


Figure 2-5. The annual water balance for Northern Africa. This is an estimate of the available runoff after evapotranspiration—water that is potentially available for water harvesting. The red hatching overlaying the water balance map shows where population density of greater than 20 persons per km² coincides with areas defined as arid or semi-arid. Source: modified from UNEP 2010.

2.2 Agriculture, livestock, and water resources

Molle *et al.* (2019) describes that “irrigation has been a determinant strategy of the adaptation of Maghreb societies to these conditions of aridity. Traditional schemes still include magnificent examples of water mines or qanat, called *khettaras* in Morocco or *foggaras* in Algeria and Tunisia, valuable small-scale mountain irrigation systems, old earthen channels (*seguias*), and ancient diversion weirs in permanent and ephemeral rivers.”

In the twentieth century development of large irrigation systems accelerated due to the presence of colonial regimes and liberation movements. Developments of groundwater use (for irrigation) also accelerated due to technological advances in borehole drilling techniques. Technical development and irrigation policies were then and are still focused to storage and use water inland and ‘not one drop lost to the sea’. Large reservoirs are in use to store water inland for use for irrigation.

Irrigation plays a critical role in the economy of the Maghreb countries. Agriculture generates 10 to 20% of GDP and exports. Both in Tunisia and Morocco 20 to 33% of their labour force is engaged in the irrigated agricultural sector. Irrigation is essential to sustain the rural population (Molle *et al.*, 2019). Therefore, considerable attention will be paid to irrigation in this report, and in the optimisation of irrigation also lie some of the opportunities (see chapter 7).

2.2.1 Current status agriculture and developments

There are different types of agricultural activities in the Maghreb region that are dependent on water resources for its functioning. We consider the main categories of agriculture (rainfed and irrigated), greenhouse farming and animal husbandry.

Rainfed and irrigated agriculture

In Algeria, Libya, Morocco, and Tunisia, rain-fed agriculture is practiced on more than half of all arable land (AOAD, 2007). The remaining land is irrigated. In the Maghreb, 40% of irrigated land is dedicated to growing cereals (World bank, 2009). More details on the different focus crops per country are given in the country specific chapters.

Surface irrigation (furrow irrigation), drip irrigation and sprinkler irrigation systems are in use in the Maghreb region, which differ in their water use efficiency. Drip irrigation is becoming more important and often promoted and subsidized by governments as being part of water saving technologies. Irrigation schemes are often managed by Agricultural Development Groups or farmers associations. The options for Wastewater Treatment (WWT) are being explored and there seems potential for several sectors (such as industry, landscaping and golf courses). The use of treated wastewater for agriculture is still in progress to meet the demand in water quality.

Several techniques for improved water efficiency are piloted in the Maghreb region. For example, in Algeria a subsurface fertigation system is piloted in the desert (Blom-Zandstra & Michielsen, 2020) and a portable sprinkler system was piloted in Northern Algeria (de Braber, 2017).

Protected cultivation

The number of areas with protected cultivation are still growing in the Maghreb region. Driving forces range from improved food production with higher production levels, extended growing seasons, decreased water use compared to open field production and/or diminished risks of crop failure by for instance storm, rain and pests and diseases, to better quality and safer food products (Van Os *et al.*, 2012). These solutions range from low-tech, low-cost plastic tunnels to high-tech expensive glasshouses. Because crop production in green houses is a very water use efficient way of crop production, extra attention will be given to this topic in chapter six, since great opportunities lie here for Dutch business.

Animal husbandry

Table 2-2 shows the number of livestock in the three Maghreb countries. This livestock is produced for meat; smaller livestock such as poultry and rabbits are not included. The relative dominance of the different livestock animals is to a large part comparable between the three countries, with all of them sharing the same top three livestock animals. In total, Algeria has the largest livestock population consuming over one hundred million litres of water per day.

The effect of livestock on water use are strong and increasing (FAO, Livestock's long shadow, 2006). More than 25% of humans' water footprint is through the consumption of meat (Hoekstra, 2012). However, it depends strongly on what type of water is being considered: blue, green or grey water (Doreau *et al.*, 2012). The main use of blue water by livestock is when their feed is being irrigated. As can be read below in the section on Morocco, 75% of the fodder crops are produced under irrigated agriculture. Thus, minimizing the use of blue water by livestock is mainly achieved by not irrigating their feed (Doreau *et al.*, 2012), or possibly by using brackish water for irrigation for the feed. For example, Sorghum is more drought and salinity tolerant than corn is (a commonly grown feed crop) and could serve as an alternative in certain areas. However, it should be taken into considering that the sustainable use of saline water for irrigation is complex (see Chapter 7) and when livestock consume more salts, the drinking water intake will likely also increase.

Table 2-2. Livestock numbers for the 3 focus countries and their water use. Data from Faostat (2020).

Country	Meat, indigenous	average Nº heads 2006-2008	average Nº heads 2016-2018	change in 2016-2018 compared to 10 years earlier (%)	Total water use 2016-2018 (million l/day)
Algeria	sheep	10789000	17387148	61,2	86,94
	goat	1406333	1878092	33,5	9,39
	cattle	624924	732918	17,3	18,32
	camel	28667	40563	41,5	2,23
	pig	3200	2845	-11,1	
	horse	3070	2702	-12,0	
Subtotal					*116,88*
Morocco	sheep	8473333	10882713	28,4	54,40
	goat	1976400	2155056	9,0	10,78
	cattle	844438	1268962	50,3	31,72
	horse	16503	15383	-6,8	
	camel	15964	13903	-12,9	0,76
	pig	12000	12835	7,0	
Subtotal					*97,66*
Tunisia	sheep	4216667	3487854	-17,3	17,44
	goat	883317	752097	-14,9	3,76
	cattle	236490	239632	1,3	5,99
	camel	18000	12184	-32,3	0,67
	pig	8628	6737	-21,9	
	horse	2999	2485	-17,1	
Subtotal					*27,86*

2.2.2 Availability of water resources

The Maghreb countries are water-scarce and have a great challenge in sustainable water use (balancing water use with the water recharge rate). A general overview of the availability of water resources is provided below, a more detailed situation description can be found in the country specific chapters.

Surface water

Surface water is unevenly distributed, due to the topography and rainfall distribution. More is available in the north of the Maghreb and downstream of the atlas mountain range. Surface water reservoirs in the Maghreb are widespread and store large quantities of water. Sedimentation of reservoirs due to upstream soil erosion is one of the key issues since it negatively affects the storage capacity in the reservoirs. Also, evaporation losses are high.

In several regions, surface waters (e.g. streams) are known to be polluted by untreated municipal and industrial wastewater. Loads from intensive agricultural management practices have also resulted in high phosphorous, nitrate and pesticide concentrations. In addition, various surface waters in West Algeria have shown heavy metal concentrations above the WHO standards (Djediai *et al.*, 2016).

Rainwater

Climate varies highly in the Maghreb, but rainwater can be harvested in wintertime. In the northern part of the Maghreb region, there is a high potential for rainwater harvesting. Also in the Atlas mountains in Morocco there is a rainfall surplus. Runoff occurs in the form of rapid and powerful floods that replenish dams during the short rainy season.

Groundwater

There are three transboundary aquifer systems shared between Morocco, Algeria and Tunisia:

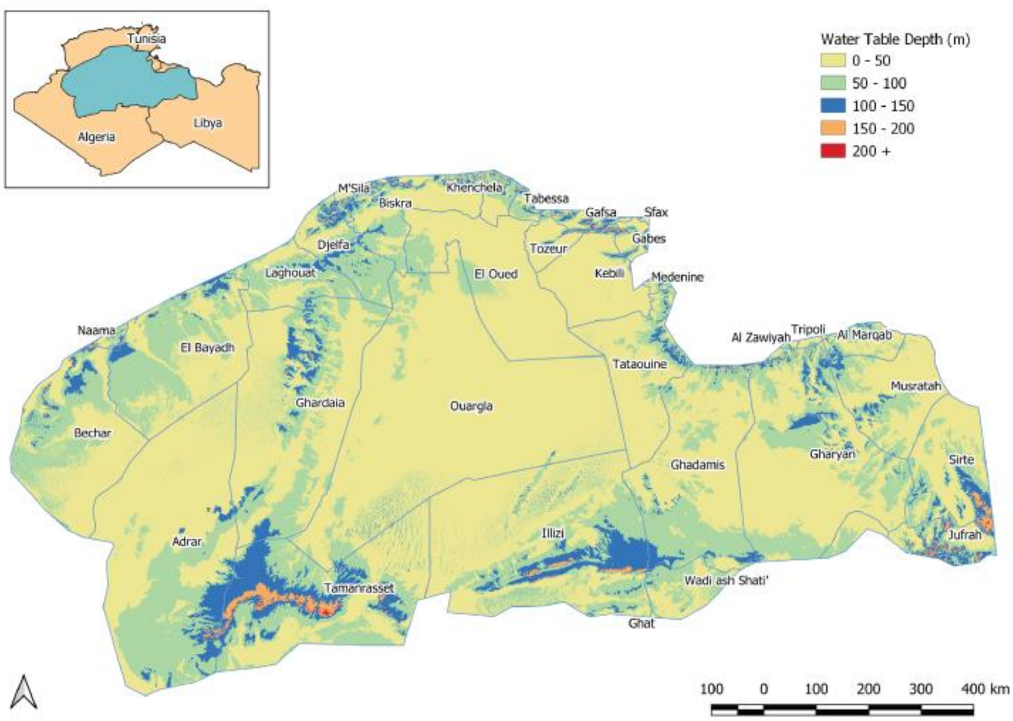
1) The **Errachidia Basin** between Algeria and Morocco. With the extent of 60.000 km^2, it is a relatively small transboundary basin. Rainfall rates are low (200 – 80 mm). Abstraction of groundwater causes water quantity problems in this basin due to reduced groundwater recharge rates (UNESCO, 2009).

2) The **Tindouf basin** is mainly shared between Algeria and Morocco and to a lesser extent with Mauritania. With an extent of 210.000 km^2, it is also a relatively small transboundary basin. There is a low demographic density in this basin. Due to low rainfall rates (extreme climatic conditions), active recharge to the aquifer is extremely low (UNESCO, 2009).

3) Algeria and Tunisia (and Libya) are relying strongly on the transboundary aquifer of the **North Western Sahara Aquifer System (NWSAS)** (Figure 2-6). The NWSAS is the largest transboundary groundwater reserve in North Africa, extending over 1 million km^2. However, its water resources are largely non-renewable (and can therefore be considered a fossil groundwater resource). Over the last decades the agricultural and industrial development in the basin, as well as the technological advances in well drilling led to steadily growing water abstraction.

The NWSAS is composed of two major water-bearing layers, the Continental Intercalary (CI) and the Terminal Complex (CT). From the 1970 to the 2000s, abstraction by drilling has risen from 0.6 to 2.5 billion m^3/year. This rate of abstraction involves many risks: strong impact on neighbouring countries, salinization, elimination of artesianism, drying up of outlets, etc. (OSS, 2004). For more information on this, see the country specific chapters. Today, the rate of withdrawals from the aquifer far exceeds the rate of its replenishment. The water abstraction is currently standing at three times the aquifer's natural recharge rate (1 billion m^3 per year) (UNECE, 2020).

Water table depth in NWSAS region (m)



Source: Fan, Li, and Miguez-Macho (2013)[73]

Figure 2-6. Depth to the water table in the extent of the North Western Sahara Aquifer System (NWSAS). Source: UNECE, 2020. From the 1970 to the 2000s, abstraction of groundwater by drilling has risen from 0.6 to 2.5 billion m3/yr.

2.2.3 Water quality

Ground water quality in the Maghreb region is variable. In all three countries, some of it is fresh, but all countries also suffer from salinized ground water (Table 2-3). The salinization of groundwater is also predicted to get worse in the future (Hamed *et al.*, 2018).

The salinity threshold at which water is generally classified as moderately saline is 1.5 to 3 dS/m. These levels can affect salt sensitive crops and require careful management practices. Water with an Electrical Conductivity (EC) from 3 dS/m up to 7.5 dS/m may cause severe salinity effects and only salt tolerant crops on permeable (i.e. containing a high fraction of sand) soils with careful management practices are suitable for the use of this type of water. Table 2-3 shows that the average salinity level of most of the reported shallow wells in all three countries can be classified as moderately or severely saline.

Salinization is not new to the Maghreb and as such, farmers have learned to deal with it, at least to a certain extent. When brackish water is not used properly, there is a risk of salinizing, and thereby possibly degrading the soil, especially in the case of clay soils. In areas with very low rainfall this is a significant risk since there is no sufficient rain to leach accumulated salts away from the rootzone of crops.

However, when irrigation is done properly (sustainable leaching and drainage to control rootzone salinity, maintain good soil health) conventional crop production is possible with most of the average salinity levels shown in Table 2-3. For most levels of salinity, suitable crops and crop varieties can be selected. With the high (max) values shown in Table 2-3, EC values of 12 dS/m or higher, only a very limited number of specific halophytic crops can be cultivated. Since there is considerable expertise in The Netherlands on how to produce crops using saline resources, some opportunities regarding this form of agriculture are identified and can be found in chapter 6.

Table 2-3. Summary of salinity levels in shallow wells in the three Maghreb countries. Original values are shown, as well as the TDS values calculated to the Electrical Conductivity values (in dS/m) are shown to allow for easy comparison. Source data Algeria and Tunisia: OSS, source data for Morocco: El Mountassir *et al.*, 2020, Najib *et al.*, 2015, Sehlaoui *et al.*, 2020, Kadaoui *et al.*, 2019, Re *et al.*, 2013

		Orignal sources			Equivalent EC values (dS/m)		
Country	Region	Average	Min	Max	Average	Min	Max
Algeria (TDS mg/l)	Adrar	858	400	5200	1,3	0,6	8,1
	Biskra	3168	858	8816	5,0	1,3	13,8
	Djelfa	2000	1500	2500	3,2	2,4	4,0
	El Oued	3299	1632	8002	5,2	2,6	12,5
	Ghardaïa	1287	160	3592	2,0	0,3	5,6
	Illizi	2104	348	8166	3,3	0,5	12,8
	Khenchela	2500	2000	3000	3,9	3,1	4,7
	Laghouat	1250	1000	1500	2,0	1,6	2,3
	Ouargla	3845	1170	10010	6,0	1,8	15,6
	Tanabrasset	1750	1000	2500	2,7	1,6	3,9
	Tébessa	2673	1700	4360	4,2	2,7	6,8
Tunisia (TDS (mg/l)	Gabès	2858	1400	4350	4,5	2,2	6,8
	Kebili	3322	630	15400	5,2	1,0	24,1
	Tatouine	3105	790	7200	4,9	1,2	11,3
	Tozeur	2580	760	5300	4,0	1,2	8,3
Morocco (µS/cm)	Essaouira, krimat aquifer	1179	390	2520	1,2	0,4	2,5
	Chaoia	1845	464	7786	1,8	0,5	7,8
	Benslimane	2500	500	8000	2,5	0,5	8,0
	Triffa plain	N/A	900	9100	N/A	0,9	9,1
	Bou-Areg coastal aquifer	5970	1740	10520	6,0	1,7	10,5

For the agricultural sector (for example for vegetable production), the pH of the water is also an important factor. This is highly dependent on the bicarbonate concentration of the water source. There is little information available on the bicarbonate concentrations of water resources in the Maghreb countries, and the agricultural sector could be supported with a widespread mapping exercise on the pH (or bicarbonate concentrations) and salinity concentrations.

2.2.4 Water demand agricultural sector

Table 2-4 shows where water is used in the three Maghreb countries. There are considerable differences between countries. For example, we can see that the contribution of domestic water use to total water use ranges from 9 to 36%. Other numbers are much more comparable between the countries, such as the use of fresh water by industry in the three countries.

Table 2-4 Overview of water resources and water use (with BCM=billion cubic metre)

Type	Algeria	Morocco	Tunisia
Total water resources	19 BCM/yr	22 BCM/yr	4800 MCM/yr
Total water use for livestock 2016-2018 (million l/day)	116,88	97,66	27,86
Percentage of water resources used for domestic use	36%	9%	15%
Percentage of water resources used for industry	5%	4%	5%
Percentage of water resources used in agriculture	59%	87%	80%

Water losses in the Water Agri food chain

There are large water losses in the agricultural sector for different reasons. Losses due to non-functional or broken irrigation conveyance systems, or evaporation losses in sprinkler systems, or even an over application of irrigation water regarding the water need of the crop. For example, the agricultural sector of Morocco, using nearly 87% of the countries water resources, still has an efficiency rate of only 48%.

Also, the system of drinking water pipes experiences water losses, with a performance rate of less than 70%, meaning water losses close to a third. Food losses in the stage of harvesting, storage and transport could also be considered water lost. All of these steps need improvement to reduce indirect water losses.

2.2.5 Water Pricing

Specifics on water tariffs can be found in the country specific chapters. Most tariffs are applicable for irrigated agriculture. Volumetric pricing is applied. Water pricing is an incentive to reduce water use, but it is in general a low incentive in the area. For groundwater there is often no water pricing because groundwater use is often not controlled/measured.

2.2.6 Water balance in the Maghreb

Table 2-5 provides an overview of the water use of different sectors of the 3 focus countries in the Maghreb region. The numbers show a clear overexploitation of the non-renewable groundwater resources in all 3 countries. In this overview, the water scarcity on a monthly scale is hidden by the annual analysis of demand versus supply. A monthly assessment of the water balance could show severe shortages in water supply vs demand.

Table 2-5. Water balance in the Maghreb. Sources: OSS, 2015; Fanack; Hamiche, 2015 and Hssouaine, 2020.

Type	Algeria	Morocco	Tunisia
Total water resources	19 BCM/yr	29 BCM/yr	4.8 BCM/yr
Estimated water demand for all sectors	10.5 BCM/yr	15.9 BCM/yr	11 BCM/yr
Estimated renewable water resources	13.6 BCM/yr	22 BCM/yr	4.4 BCM/yr
Estimated withdrawals for irrigation	6 BCM/yr	13,7 BCM/yr	2.3 BCM/yr
Estimated non-renewable used groundwater resources	2 BCM/yr	1.1 BCM/yr	0.65 BCM/yr
Estimated water use for domestic purposes	2.9 BCM/yr	1.5 BCM/yr	641 MCM/yr
Estimated yearly water use for livestock 2016-2018	42.7 MCM/yr	35.6 MCM/yr	10.2 MCM/yr

Tunisia already shows a clear imbalance in the estimated water demand for all sectors compared to the total water resources. Looking at the future water balance for Algeria and Morocco, the following can be stated:

- Algeria: Based on population growth, rural-to-urban migration and per capita water demand projections, the overall water demand for all sectors is projected to be approximately 18.9 BCM by 2030 (Hamiche, 2015)
- Morocco: The estimated water demand for all sectors is expected to grow to 24.2 BCM after 2040 (Hssouaine, 2020)

2.2.7 Water scarcity and climate change

The trend is that the availability of water resources in the Maghreb region is decreasing due to climate change and a degradation in water quality. The surface water availability and quality has decreased, which will lead to more extensive use of groundwater.
According to IPCC (2014), climate change is expected to induce a warmer and drier climate. Current projections for climate change suggest an increase in the frequency, intensity and duration of droughts accompanied by a decrease in precipitation. There are regional differences in anticipated climate change impacts in temperature and precipitation. For more details on future water availability, see the separate country chapters.

2.3 Agriculture and trade

Europe is the Maghreb's major trading partner in agricultural products. The strategic location, the production potential and the extensive markets of the Maghreb countries makes the EU, among some other social and political reasons, to want to increase its cooperation (Alterra, 2010). For example, a large part of the Tunisian export products goes to France.

One could also consider trade in agricultural products, as water export. However, this export also contributes to the economy. On a national level, several arid or even desert regions of the Maghreb region produce water-intensive crops such as watermelon or several other market garden crops or intensive and hyper-intensive irrigation systems to meet the food needs of large cities and more watered regions. At the international level, Tunisia exports several agricultural products to European countries. The variability of rainfall affects agricultural production with abundant annual harvests but does not prevent the export of food products especially those provided by irrigation.

3 Algeria

Table 3-1. Country summary of Algeria

Country overview	Algeria
Water availability and use	-19 BCM renewable water sources, 11 BCM/year is surface water mainly in the North and 8 BCM is groundwater, that is exploited above recharge level. - 80 dams provide an annual volume of 20 Million m^3 for human consumption, industry and irrigation. - The water availability is approx. 440 m^3 per capita per year, which puts Algeria below the threshold of water scarcity. - Currently 60% of the water used goes to agriculture and 36% to drinking water facilities.
Future water availability	- Precipitation is expected to decrease (with a maximum of 16%) in March-May and increases during September-November (a maximum of 22% and an average of 6%). - Climate change will also impact the capacity of dams by increasing evaporation (higher temperatures) and siltation (more extreme weather and erosional events) - Water demand is expected to increase drastically.
Water quality (salinity)	-Surface water is polluted in some rivers by municipal and industrial wastewater. -Groundwater is becoming increasingly salty and of lower quality due to overexploitation and sea water intrusion.
Irrigation types	-The top three products (wheat, barley and olives) are produced under rainfed conditions and the second three (fruits, dates and potatoes) are cultivated under irrigation. -In the North crops are irrigated from dams or reservoirs and in the South from deep boreholes that extract groundwater from (often overexploited) aquifers. - Gravity irrigation is still the most used irrigation method in small and medium-scale farms.
Trends in irrigated agriculture	-Since 2001, production in greenhouses has increased from over 4,300 ha to over 15,800 ha in 2018. Especially production on the edge of the Sahara is increasing. This is now the most important horticultural area in the country. -Reuse of wastewater is happening on a reasonably large scale. Of 154 treatment plants operated by 'Office National d'Assinissement' across 44 wilayas, 16 plants are

	concerned with the reuse of purified wastewater in agriculture.
Trends in greenhouse cultivation	The polytunnels are being substituted by canarian greenhouses. Since 2009 the introduction of the canarian greenhouse has ensured better yields. There are in Biskra alone 2000 ha of this type of greenhouse. Government's policy aims to the extension of the irrigated area of one million hectares. The agreed objective is to reach 2,136,000 ha by 2020,
Trends in livestock	-There is a significant increase in the number of sheep, goats, camels and cattle in Algeria. -The number of pigs and horses are decreasing.
Water productivity & efficiency	The Priority Program of the Ministry of Agriculture and Rural development has set as a goal for 2021 The extension of irrigated areas and the promotion of water-saving systems, essential for increasing production and productivity, particularly of cereals as well as in terms of rational management of water resources and use supplemental irrigation, particularly in the eastern wilayas;
Trend in governance	- control of information in real time, on the availability of resources and withdrawals - mobilization of the necessary financial means, including alternative financing, for investments in infrastructure and rationalization of their use - mastery of the most innovative technologies to improve the technical efficiency of the water production / distribution system -mastery of the economic management of the system mobilization, production and distribution of water, in order to reduce the cost of water
Water pricing	The actual tariffication by the Executive Decree no7-270 of September 2007 is still low and apply only in large public irrigation perimeters (Table 3-7)
Focus region: Coastal zones and Biskra-region in Algeria	Biskra has sharply increased its greenhouse production, mainly due to relocation or expansion of horticultural businesses from the north. This is now the most important horticultural area in the country with more than 40% of the total area of greenhouses in Algeria

3.1 Water and agriculture

3.1.1 Topography and climate

Algeria has three distinct climatic zones: 1) The coast and Tell Atlas Mountains in the north make up 4% of the total area and enjoy a Mediterranean climate of wet, cool winters and hot, dry summers, 2) In the centre of the country are the semi-arid highlands and 3) The Sahara occupies 87% of the country and is characterized by extreme weather conditions with strong thermal amplitudes (FAO Aquastat, 2015).

Rainfall is characterized by significant spatio-temporal variability. The Mediterranean strip in the north receives up to 1,200 mm per year, and varies from year to year while decreasing towards the west. The central regions are transitional and receive average annual rainfall of 100-400 mm. The desert receives less than 100 mm of rain per year. The natural losses through potential evapotranspiration range from 1,000 mm in the north-east to almost 3,000 mm in the south-east (Figure 3-1).

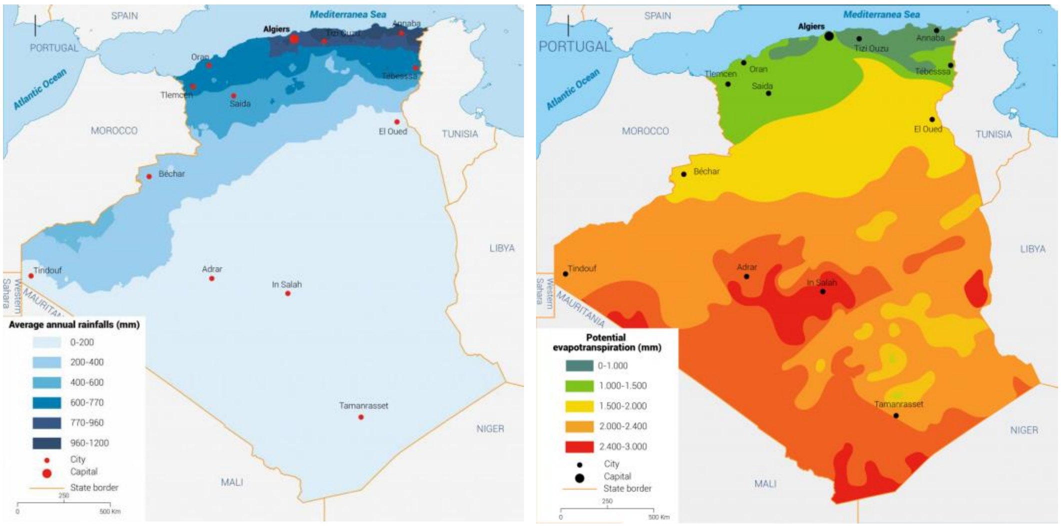


Figure 3-1. Left: Annual average precipitation in mm, right annual potential evapotranspiration.

Apart from spatial variability, rainfall also varies considerably on a temporal scale, with large intra- and inter-annual variability. This variability has a strong effect on crop production.

According to the climate change projections gathered by the World Bank derived from 35 available global circulation models (GCMs) used by the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report, mean temperatures are expected to increase by 2.6°C by 2050, with more frequent heat waves and fewer frost days (Figure 3-2). Precipitation is expected to reduce (by a maximum of 16%) in March-May and increases are projected during September-November (a maximum of 22%, Figure 3-3), related to an increase in rainfall intensity of 7% and a general increase of rainfall of 6%. Higher-resolution (finer spatial scale) climate models project that Algeria will become wetter by the end of the century.

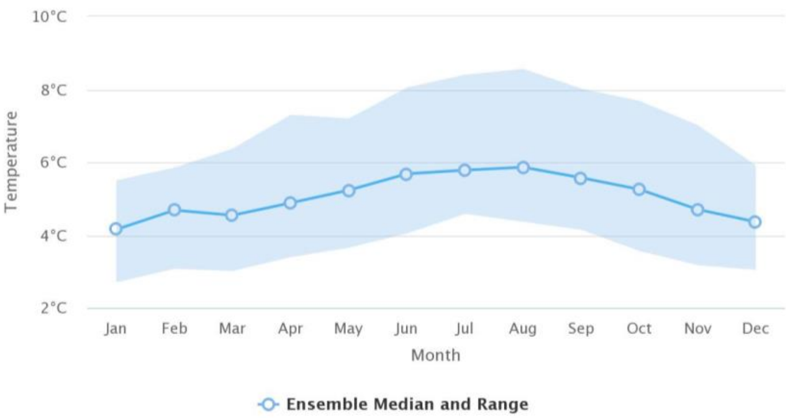


Figure 3-2. Projected change in Monthly Temperature for Algeria for 2080-2099, compared to the reference period (1986-2005) (figure from the World Bank Climate Change Knowledge Portal)

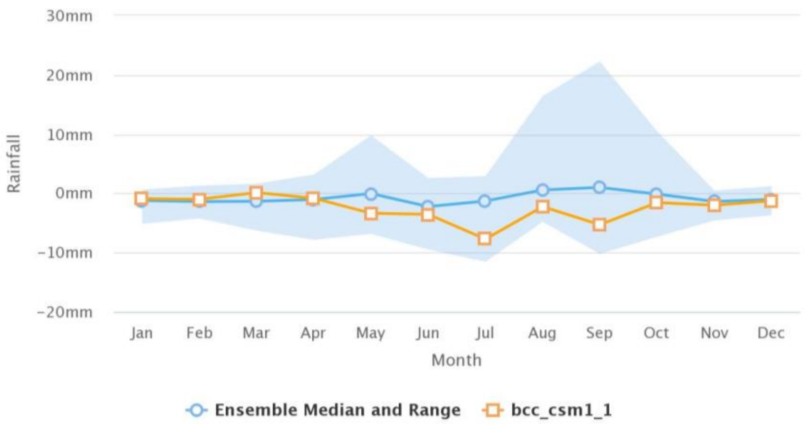


Figure 3-3. Left: Change in Monthly Precipitation for Algeria for 2080-2099, compared to the reference period (1986-2005) (figure from the World Bank Climate Change Knowledge Portal)

3.1.2 Landuse and agro-ecological zones

The agricultural sector contributes to about 12% of Algeria's GDP (2016 estimates) and employs ca. 20% of the population in rural areas (Algeria has about 8.4 million ha of arable land. About 51% of the total arable land is dedicated to field crops, mostly cereals and pulses (Blom-Zandstra & Michielsen, 2020).

The more humid zones of the coast and Tell Atlas Mountains in the north have sufficient rainfall that allows diversified agricultural production as cereals, vegetables, fruits and of semi-intensive livestock (especially milk and meat). In the centre of the country are the semi-arid highlands in favour of livestock, especially sheep farming due to its large and extensive grazing areas; and the arid Sahara occupying ca. 87% of the country with agricultural activities based on irrigated agriculture or crops storied and exploitation of the palm trees (Figure 3.3).

Two locations within Algeria, Algiers and Biskra, show important concentrations of greenhouses. Algiers is at the coast and has a Mediterranean climate. Biskra is at the Southside of the Atlas mountain range and has a warmer, arid climate (Van Os *et al.*, 2012).

3.1.3 Agriculture and crops

Algeria's imports of agricultural commodities and food represented about 17.6% of the total imports (ca. 40 billion euro's) in 2016. Algeria is one of the world's largest importers of wheat and dairy products (USDA Foreign Agricultural Service, 2018). The main crops grown in Algeria are shown in Figure 3-5 comparing the main cultivated area per crop in 2016-2018 (latest available data on FAOSTAT) with the surface used ten years before (2006-2008). The numbers above the bars indicate the yield in ton/ha. Table 3-2 shows the trends in area cultivated and in yield over the ten years is presented here.

The top three crops have remained the same. The cultivated area of wheat, barley, olives and potatoes has increased. Yields of both wheat and olives have increased and fresh vegetables and oranges have made it to the top ten in 2016-2018 meanwhile figs and stone fruits have dropped out of the top ten.

The top three crops are all produced under rainfed conditions. However, the next three crops, stone fruits (recently not in the top ten anymore), dates and potatoes are all produced under irrigation, and so are grapes under certain conditions. Figs and watermelons are also produced under irrigation, as well as vegetables and oranges.

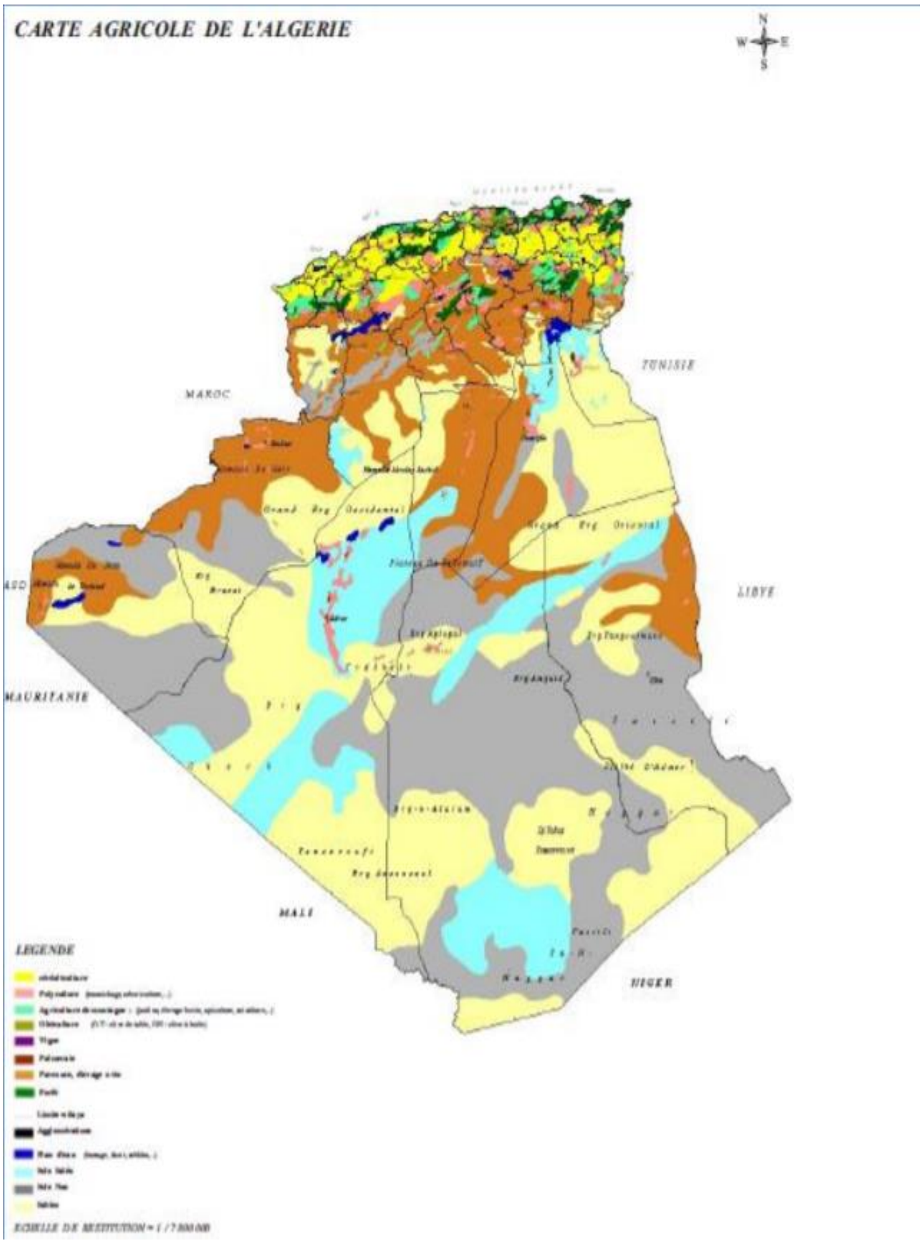


Figure 3-4 Agricultural crop map of Algeria (From ALTERRA, 2018, source: INSID).

This data shows that most of the increase of agricultural production is under rainfed conditions, but some of the upcoming crops such as potatoes, watermelons vegetables and oranges are all produced under irrigated conditions.

The relevance of rainfed crops gains new significance when considered within the climate projections. A study on the impact of climate change on durum wheat, proposed early sowing, reduced crop cycle and earlier harvest as adaptations to try keep yields at current levels in Algeria (Churgal *et al.*, 2016)

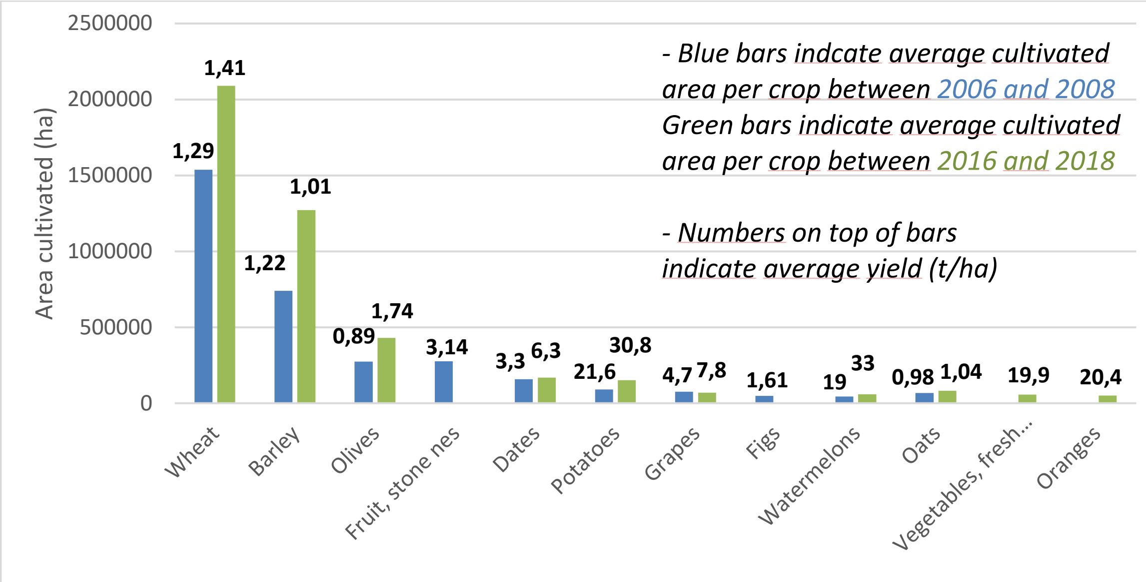


Figure 3-5. Top ten crop production in Algeria 2006-2008, compared to the top ten crop production ten years later (2016-2018). Bars indicate the total area cultivated in ha, numbers on top of the bars indicate the yield in t/ha over the respective periods. Data from FAOSTAT (2018-2018 most recent available data).

Table 3-2. The changes in cultivated area and yield of the top ten crops as shown in Figure . Ranking is based on the mean cultivated area in hectares over 2016-2018.

Crop	Change in area over ten years (%)	Change in yield over ten years (%)
Wheat	35,9	9,2
Barley	72,0	-17,3
Olives	56,6	96,2
Dates	3,3	96,2
Potatoes	68,4	34,0
Oats	23,1	6,3
Grapes	-7,3	68,8
Watermelons	34,7	78,0
Vegetables	N/A	N/A
Oranges	N/A	N/A

Agriculture is the leading consumer of water in Algeria, but its share within the other uses (industries, municipalities) has decreased from 80% to 60% from 1975 to 2019. This is partly due to the increased adoption of more efficient irrigation techniques but is also due to the increase in the drinking water share, which increased from 16% to 36% in that same period (FAO Aquastat).

3.1.4 Water resources

Based on the water stress index, Algeria is below the threshold of absolute water scarcity and most of the renewable water is located in the north of the country (less than 500 m^3 per inhabitant). The available estimated 19 BCM/yr of water resources consist of 11 BCM surface water and 7.6 BCM groundwater (Hamiche *et al.*, 2015). This amount adds up to approximately 440 m^3 per capita per year.

Unevenly distributed, the surface waters decrease from north to south and from east to west. Covering 7% of the national territory, the Tell Atlas represents 90% of the total availability, of which 80% comes from the Center and the East. Algeria has five major river basins comprising a total of 21 catchments concentrated mainly in the north (Figure 3-6).

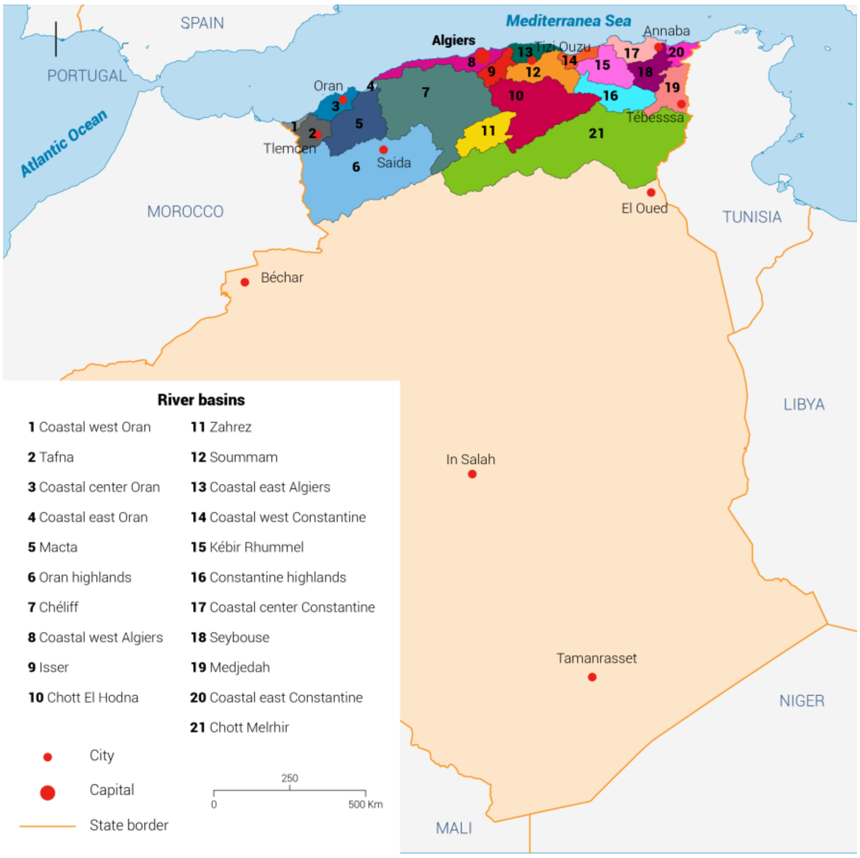


Figure 3-6. Main river basins in Algeria (source: Fanack)

Surface water

Annual available surface water is an estimated 11 BCM with only 0.5 BCM flowing into the Saharan basin. The North, however, relies mainly on surface water since ca. 7 BCM is captured by several medium and large dams Figure 3-7). Runoff occurs in the form of rapid and powerful floods that replenish the dams during the short rainy season, which typically runs from December to February (Hamiche, 2016).

In the whole of Algeria there are 80 dams, with a capacity of 8.6 billion m^3, providing an annual volume of 20 billion m^3 of water for human consumption, industry and irrigation. Most Algerian dams have a short lifespan of about thirty years due to losses from evaporation, high levels of sedimentation and leakage (Benfetta & Ouadja, 2017). 57 major dams currently operate in the coastal and central areas, while only eight are located in the (arid) south.

Sedimentation due to upstream soil erosion is one of the key issues since it negatively affects the storage capacity in the reservoirs. For example, annual average losses for the Bouhanifia dam, reportedly never reaching its maximal capacity due to sedimentation, are estimated at 50 million m^3/year for the period 1986–2015. Certain dams are particularly affected: average annual leakage from the Foum El Gherza dam is estimated at 5 million m^3/year and 11 million m^3/year from the Ouizert dam, where record losses of 23.34 million m^3 were recorded for the year 1995–1996 (Benfetta & Ouadja, 2017).

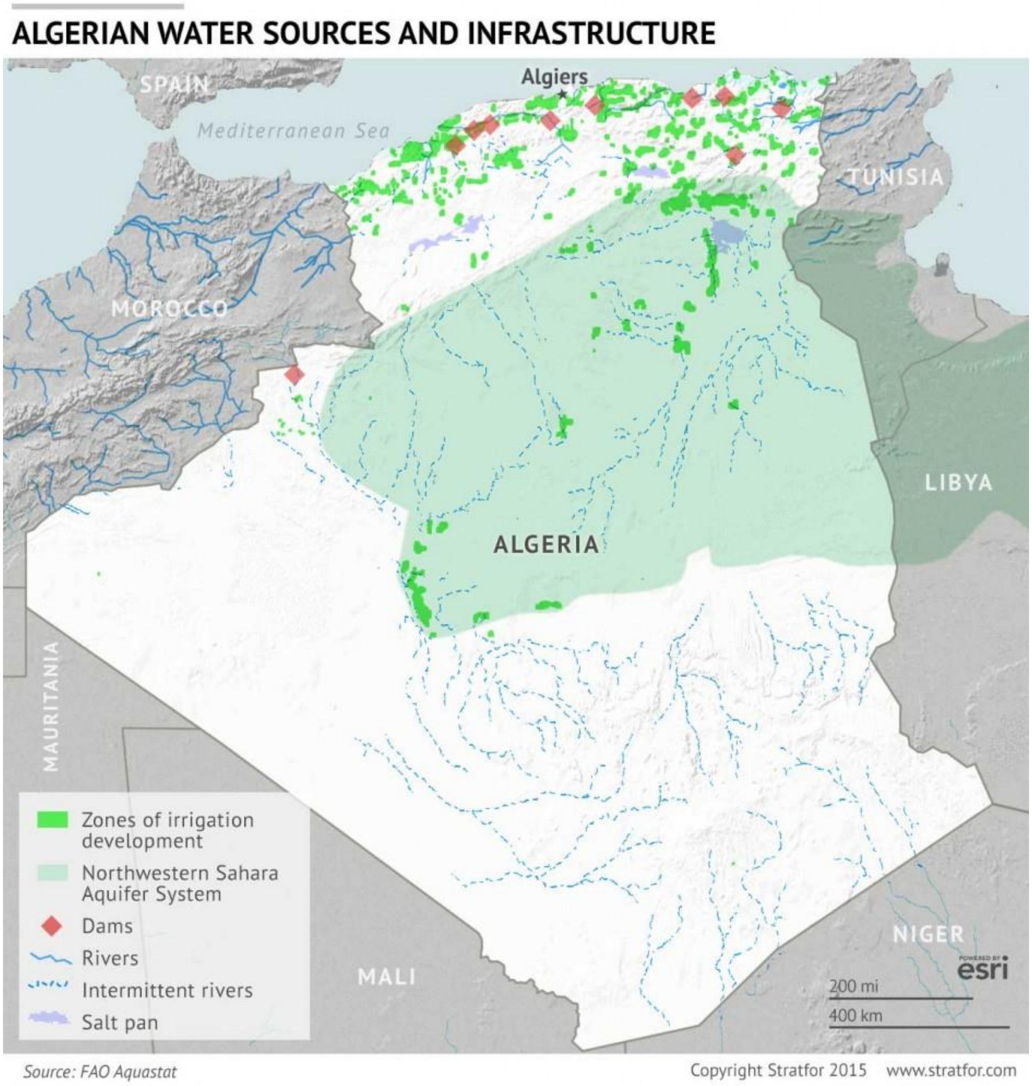


Figure 3-7. Zones of irrigation development and major dams in Algeria. In transparent green overlay, the extent of the North-western Sahara Aquifer system. Source Stratfor 2015.

Evaporation losses are high as well. In the coastal zone (up to 50 km from the sea) annual evaporation is <0.5 m^3/year, compared with a band 50–150 km from the coast, where it is 0.5 – 1 m^3/year (Benfetta & Ouadja, 2017). The sediment deposited in Algerian dams is estimated to be 20 million m^3/year in total. Losses vary per dam; it can range from 50m^3 to 5m^3 per year.

The traditional system of foggaras is widespread in Algeria. They represent a system used for the acquisition and distribution of water, based on horizontal drainage galleries. These systems are less troubled by sedimentation or evaporation losses. They are however at risk when water tables drop, and the system is disconnected from water flow. In Algeria, seven types of foggara were identified by Remini *et al.*, (2010): 1) receiving water from the water table at the foot of a mountain range; 2) draining waters of the intermittent streams; 3) receiving waters from the Continental Intercalaire aquifer; 4) receiving water from a spring; 5) receiving waters from the Occidental Great Erg aquifer; 6) capturing drainage and infiltration; 7) capturing only flood waters (foggara of Mzab).

Groundwater

In the mountainous region in the north, the aquifers are shallow and much exploited using wells and springs. While these aquifers are naturally recharged with 1.9 BCM/yr, the total withdrawals are estimated at 2.4 BCM/yr. The deficit is mainly due to a lack of effective groundwater management, linked to poor knowledge of the resource, an increase in the number of unregistered wells and an inadequate coordination between the water authorities (Bouchekima, 2008; British Geological Survey, 2018).

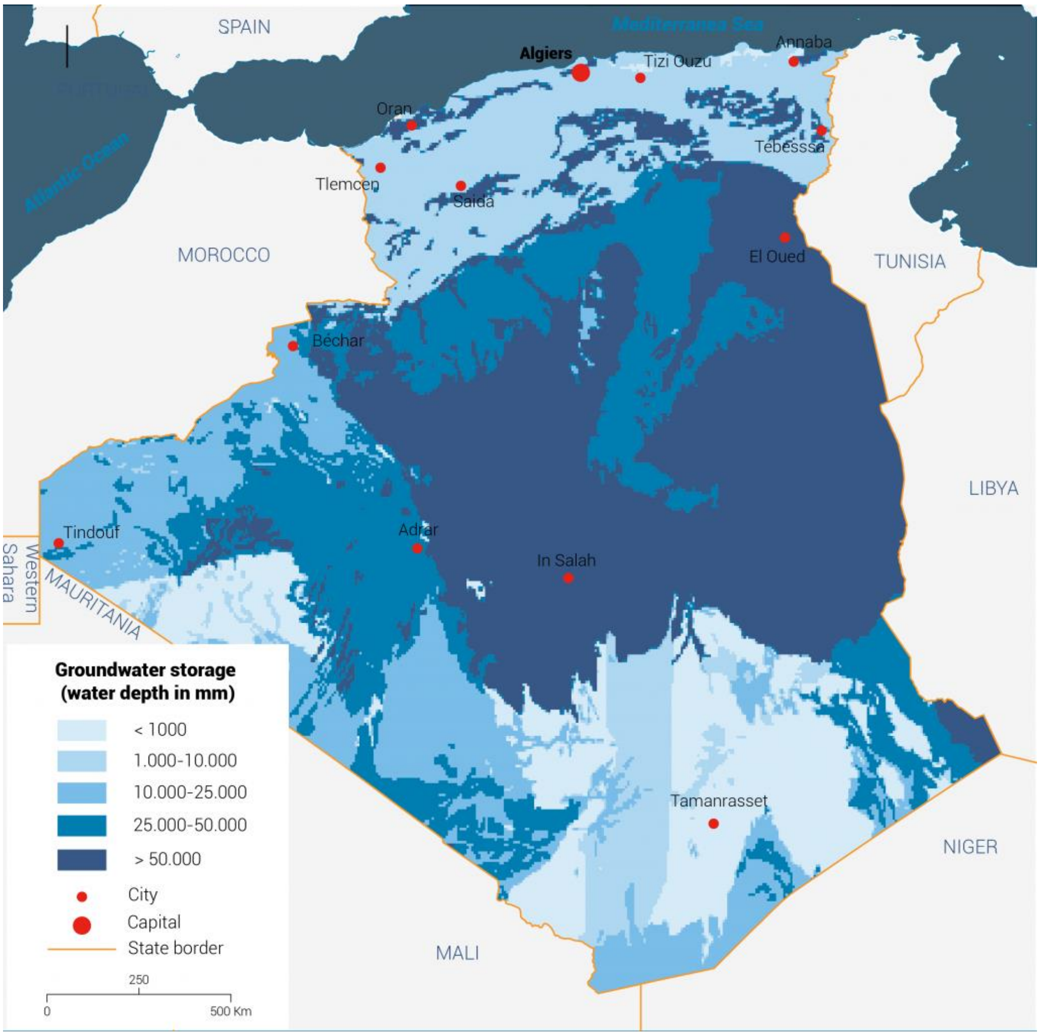


Figure 3-8. Groundwater storage (water depth in mm), source: Fanack.

The Complex Terminal (100-400 meters deep) and the Continental Interlayer (1,000-1,500 meters deep) contain significant reserves of 30,000-40,000 Billion m^3. The coastal region of Algeria has already seen a decrease in annual precipitation of more than 50 mm/year since the 1950s and water demand is expected to increase drastically in the near future (Sebri, 2016). Climate models predict a temperature rise, more erratic precipitation and an increase in exploitation in the future. As a result, groundwater levels are expected to decrease further (Garcia-Ruiz *et al.*, 2011).

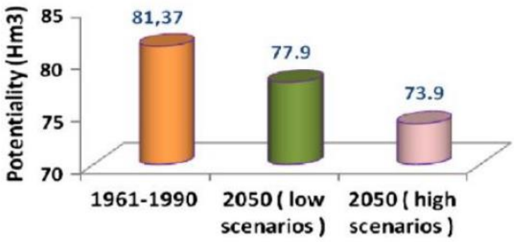


Figure 3-9. Expected decrease in groundwater resources in the High and Middle Cheliff Basin. Source: Elmeddahi et al, 204.

Trend in groundwater resources

Algeria is among the countries with the lowest renewable water resources per capita in the world (Mohtar, Assi & Daher, 2017, WRI, 2005),

Elmadahi *et al.* (2014) analysed data about piezometric levels for the middle Cheliff Basin. the main exploited groundwater reservoirs in the Middle Cheliff basin belong to the alluvial aquifer (limestone and sandstone). Long time series of data were collected between 1972 and 2003 which show significant decreases in the piezometric levels as a result of the combined effects of drought and excessive exploitation of groundwater, starting in 1994. Examples of this are drops of 6.3m in well nr. 82–13 during a period of high water and 14.6m in a low water period between 1988 and 2003 (Figure 3-10). In 2009, the well was dry. Well nr. 105/91 also shows depletion but to a lesser extent; there was a slight rise in the groundwater level of about 0.5–0.6m despite low rainfall. This would have been the result of dam releases and re-infiltration of irrigation water. Figure 3-11 shows more examples of groundwater levels depletion and overexploitation.

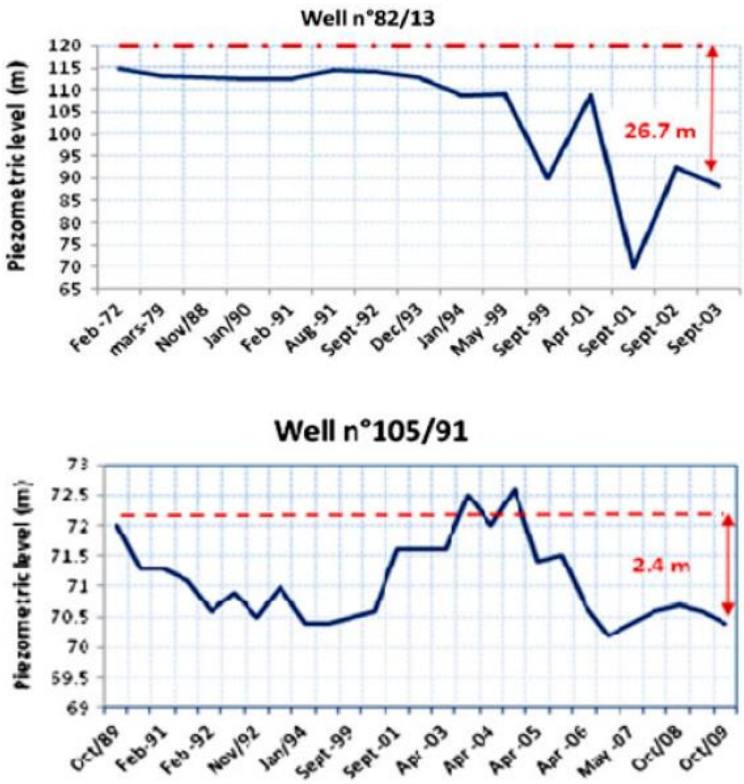


Figure 3-10. Variation and progression of piezometric levels. Above: well nr. 82/13. Below: well nr 105/91 source OSS, 2004.

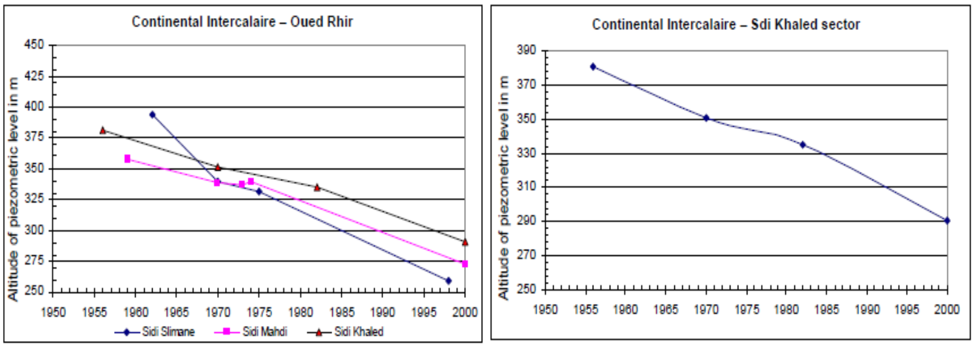


Figure 3-11. Examples of drawdowns in Algeria of the Continental Intercalaire of the NWSAS system. Source: OSS, 2004.

Water quality

Surface water is known to be polluted in several sections of rivers: the Tafna, Macta, Cheliff, Soummam and Seybous are affected by inflowing untreated municipal and industrial wastewater. Irregular and intensive agricultural management practices have also resulted in elevated phosphorous, nitrate and pesticide concentrations in some natural waterbodies. In addition, surface waters in West Algeria have shown heavy metal concentrations above the WHO standards (Djediai *et al.*, 2016).

Groundwater in Algeria is often hard, with high Electrical Conductivity (EC) and high levels of mineralisation, in particular sulphate (Britisch Geological Survey Earthwise). The salinity is caused by, in some places, the lithology and mineralogy of the aquifers, but also by relatively low rainfall and high evaporation in arid and semi-arid zones, and by aquifer overexploitation. Some coastal aquifers have been intruded by sea water - such as the aquifer at Algiers; the alluvial aquifers of Bas Sebaou; and coastal aquifers in the Annaba-Bouteldja region (Britisch Geological Survey Earthwise). Salinisation of aquifers also occurs close to saline lakes, such as at Chott.

Anthropogenic groundwater pollution occurs mainly in the coastal aquifers, which underlie highly urbanised areas where levels of dissolved oxygen in groundwater are low. Despite intensive farming, nitrate concentrations in groundwater generally remain below international standards.
OSS (2004) reported that of seven locations where groundwater salinity has been monitored over a period of ten years or more, the salinity increased in all but one of the locations (e.g. M'Rara). In Algeria, the wells of Oued Rhir and of Ouargla show a clear trend of increasing salinity.
The reuse of wastewater is happening on a reasonably large scale. Of 154 treatment plants operated by 'Office National d'Assinissement' across 44 wilayas, 16 plants are concerned with the reuse of purified wastewater in agriculture. During 2019, a volume of 12.325.269 m^3 of purified water was used for the irrigation of 11,045 hectares of agricultural land.

The salinity issue north west Algeria

In the agriculture sector north west Algeria covering ca. 1 million ha, the salinity issue is a most urgent threat for the agriculture sustainability. For example, the sub-area called "Oued Rhiou" near the lower Cheliff, Gargar and Merdjet Sidi Abed dam reservoirs, is a representative area for the pressing salinity issue.
At this moment the irrigation schemes there use poor quality waters, and the average rainfall and evaporation is about 250 mm/year and 1900 mm/year respectively (Bradai, *et al.*, 2012). The data also exhibits a strong trend for high temperatures in summer which commonly reaches 38°C. The soils there developed from quaternary alluvial material, have

a clayey texture, and commonly have distinct levels of salinity. Light-textured soils, usually found on the upper part of the irrigation areas, are generally not saline (Douaoui *et al.*, 2004, 2006; Bouarfa *et al.*, 2009).

Figure 3-12 Google earth imagery of the Lower Cheliff plain

In the past decade, the non-irrigated barley, oats, common wheat and silage corn were cultivated due to the demand for cattle farms and the attractive price of unpasteurized milk. More recently, with irrigation, Globe artichokes have become the main crop grown in the region along with melons, barley, olive and citrus trees. The local artichoke variety called "Violet de Provence" (*Cynara cardunculus Var Scolymus L.*) is known throughout Algeria to have a distinct flavour and mature early due to climate conditions and the soil. These two characteristics ensure that the product has a high market demand.

The irrigation schemes have already had to face several periods of water scarcity, but the crises were somewhat mitigated by the increase in both public and private tube wells and the increasing use of groundwater. More often, the agriculture water demands are not met according to the National Office of the Irrigation and Drainage data. The allocated water could not be distributed and the consequent shortage in irrigation water constrained the farmers to use more groundwater. A secondary salinization process of top soils due to human activities has been observed here as in other parts of these plains (Cheliff, Habra, Mina, Macta, etc …), resulting in biodiversity losses and decreases in crop yields (Bouarfa *et al.,* 2009).

It was found that local farmers have become more familiar with techniques and strategies to mitigate salinity effects, e.g., the mixing of surface waters with ground waters, the introduction of salinity tolerant crop varieties and a smart use of sloping lands have been observed to give good results (Hartani *et al.,* 2012). However, farmers find it difficult to perceive the long-term risk of changing the irrigation water source from surface to groundwater, like the increase in soil degradation hazard (Bradai *et al.*, 2012).

3.1.5 Developments in irrigation and production

In the North, crops are irrigated from dams or reservoirs and in the South from deep boreholes that extract groundwater from (often overexploited) aquifers. Large irrigated

crop areas are usually managed by the National Office of Irrigation and Drainage and small and medium cultivated surfaces are generally run privately. Gravity irrigation is still the most used irrigation method in small and medium-scale farms.
Several studies and pilot projects have been carried out in the last years to research the possible positive impacts of innovation in the agricultural sector. E.g., potatoes are generally irrigated via pivot or sprinkler irrigation that, when not functioning optimally, waste significant amounts of water (Serbi, 2016). With modern subsurface drip irrigation the water savings can be increased by around 50%. Blom-Zandstra & Michielsen (2020) described in their study that the introduction of subsurface irrigation increased potato yields significantly and also the water use efficiency in their demonstration pilot. The Algerian pilot was received very positively; however, the adoption rate of the new technology was low, but is expected to increase with financial and societal support. From observations in the Dutch DELTADRIP project with high water savings and yield improvements, it was found positive that drip irrigation also does need not to be more labour intensive since the installation of driplines can be done at the same time as the plantation.

Since 2001, production in greenhouses has increased from over 4,300 ha to over 15,800 ha in 2018. Protected cultivation on the edge of the Sahara is increasing: from 1990, greenhouse production in Biskra, an oasis area on the edge of the Sahara, 450 km southeast of Algiers, has increased sharply, mainly due to relocation or the expansion of horticultural businesses from the North. This has become the most important horticultural area in the country with more than 40% of the total area of greenhouses in Algeria. There is room for new greenhouses in Biskra and there is room for modernization since most of the greenhouses are still polytunnels.

Since 2009 the introduction of the canarian type greenhouse has ensured better yields and since then the share of this type of greenhouses in Biskra alone is 2000 ha. This greenhouse is an improvement compared to the usual polytunnels since it is more resistant to wind and it is often combined with drip irrigation.

3.2 Water governance

An overview of the relevant water and agriculture policies and supportive governmental programs are elaborated in the following chapters.

3.2.1 National and regional plans, policies

Algeria has chosen to move towards a new model of agricultural economic development that aims to promote growth, diversification, and create jobs and is able to increase self-sufficiency and decrease import dependency through enhancing current production practices. To reach those objectives, Algeria intends to close current gaps by initiating research, stimulate knowledge and technology transfer, in particular to improve sustainability (Arous *et al.*, 2013; Ayad *et al.*, 2020), setting up consistent structures for evaluation and exchange (Bernaoui and Hassoun, 2011), and improving on certain restrictions for the proper development of the water-agriculture sector (Ayad *et al.*, 2020; Laoubi & Yamao, 2012).

The new economic model sets a new course for the country's economic policies, by redefining objectives and priorities and by changing the mechanisms and modes of economic trade-offs with regards to the resource-allocation issue. Economic growth, job creation, but also food security, hydraulic security and energy transition are among the priorities of this new development model.

3.2.2 Important Governmental programs

The Ministry of Agriculture and Rural development (2020) has two major supportive programs: The so-called *priority program* (2021) and the *transversal and continuous program* (2020-2024).

The Priority program concerns:

1. The development of Saharan agriculture, through the enhancement of existing potential, the extension of areas with proven potential, the development of industrial crops in the South (corn; soybeans, sugar beet, etc.) and the creation and implementation of effective action by the National Office for the Development of Industrial Agriculture in Saharan Lands (ODAS);
2. The development of mountain areas through actions allowing the improvement of the living conditions of the populations and the reinforcement of the actions of opening up of the isolation by the opening and the development of agricultural tracks, the mobilization of the water resource, the tree planting and the creation of small breeding units, especially for young people;
3. The development of hardy species, including the carob tree and the argan tree, in the various agroecological zones of predilection (mountains, highlands, steppe and the south);
4. Agricultural electrification by supplying electric or renewable energy to farms and development areas through, on the one hand, the current program (even if a significant part is affected by the freezing measure), and on the other hand, farms requiring a connection, recently pre-identified especially in the South, following the census launched in May 2020;
5. Rational exploitation of agricultural land by developing land, securing operators, simplifying and facilitating access procedures to agricultural land and the recovery of unused land;
6. The extension of irrigated areas and the promotion of water-saving systems, essential for increasing production and productivity, particularly of cereals as well as in terms of rational management of water resources and use supplemental irrigation, particularly in the eastern wilayas;
7. Strengthening the logistical base for the regulation and promotion of agricultural production;
8. Digitization, strengthening of the information system and the fight against bureaucracy by simplifying and improving administrative procedures,
9. Support for professionals through the cooperative system for better organization

The transversal and continuous program concerns:

1. The modernization of agriculture by strengthening the value chain of the plant, animal, forestry, pastoral and regional products sectors;
2. The strengthening of human capacities and technical assistance, intended for all actors in the sector, manager or producer, by improving knowledge, popularization, technical and scientific supervision, innovation and transfer. technologies, and finally research;
3. The strengthening of phytosanitary systems in terms of phytosanitary and phytotechnical control, the protection of plant varieties, the strengthening of diagnostic capacities and the establishment of an information system for phytosanitary services as well as the fight against the desert locust;
4. Strengthening veterinary health systems for the protection of the national animal heritage against contagious diseases. Animal health control and animal products at borders. The development of an Algerian veterinary information and communication system, and the establishment of a cattle identification system;
5. The sustainable preservation of natural resources, in particular water and soil, particularly through the restoration of forest and pastoral areas, the promotion of renewable energies and water-saving systems and the fight against desertification;
6. The strengthening and continuous adaptation of the legislative and regulatory framework;
7. Improving accessibility to financing and the management of public funds, in particular through the establishment of Microcredit (Crédit Mutuel Rural), the diversification of financial institutions, the targeting of State support and subsidies, revival of social coverage for farmers and breeders and promotion of agricultural insurance, including agricultural disaster.

As stated, the importance of the agricultural sector for the society and economy of Algeria is significant. With the expected increasing climate change impacts the Algerian government seeks to support its development. It does so by providing grants or favourable loans or other incentives. Important incentives are given below.

- Companies can obtain grants or favourable loans of up to 90% of the investment amount. The main focus of investments is however in the arid south of Algeria, where an increase in use of non-renewable fossil groundwater lowers sustainability and longer-term viability.
- Discounts are offered for purchasing the following: 25% fertilizer discount, 20-30% machinery discount, 20-30% irrigation systems discount (Houben, 2017).
- The Ministry of Agriculture established the fund called *The Regulatory System for Agricultural Products of Large Consumption* or *Le Système de régulation des produits agricoles de large consommation (SYRPALAC),* aiming to support growers to store their potatoes (during times of scarcity) and support seed potato production financially. This support is subjective to certain restrictions (water and fertiliser use) and regular QC (product and sanitary conditions) of *the National Center for Seed Control and Certification* or *Centre national de contrôle et de certification des semences (CNCC).*
- Once assessed and permitted by the Wilayas' *The Department of Water* or *Le Direction de hydrolique* new wells can be established by farmers and water pumped up is for free (Houben, 2017).

To a degree, also water and energy are being subsidized, all in all making the farmers unaware of the costs. This slows down the push for creating new applications and reach more sustainable water-agri practises, which the government seeks to obtain in the light of increasing impacts due to climate change.

3.2.3 Implementation and Water Resource management

With regard to the water resource management in Algeria the key expert and stakeholders' interviews interest most urgent was found the governance of *large irrigated perimeters* or *Grand Périmètre Irrigué (GPI)*, the low irrigation efficiency in relation to the sustainable water resource management and the hydric security. Currently, water losses of 40% through the transport from the dam to the head of the distribution irrigation pipe are common.

Important outcomes of WRM consultations were foremost on the:

- *Mastering the water support*. The scarcity of water makes controlling its mobilization, preservation, use and development a major issue. This issue implies for the country the imperative need to continue the effort in terms of:
    - i) control of information in real time, on the availability of resources and withdrawals.
    - ii) mobilization of the necessary financial means, including alternative financing, for investments in infrastructure and rationalization of their use.
    - iii) mastery of the most innovative technologies to improve the technical efficiency of the water production / distribution system and.
    - iv) mastery of the economic management of the system mobilization, production and distribution of water, in order to reduce the cost of water.
- *Mastering the water demand*. Controlling demand will ultimately be the main adjustment variable for the water equation. It involves the eradication of all forms of water wasting, including the undervaluation of the resource, in all sectors. Controlling demand involves:

i) controlling the quantification of demand and its evolution by type of use and by territory,

ii) identifying and implementing appropriate and effective economic incentives and institutional changes to rationalize the use of water and

iii) the establishment of a water allocation system favouring, among the economic uses, the most efficient.

- *Disconnect the economic growth from the water section in the long term.* Building an economy whose growth is resilient to the relative scarcity of water is one of the country's main challenges for the coming decades. In addition to controlling water supply and demand, it is a question of making new economic choices, which would make it possible to replace economic activities that consume a great deal of water by others that consume less. Developing an exit strategy from an economic model that is significantly based on water is particularly crucial in areas where the available resources are overexploited and / or non-renewable groundwater.

With regard to the hydric security.

- *Rethinking the water allocation system with a better economic rational.* The balance between supply and demand can be equilibrated by matching the cost of water with its value. Real-cost pricing should be seen as an appropriate way to impose rigor on different users so that they moderate water use, but also provide the right incentives for water producers and distributors, in terms of water use. The investment and quality of services and the transition to this type of pricing should be guided by the following general principles: i) guarantee the transparency of pricing rules for all stakeholders, ii) give priority to water billing in the quantities withdrawn, iii) reflect in the price the operating, environmental and scarcity costs, taking into account territorial differentiations, iv) guarantee the financial autonomy of water producers/distributors to encourage them to minimize costs and make the necessary investments, v) disconnect water pricing from public aid mechanisms for paying water bills (for example: target subsidies to disadvantaged households) and vi) use mixed pricing with the quota system for irrigation from groundwater, especially in areas where resources are scarce.
- *Maintain the effort of investing in water mobilization and diversifying the financing sources.* The investments made, especially over the past two decades, have made it possible to considerably increase the capacity to mobilize and supply water. It is important that Algeria continues its investment efforts in the mobilization of surface water, in order to mobilize the maximum of its water potential. The investment effort should not be limited to conventional water, but should also allow the production of unconventional water, in particular treated wastewater. This investment effort should no longer only be supported by the public capital, but alternative sources of funding must also be mobilized. The choice of investment solutions must take into account both capital costs and operating costs, in particular the choice to use less energy-consuming technologies. The gradual move towards the application of water pricing that corresponds to the average cost of production will allow recourse to bank financing (national or international) and the involvement of the private sector in this effort to be considered.
- *Enhancing the governance of water production and use.* The investment in infrastructure alone does not guarantee water security. It is imperative to ensure the efficiency, hydraulic and economic, of the entire water production and distribution system.
- Improving the methods used by operators in charge of water production/distribution and improving their technical and economic performance will lead to considerable

savings, which will positively impact the actual availability of water. The current regulations provide for principles of a system of governance; however, given the scarcity of water, it is imperative to: (i) control information on water (declared and unreported supply and withdrawals); (ii) set up a system to control and avoid unreported water withdrawals ; (iii) set up mechanisms for the involvement of the territorial authorities in the application of the control measures for withdrawals and payments provided for in the 2005 law; (iv) strengthen the independence and financial autonomy of the regulatory authority and operators.

3.2.4 Targets and forecasting water needs

Allocation of water resources by type

The actual water potential for irrigation and the projected needs are presented in Table 3-3 and Table 3-4. In Table 3-3, the volumes expressed in billion m^3 are detailed according to the origin of the water: surface water collected in dams, groundwater and treated waste water (MRE, 2017). Groundwater is the main water resource and should increase in the horizon 2035 approaching 8 billion m^3. An effort from the authorities is planned concerning the use of treated wastewater in agriculture.

Table 3-3. Water needs in large and small irrigation perimeters according to the water origin (MRE, 2017)

Planning Horizons	Type of resources - Volume (in billion m³)			
	Surface water	Groundwater	Treated wastewater	Total
Actual	1,82	4,90	0,06	6,78
Short term	0,56	1,08	0,03	1,67
Middle term	1, 00	1,50	0,21	2,51
Long term	0,38	0,5	0,10	1,18
Total	3,76	7,98	0,40	12,14

Water resource allocation by type in irrigation

Table 3-4 shows the irrigation water changes allowed for the large irrigation perimeters (LIP) and the small and medium hydraulic (SMH) according to the state agencies projections (MRE, 2017). The small and medium irrigation areas will consume the largest volumes of water, nearly 8,4 billion m^3, indicating the predominant role in the future of small agriculture based on groundwater pumping (Kuper *et al.*, 2016).

Table 3-4 Water needs in large and small irrigation perimeters (MRE, 2017). LIP : large irrigation perimeters and SMH : small and medium hydraulic.

	Water needs (in billion m3)			
	Actual	Short term	Middle term	long term
LIP	1.520	1.750	2.55	2.610
SMH	5.260	6.700	8.410	9.530
Total	6.780	8.450	10.960	12.140

The of the irrigation sector problematic in Algeria

The diversity of the institutions in the water resources sector in Algeria and the poor coordination between them still constitute a barrier for the development of an integrated approach. This situation leads to many gaps between hydraulic structures and the perimeters they made for.

Additionally, the reduced price of the mobilized water to pay by the consumer (farmers) compared to its real value has a negative consequence on the quality of services in the GPI area, because of the fact that the mobilized water is subsidized by the state (2.5 DZD/m³ while the real costs are around 5 - 7 DZD/m³ respectively 1.5 vs real cost of 3 -4.5 eurocent)

Water tariffs and development

The tariffs applicable in the irrigated perimeters are set in accordance with Table 3-5. In Table 3-6 the development of water tariffs since 1985 is presented.

Table 3-5. Tariffs applicable in the irrigated perimeters (Executive Decree n05-14, January 09, 2005). (on feb 2021, 160 DZD is equiv. To ca. €1).

PERIMETER	Wilaya	Volumetric price (DZD/m³)	Fixed price (DZD/l/s/h)
Sig	Mascara	2,50	250
Habra		2,50	250
Mina	Relizane	2,00	250
Low Cheliff		2,00	250
Middle Cheliff	Chlef	2,00	250
Upper Cheliff	Ain Defla	2,50	400
Mitidja Ouest	Blida - Tipaza	2,50	400
Hamiz	Algiers — Boumerdes — Blida	2,50	400
Guelma Bouchegouf	Guelma	2,50	400
SafSaf	Skikda	2,00	400
Bounamoussa	El Tarf — Annaba	2,50	400

The water prices applying in the other perimeters are:

1. Volumetric price: 2,00 DZD per cubic meter upstream the plots
2. The price is fixed to 250 DZD per subscribed hectare.

Table 3-6 Price development since 1985 in Algeria

Year	Water price DZD/M³	Fixed price (DZD/l/s/ha)
1985	0,12 à 0,17	150 à 200
1988	0,35	150 à 200
1993	0,80	150 à 300
1995	1 à 1,25	250 à 400
Since 2005	2 à 2,50	A 400

The actual water price

The actual pricing by the Executive Decree no. 7-270 of September 2007 is still very low and apply only in large public irrigation perimeters (Table 3-7). The small and medium hydraulic perimeters are not included in this pricing. A revision of the prices is currently under study, and a tax for drilling is also forecasted.

Table 3-7. Water cost price of water DZD per m3

Networks	Mean price	Tarif	Coverage (rate/costprice)
By gravity	5	2	40%
By pumping	8	2,50	32%

3.3 Exemplary developments and inspiring partnerships

3.3.1 Sector innovations through the Biskra and Tipaza case studies

Several new production systems have been trailed and adopted in and around Biskra and Tipaza. We report here on some of them as exemplary for current developments.

"smart irrigation" at CRSTRA (Research and Scientific Center for arid regions).

The production system adopted by the Tahraoui family farm is exemplary. This investor, involved in hydro-agricultural equipment[1], produces early market vegetables, in particular cherry tomatoes. These grow inside multi-chapel greenhouses on extra soil and using modern heating, irrigation and fertilization techniques. The agricultural group is promoting the "clean agriculture", and was awarded the prize for best producer, conditioner and exporter of agricultural products by the FAO.
Clean agriculture is based on the following practices:

- Use compost, made from waste of palm-date farmers.
- Use crop rotation system to reduce diseases, thus reducing the use of phytosanitary treatment "chemicals".
- Use mulching in addition to saving water, it reduces the germination of weeds, therefore reducing the use of herbicides.
- Use biological control practices e.g., pheromone traps, coloured traps, etc..
- Use bio-pesticides.
- Use water-saving irrigation systems with irrigation management.

The latter system was awarded the first prize for innovative projects in the field of irrigation in Algeria for the year 2019.

"Canarian Greenhouses" at Agrotins agriculture services society

Abdallah, a young farmer and investor at Agrotins is specialized in the hydro-agricultural services, in combination with Canarian Greenhouses. Over the last two decades, more than 1800 ha is covered by this kind of greenhouses in the Biskra area. Initially, greenhouses covered larger areas, 2 to 4 ha per greenhouse. Today they install small greenhouses (1/4 ha, ½ ha to 1 ha) to better control the climatic parameters inside the greenhouse. All kind of vegetables are planted inside the Canarian greenhouses, in particular tomato and sweet melon. The crops are irrigated using drip irrigation technique, the mulching is systematically used. For the fertilization, a traditional method is used to inject the fertilize solution into the irrigation system. Some farmers had opted for the installation of conventional head stations, but the inexistence on the market of simple fertilizers makes it difficult to use (all available fertilizers are composed of NPK elements at different percentages).

[1] http://www.groupetahraoui.com/#/

The heating of greenhouses constitutes a handicap for the Canarian greenhouses. Although a traditional technique of diesel heating is used by some farmers, recent frosts in Biskra area (January 2021), affected more than 30% of the cultivated area.
The pollination by bumblebees imported from EU inside Canarian greenhouses is used. Recently, due to CIVID restrictions, local entrepreneurs started the reproduction of this type of bees.

"new entrepreneurship" of Tipaza farmers chamber

Tipaza district can be divided into 3 agricultural zones: The South zone which belongs to the West Mitidja whose main speculation is arboriculture and in particular citrus fruits. The coastal zone characterized by market gardening, especially early vegetables and the western zone characterized by mountain agriculture requiring a lot of intervention for its development.
The Tipaza farmers chamber incorporation with *the renewable energy centre* or *le Centre de Développement des Energies Renouvelables* (CDER) initiated several businesses like the:

- the production and extraction of essential oil in the municipality of Mered.
- developing the Beekeeping sector in Douaouda.
- Improving the Rabbit sector in Sidi Ghiles, from breeding to catering.
- Production of 'Roticides' rodent control product based on organic products.
- Production of organic fruit and vegetables.
- Plum drying (the municipality of Aghbel with ca. 160 Ha of plum plantation.
- Vegetable and fruits by photovoltaic cells for family farm size setups.

3.3.2 Water- agriculture partnerships

Many local companies and start-ups are ready to engage in the process of making visible an innovative solution (Agriholdings and companies above but also Ouartsi holding, etc.)
The interventions of the Dutch partner in the Biskra Zone took several forms:

- ORIO project which was intended for the preservation and development of Chott Melghir (South of Biskra and wilaya of Oued Souf) through the proposal of methods to fight against salinity. The project aims to protect groundwater, agricultural land and also biodiversity (the Chott classified as a wetland).
- A training project was carried out in the Biskra area on market regulation.
- A project related to subsurface irrigation technique carried out in El Oued
- The Grow Algeria group: A nursery created by Algerian, Tunisian and Dutch partners. PROFERT-agri (an Algerian company whose main activity is the supply of inputs to agriculture) acquired the participation of the Algerian partner.

4 Morocco

Table 4-1. Summary table for Morocco

Country overview	Morocco
Water availability and use	- 22 BCM renewable water sources. -The north receives up to 800 mm of rain annually, in the south ca. 100 mm, with large differences between years. - 145 large dams with a total storage capacity estimated at 18.6 billion m³, and 14 other dams under construction with a total storage capacity of 3.2 billion m³, which will bring the storage capacity to 21.8 billion m³. -Irrigated agriculture accounts for 15% of the agricultural production. Around 40% of the irrigated agriculture uses groundwater as a water source.
Future water availability	-Recent studies show that precipitation can be reduced by 10 up to 50% in the most important agricultural areas by 2100. -Reducing surface water volumes will increase pressure on groundwater use. In many locations groundwater level is dropping as a sign of overuse. -Water demand is expected to increase.
Water quality (salinity)	-Water quality is decreasing in Morocco, especially that of ground water and aquifers. Salinity levels are increasing due to sea water intrusion and natural salinisation. -In general, upstream basin areas has a good water quality; downstream (e.g., coastal and agricultural areas) areas have poor water quality. -Saline water is used in agriculture where it is the only water source available though, and because this is an ancient problem, farmers have some experience in how to deal with it. However, there is still considerable room for improvement.
Irrigation types	Only about 15% of the agriculture in Morocco is irrigated, but this 15% produces around 40% of the agricultural outputs. Much of the land is irrigated by furrow irrigation, but a transition is happening towards drip irrigation.
Trends in irrigated agriculture	-The top three products (wheat, barley and olives) are produced under rainfed conditions. -Irrigated agriculture is increasing in Morocco. In the Souss region, around 80% of the farmers use drip

	irrigation, which has been accomplished through subsidies that were part of Le Plan Vert. -The Green Generation plan will invest in a further transition towards the use of more drip irrigation.
Trends in greenhouse cultivation	-The use of greenhouses is increasing. -In the Souss region, there are even greenhouses using soil-less cultivation, even though the total area is still relatively small, the high water use efficiency and productivity is recognized and future investments will be made to increase their surface area.
Trends in livestock	-The number of heads of cattle in Morocco is increasing. -The number of sheep is increasing, while numbers of horses and camels are decreasing.
Water productivity & efficiency	The water use efficiency in general is low. One source states that only 40% of the applied water reaches the crops. Drip irrigation is promoted and used more and more.
Trend in governance	The government is actively promoting and supporting agricultural developments. For the past ten years the "Plan Maroc Vert" has been implemented with success and a new ten year plan is being developed.
Water pricing	In some cases farmers pay a volumetric water fee, but no specific information is known at present.
Focus regions: Souss/Masa and Fez/Meknes	The Souss region, in the south-west of Morocco, has a semi-arid climate, with average annual rainfall not exceeding 250 mm. The region ranks first in production and export of citrus fruits and fresh vegetables. Irrigated agriculture covers nearly 120,000 ha, relying mostly on groundwater (72%). At present, groundwater is overused and plans are made to improve water use and the water use efficiency. The Fez-Meknes region features an aquifer system of major socio-economic importance due to its contribution to the supply of drinking water to the region, and because of its importance in the development of the agricultural sector. However, the level of this and other groundwater falls on average with 3m/year due to overexploitation. The agricultural sector is a very promising sector and is referred to as the fruit basket of Morocco.

4.1 Water and agriculture

4.1.1 Topography and climate

Morocco's geography is characterized by mountains: The Rif, High Atlas, Middle Atlas, and Anti-Atlas (Figure 4-1). The mountainous areas with bordering plateaus distinguish Morocco from its neighbouring countries. The mountains play an important role in the country's climate as they serve as natural barriers against the extreme climatic conditions of the Sahara (Alterra, 2012). The coastal plains have fertile soils and are the main location for agricultural production.

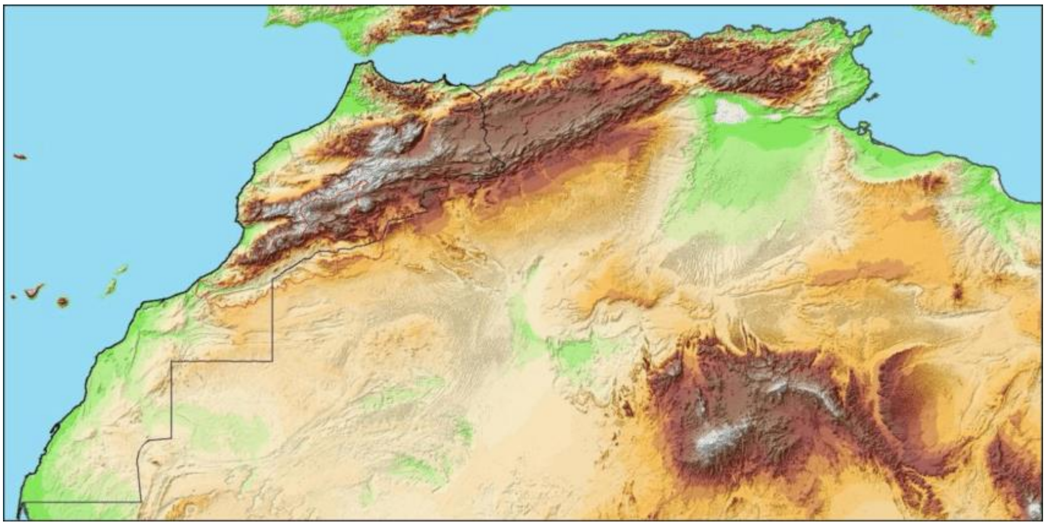


Figure 4-1. Topographical map of north eastern Africa and borders of the Moroccan country indicated with dark grey line. Adapted from Bouman (2009).

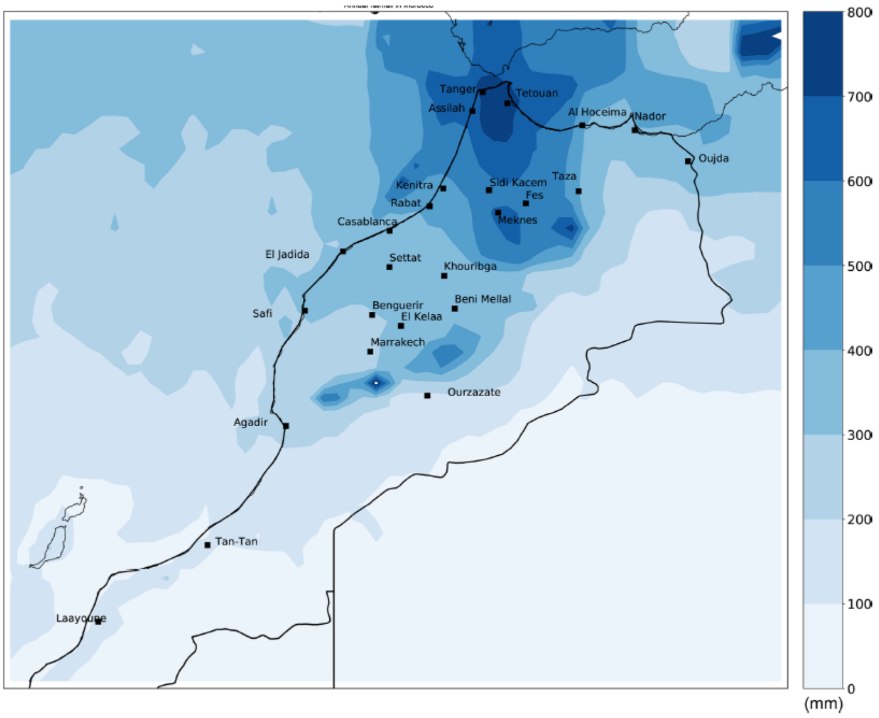


Figure 4-2. Annual precipitation (in millimetres) in the central and northern part of Morocco using Tropical Rainfall Measurement Mission (TRMM) data. Source: El Mocayd et al. 2020.

The precipitation over Morocco shows strong spatial variability. Figure shows the annual mean precipitation over Morocco (based on TRMM (Tropical Rainfall Measuring Mission) data). The annual precipitation reaches 800 mm/year in the north, whereas the south barely receives 100 mm/year. As a result, only the north-western part of the country enjoys an excess water supply. However, there is large inter-annual variation. The unequal temporal rainfall distribution results in irregular water flows, which led to the construction of large dams and reservoirs for water storage in dry periods (Alterra, 2012).

There is a clear global warming trend in Morocco. According to several studies, climate change would induce a warmer and drier climate. From 1961 to 2016, Morocco has faced a decrease in cold days, an increase in hot days, and a rise in average temperatures and heat waves (Figure 4-3). The warming was accompanied by a decrease in total rainfall and an increase in the maximum number of consecutive dry days. Current projections for climate change suggest an increase in the frequency, intensity and duration of droughts accompanied by a decrease in precipitation (Figure 4-4) resulting in significant impacts on the food, water, energy and health sectors. Climate change is generating losses estimated at an average of 362.3 million dirhams/year (± 33,5 million euros/year), with estimates varying between 241.5 million dirhams and 483 million dirhams/year.

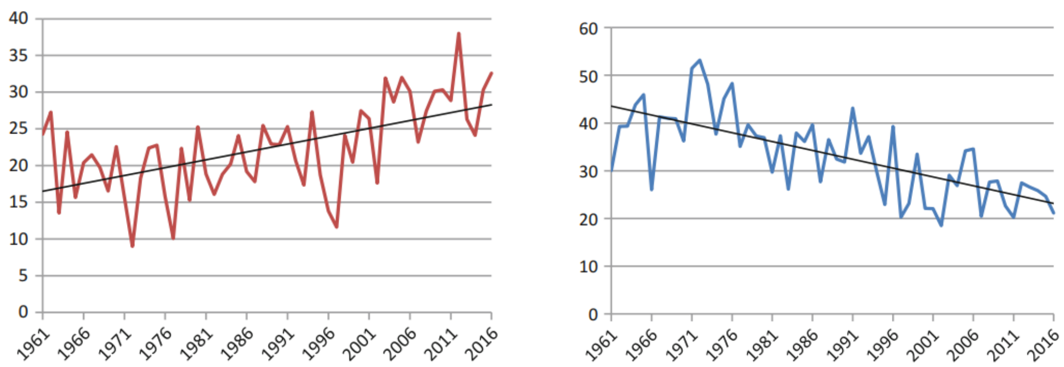


Figure 4-3. Left: Number of hot days per year in Morocco 1961-2016. Right: Number of cold days per year in Morocco 1961-2016. Source: Ait Kadi and Ziyadd, 2018.

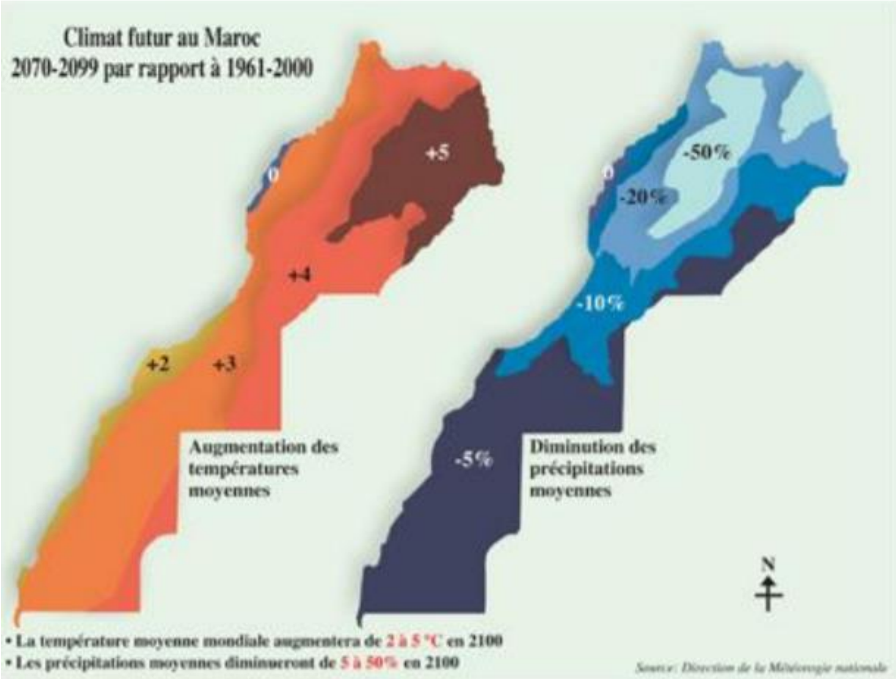


Figure 4-4. Regional differences in anticipated climate change impacts in temperatures (left) and precipitation (right). The numbers in the maps indicate the projected change in percentage by 2100. Source: Direction de la meteorology national.

4.1.2 Landuse and agro-ecological zones

In general, there are three climatic zones in Morocco that determine the agricultural suitability:

1) The coastal plains and plateaus with a mild climate and fertile soils. Here mainly cereals and vegetables are produced.

2) The Rif- and Atlas Mountains (highlands). These are characterized by a mild climate with colder temperatures and sufficient rainfall. Here a diverse agriculture is present with pasture (crop and livestock) and forest areas.

3) The southern part of the country has a desert climate. There are some oases where dates are being cultivated (Alterra, 2012).

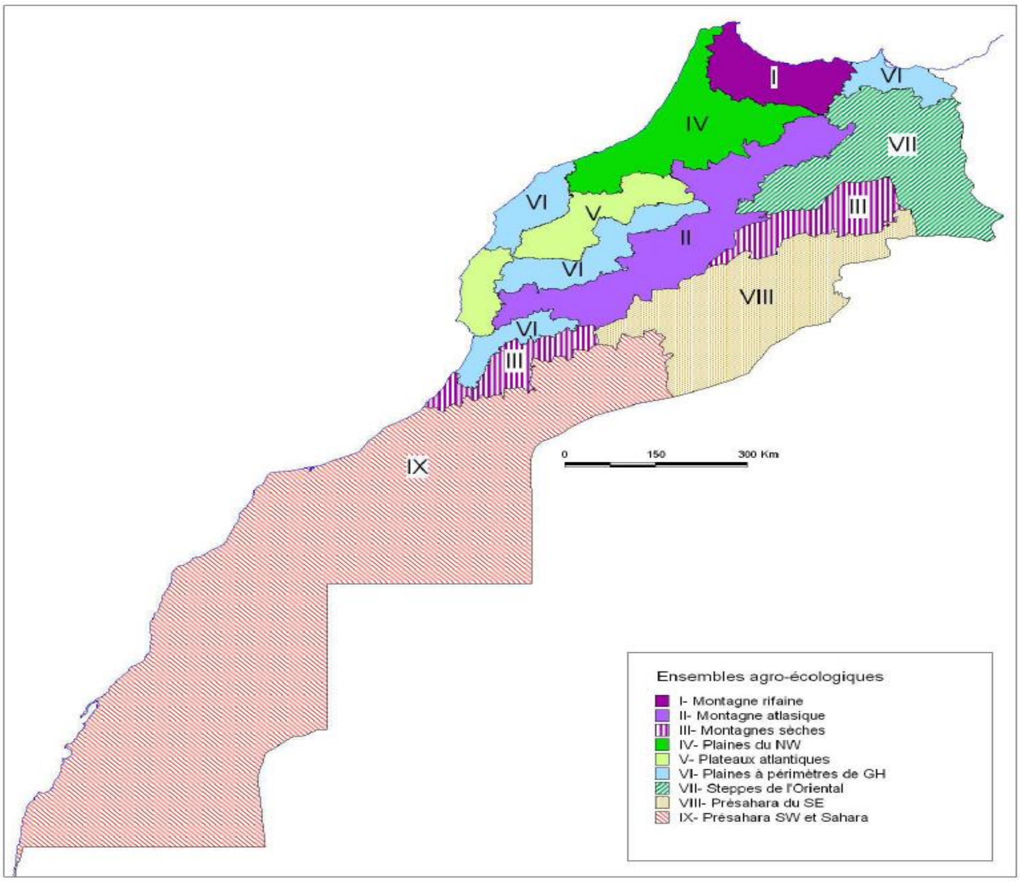


Figure 4-5 The 9 Agro-ecological zones as presented in the Agricultural Atlas of Morocco (CGDA, 2009).

Water use efficiency in agriculture

For most of the river basin the efficiency of water use in agriculture is very low, with the exception of the Souss Massa River basin, where more than 80% of the irrigated area is using drip irrigation and large farms are using new technologies to pilot their irrigation (humidity sensors, solar radiation daily measurements, etc). In the Souss Massa the drainage water is reused within some farms using soilless culture. It is estimated that the total area where this type of cultivation takes place is around 300 ha.

Irrigated agriculture

Irrigated agriculture plays a major role in the national and regional economy as it stimulates both the production of wealth and the creation of jobs. In fact, irrigated agriculture in Morocco, although it occupies only 15% of the total area under cultivation, contributes around 45% on average to agricultural value added and accounts for 75% of agricultural exports. This contribution is greater during drought years when production in rainfed zones is severely affected. During the 1994-1995 campaign, a dry year, this contribution amounted to 70% of this added value. Figure 4-6 shows the evolution of irrigated agriculture in Morocco.

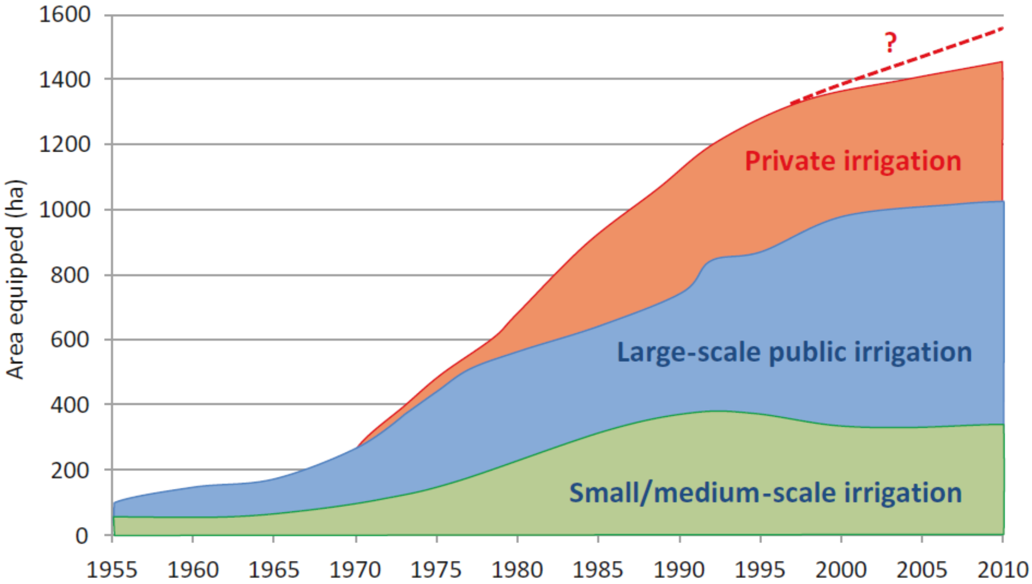


Figure 4-6. Evolution of the areas equipped for irrigation. From Molle *et al.*, 2019. Source: Various official reports, the area under private irrigation has been drawn approximately, based in intensive phases of well drilling reported during the dry years of the early 1980s and early 1990s.

The Ministry of Agriculture states that the irrigated sector contributes on average 99% for the production of sugar, 82% for vegetable crops, 100% for citrus fruits, 75% for fodder and 75% for milk. In addition, this sector provides nearly 120 million working days per year, or approximately 1,600,000 jobs, of which 250,000 are permanent. Additionally, farmers' incomes have improved, which have been multiplied by a factor of 5 to 13, depending on the perimeters.

This has been accomplished through some of the investments made in Le Plan Vert (see below). The positive effects that these investments have caused can serve as an example for the other Maghreb countries to boost the local economy, create jobs and improve the livelihoods of farmers. Figure 4-7 shows the areas where irrigated agriculture is concentrated.

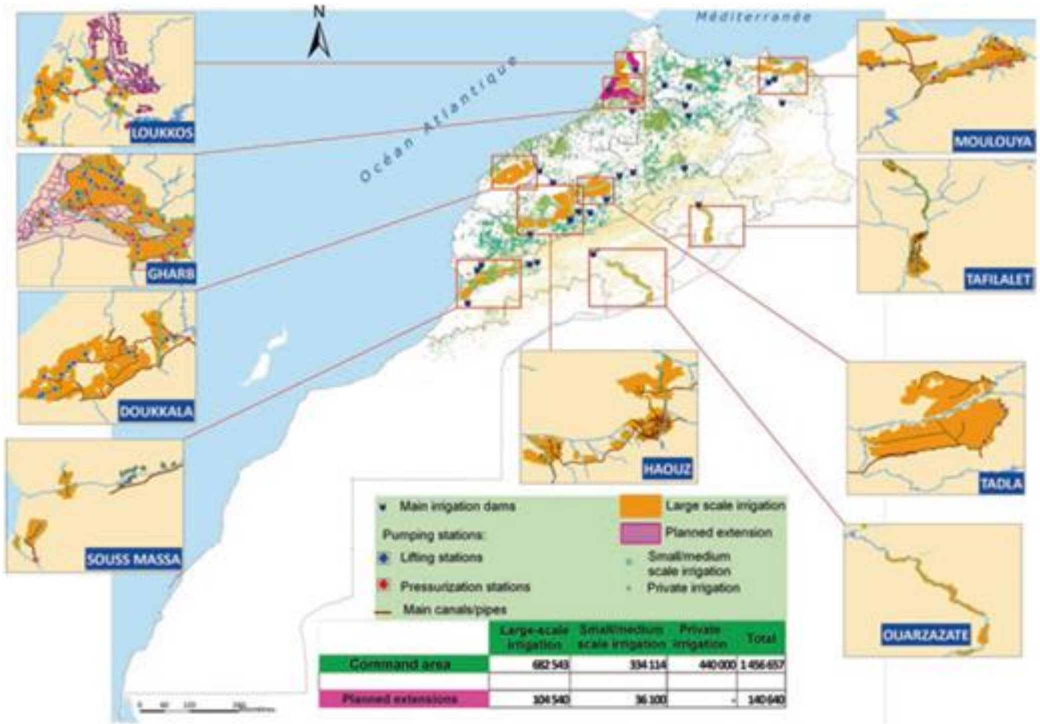


Figure 4-7. Main irrigated areas in Morocco. (Adapted from Molle et al. 2019).

4.1.3 Agriculture and crops

The main crops grown in Morocco are shown in Figure 4-8. The top ten crops grown by cultivated area averaged over 2016-2018 (latest available data on FAOSTAT) are compared with the top ten crops grown ten years before that (i.e. 2006-2008). The numbers above the bars indicate the yield in t/ha. Table 4-2 shows the trends in area cultivated and in yield over the ten years presented here.

The top three crops have remained the same over the ten-year period. The fourth crop in 2006-2008 was maize (corn) whereas ten years later this was almonds. The cultivated area of wheat and olives has increased, but barley is cultivated on a much smaller area currently. Yields of all but chickpeas have increased (no data available on tangerines, mandarins, clementins, satsumas, the only newcomer in the top ten). The area cultivated with lupins and olives have increased significantly, both are crops that are grown under rainfed conditions (except some exceptional cases of olives, which are in rare cases produced under irrigated conditions).

The top three crops are all produced under rainfed conditions, as usually are also maize, broad- and horse beans and almonds. Only the citrus fruits, i.e. oranges in one category and tangerines, mandarins, clementins, satsumas in another category are always produced under irrigated agriculture, as well as most of the vegetable cultivation.

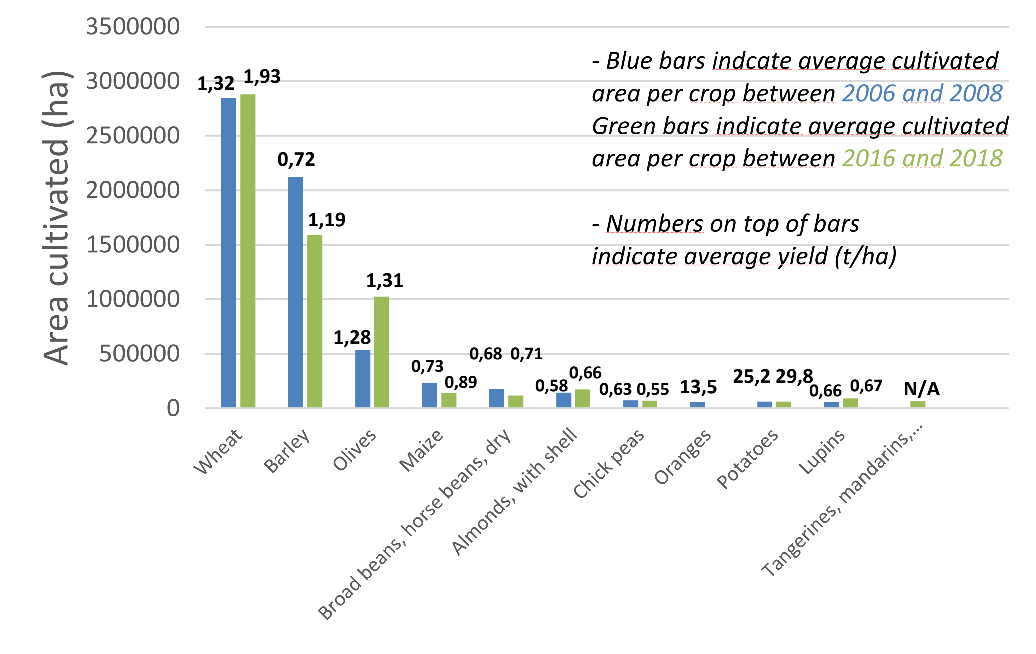


Figure 4-8. Top ten crop production in Morocco 2006-2008, compared to the top ten crop production ten years later (2016-2018). Bars indicate the total area cultivated in ha, numbers on top of the bars indicate the average yield in t/ha over the respective periods. Data from FAOSTAT (2016-2018 most recent available data).

The changes in crop production area and yield in the ten years between 2006-2016-2018 are shown in Table 4-2.

Table 4-2. The changes in cultivated area and yield of the top ten crops of Morocco as shown in Figure 4-8. Ranking is based on the mean cultivated area in hectares over 2016-2018.

Crop	Change in area over ten years (%)	Change in yield over ten years (%)
Wheat	1,2	46,1
Barley	-25,0	65,1
Olives	92,0	1,8
Almonds, with shell	21,0	14,3
Maize	-39,6	21,8
Broad beans, horse beans, dry	-34,0	3,2
Lupins	59,2	1,3
Chick peas	-4,3	-12,4
Tangerines, mandarins, clementins, satsumas	N/A	N/A
Potatoes	3,0	18,3

Box 1. Citrus in the Souss region

The Souss region, in the south-west of Morocco, has a semi-arid climate, with average annual rainfall not exceeding 250 mm. The region ranks first in production and export of citrus fruits and fresh vegetables. Irrigated agriculture covers nearly 120,000 ha, relying mostly on groundwater (72%). Because of a succession of droughts the region has been experiencing since 1985, the annual recharge of the aquifer does not exceed 40 million m3, compared to 650 million m3 withdrawn annually. The decline of the water table has consequently been dramatic: two to three metres per year. This situation has forced many farmers to uproot their citrus orchards, especially in the Elguerdane area (3750 ha, representing 38% of the total citrus area).

Safe the citrus

The state and the regional authorities have developed a comprehensive programme for the development and management of water resources in the Souss region. This programme is based on two major columns. Conjunctive use of groundwater and surface water. This is made possible by the development of the Elguerdane large-scale collective irrigation project. It is a pioneering public–private partnership for irrigation development and management in Morocco in the form of a 30-year build-operate-transfer contract. Its main objective is to supply an additional 45 million m3 of surface water to preserve citrus orchards threatened by rapidly sinking groundwater levels in the Elguerdane area (10,000 ha). It consists of a reservoir and piped conveyance and distribution systems supplying a portion (50–70%) of the irrigation water requirements to farms, to be used conjunctively with groundwater. Citrus farmers have subscribed to the project on the basis of their agreement to use exclusively drip irrigation, contribute 40% of the investment cost, and pay a volumetric water fee, as defined in the public– private partnership contract.

Table 4-3. The top ten crops cultivated in the Fez-Meknes region.

Crop (group)	Area cultivated (%)	Area cultivated (Ha)
Cereals	50,46	710.340
Olives	25,42	357.931
Legumes	6,91	97.216
Forages	5,99	84.350
Almonds	2,62	36.899
Vegetable crops	2,4	33.854
Fig trees	1,77	26.277
Apples	1	14.032
Oil crops	0,61	8.578
Peach-Nectarines	0,6	8.422

Protected agriculture in Morocco

Protected cultivation is expanding in Morocco (also in Algeria and Tunisia), because it is recognized that it is a more water use efficient farming technique. In Morocco, protected cultivation is based on unheated greenhouses. The area of protected agriculture is estimated at 26,000 ha including vegetables, cut flowers and fruit crops. At present, the protected cultivation industry is moving from the northern to the southern part of Morocco. Strong competition within the Mediterranean countries is forcing the plasticulture industry in Morocco to look to the development of a new greenhouse structure as well as new agro-technologies to improve the quality of production at lower costs. Improvements in the last decade in the protected culture operation and technologies include fertigation, the use of long shelf-life cultivars, bumblebee pollination, geothermal heating, mulching, substrates culture, and integrated pest management. These new improvements are becoming recognized as regular greenhouse practices.

Box 2 The Agriculture sector in the Region of Fez-Meknes

The Fez-Meknes region has a population of ca. 3 million, 72% in urban areas and 28% in rural areas. This basin features an aquifer system of major socio-economic importance, due to its contribution to the drinking water supply of the cities of Fes, Meknes and neighbouring agglomerations, and to its role in the development of the agricultural sector.

A succession of annual droughts since the 1980s and anarchic use of water has led to the groundwater overexploitation. Annual figures for the Fes-Meknes water table show a shortfall of around 100 Mm^3/year. This shortage is translated by a continual drop in the piezometric level (average of 3m/year), a reduction in the artisan aquifer, and the drying-up of some rivers and springs. If pressure on groundwater in the region continues at the same pace, it threatens the water supply in the short and midterms with negative impacts on farming, tourism, industry, the economy and the environment.

The agricultural sector in the region of Fez-Meknes is promising. The region is called the fruit basket of morocco, as most of the fruit trees are produced in the region including the rosacea's and Olives. In fact, the Cultivated agricultural area in the Fez-Meknes region is estimated at 1,335,639 hectares, or 15% of the national useful agricultural area. The total area of irrigated land is 184162 hectares, or 13.7% of the total agricultural land in the region. Recent study demonstrate that the area equipped with drip irrigation in Fez-Meknes region increased from 2174 ha in 2008 to 79 000 ha in 2020.

The use of drip irrigation allowed a great water saving in several crops. Assouli et al 2018, showed a decrease in irrigation water use by 36%, 46%, 59% and 61% for onion, potato, peach/nectarine and plum, respectively; a strong increase in the valuation of irrigation water by the different selected crops, by 208%, 151%, 83% and 431%, for onion, potato, peach/nectarine and plum, respectively. With regard to profitability, the shift to localized irrigation would allow an increase of yields of the studied crops of about 49% for onion, 29% for potato, 12% for peach/nectarine and 34% for plum. In terms of profitability, this transition would lead to an increase in the gross margin per hectare of the four crops, by 44% for onion, 23% for potato, 25% for peach/nectarine and 41% for plum.

These productions give the Region an obvious agricultural vocation with a production very varied plant life, from cereals of all kinds to industrial crops (sunflower, rapeseed, soya ...) through legumes, fruit trees (apple, peach, pear, plum, cherry, quince, pomegranate, vine, almond, walnut, date palm) and tropical species, They also offer opportunities for the production of strawberry plants, seeds of sugar beet and potato seeds, in particular on the Ifrane-Khenifra axis and the tomato in Saïss.

The region's contribution to national cereal production remains very significant, contributing to around 21% during the 2011-2012 season. Cereal cultivation recorded a total production of nearly 11 million quintals. It is made up of durum wheat, Bread Wheat, barley and corn.

4.1.4 Water resources

The emphasis in Moroccan development planning has been for the last five decades on maximizing the capture of the country's surface water resources and providing for their optimal use in irrigated agriculture, potable water supplies, industrialisation and energy generation on a sustainable basis. Enormous capital resources have been invested in the essential infrastructure to control surface water flows.
Based on the Haut Commissariat au Plan in 2020, 87% of the water resources are used in agriculture, 5% public administration, education, and health and 1% in hotels and restaurants, 1% in the industries and the rest in urban drinking water.

According to the Minister for water, "groundwater resources provide drinking water to 90% of the rural population and to almost 40% of the total area irrigated in the kingdom, contributing to more than 50% of the economic value-added generated by all irrigated areas" (Maroc.ma, 2014).

The trend is that the availability of water resources in Morocco is decreasing in the last 10 years. The increase of water demands combined with climate change induced decreases of precipitation put a lot of pressure on groundwater. Additionally, Morocco suffers from the degradation in groundwater quality due to seawater intrusion, nitrate pollution and natural salinity changes. The surface water availability has drastically decreased, which will lead to more extensive use of groundwater Figure 4-10 and Figure 4-11). Rapid declines in groundwater levels (0.5 to 2 m per year on average) are generally the result of (1) low groundwater recharge and (2) over-expansion of agricultural activities. The main aquifers in Morocco are shown in Figure 4-9.

Dams

Up to now, Morocco has 145 large dams with a total storage capacity estimated at 18.6 BCM, and 14 other dams under construction with a total storage capacity of 3.2 BCM, which will bring the storage capacity to 21.8 BCM. However, the problem is the silting up of dam reservoirs, and up to date Morocco has lost 2,4 BCM of the total capacity of these dams.

Surface water, groundwater and aquifers

Surface water resources throughout the country are estimated, in an average year, at nearly 18 BCM, varying depending on the year from 3 billion to 48 BCM. In Morocco, groundwater is a strategic resource. It represents about 20% of the country's water resources potential. Of the 130 aquifers, 32 are deep and 98 are shallow. The exploitable potential of groundwater resources is around 3.9 BCM. The country's main water tables show that the volume of groundwater withdrawn in an average year (5 BCM) exceeds the exploitable resources, i.e. an overexploitation in the order of 1.1 BCM/year.

Treated wastewater

The volume of treated wastewater mobilized for reuse at the end of 2019 is around 65 Mm^3, including nearly 19 Mm^3 for watering golf courses and green spaces in the city of Marrakech and 11 Mm^3 for the city of Agadir. Upon completion of the implementation of the projects in progress, the volume of purified wastewater mobilized will reach 100 M m^3/year in 2021.
Based on the National Shared Plan of liquid sanitation, purification, and reuse (PNAM) the reusable potential for 2050 is about 600 Mm^3/year. However, given the technical and regulatory constraints and the high cost of REU, the reusable volume by 2050 is estimated to be nearly 340 Mm^3/year, representing 30% of the total treated wastewater volume.

The rapid increase in wastewater produced and collected in urban areas over the past few decades testifies to its enormous potential. Within the framework of the National Water Plan, the National Plan for Wastewater Reuse (PNREU) aims to reuse 325 Mm³/year of treated wastewater by 2030, 43% of which will be used for watering golf courses (Table 2-1). Within the framework of this plan, reuse in industry and groundwater recharge are also planned.

Table 4-4. The use of treated wastewater and where it goes to.

	Treated wastewater reused (Mm³)	Percentage of treated wastewater (%)
Irrigation of Agricultural lands	149	**46%**
Irrigation of green spaces and golf courses	139	**43%**
groundwater recharge	20	**6%**
Industrial sector	**17**	**5%**

Desalinisation

The National water plan (PNE) proposes the construction of seawater desalination plants to produce nearly 515 MCM per year in 2030. By 2016, Morocco had 15 desalination installations, with a total desalination capacity of 132 MCM/year. Almost all desalination plants (96%) operate with reverse osmosis (RO) systems. The current capacity is relatively evenly split between medium-, large- and extra-large-scale plants.

The Agadir Desalination Plant is under construction at a cost of about $112 million, using RO technology to produce 36 MCM/year, to fulfil the drinking water and irrigation needs of 800,000 people (123 litre/capita/day). It is 65% complete (Takouleu, 2020). Two desalination plants at Jorf Lasfar – el-Jadida and Safi, with a capacity of 75 MCM/year and 25 MCM/year respectively, are under construction and set to produce 100 MCM/year of drinking and industrial water by 2025 (World Bank, 2017).

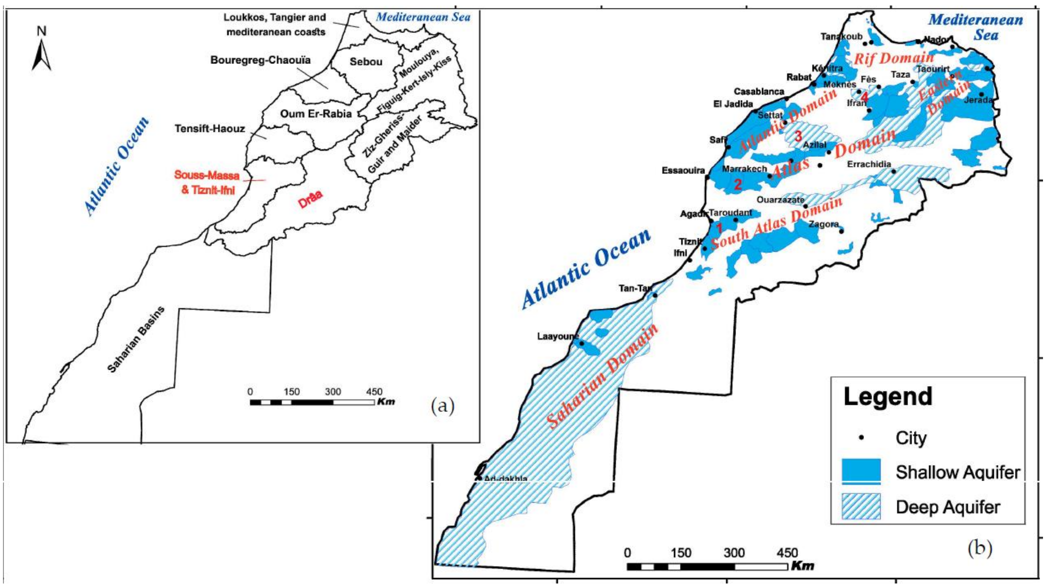


Figure 4-9 (a) main basins in Morocco, (b) Main aquifers (red digits indicate the location of major exploited aquifers: 1: Souss-Massa, 2: Maouz, 3: Tadla, 4: Sais. Figure from Hssaisoune et al. 2020. Based on documentation of the DRPE.

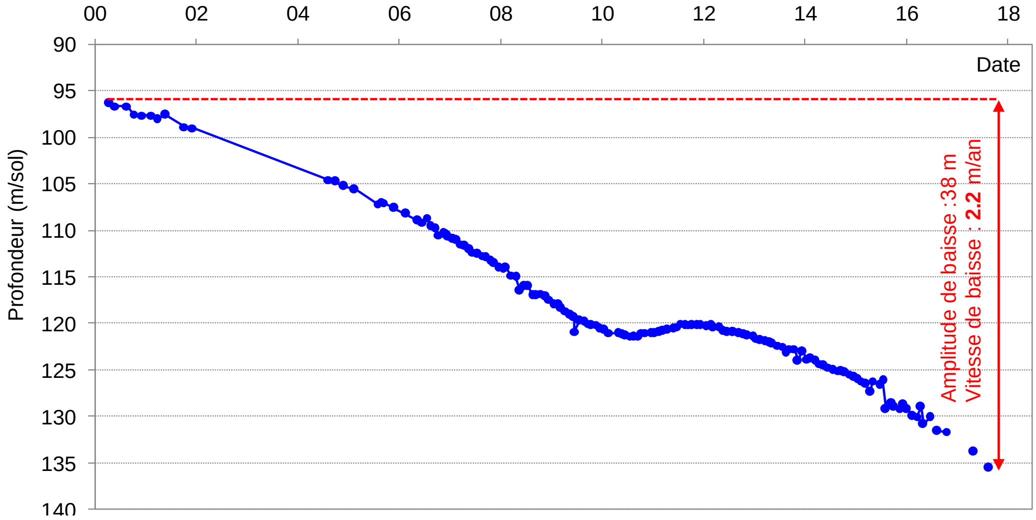


Figure 4-10. Nappe de Souss – Amont. A total lowering of the groundwater table of 38 m is visible from 2000-2018.

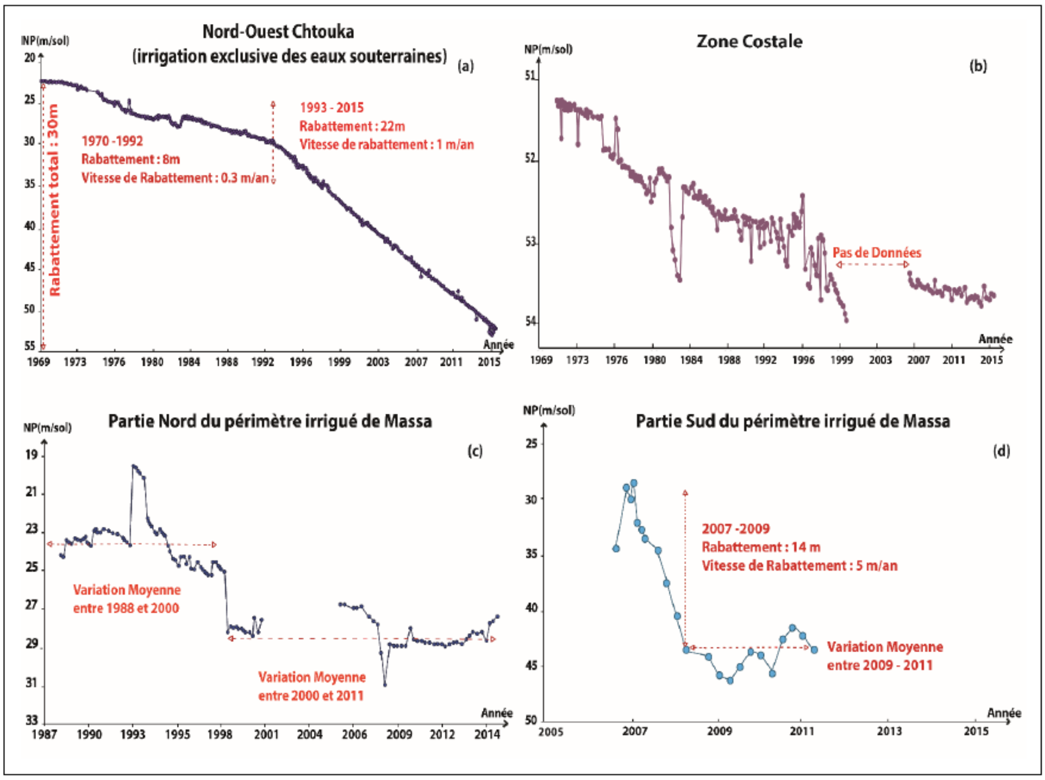


Figure 4-11. Lowering of groundwater tables in different parts of Morocco

Water quality

In addition to water scarcity, Morocco suffers from the degradation in groundwater quality. Figure 4-12 summarizes the spatial occurrence of saline groundwater. The origin of salinization is essentially from natural degradation by (Permo-Triassic) evaporites, high evaporation, low recharge and seawater intrusions in coastal areas (primary salinisation). Salinity increases are aggravated in coastal and irrigated areas by anthropogenic activities (secondary salinization). The overall degradation in quality varies among the basins depending on geological context, local climate conditions, and land use (Hssaisoune *et al.*, 2020).

Saline water (from 3 up to 11 dS/m) is used for the irrigation of forage crops (alfalfa, bleu panicum, sorghum, barley) trees (olives, figs, date palm) vegetables (artichokes, melon, cabbage, okra) and occasionally lead to increased salinisation over time depending on seasonal rainfall patterns (Choukr-Allah, personal communication).

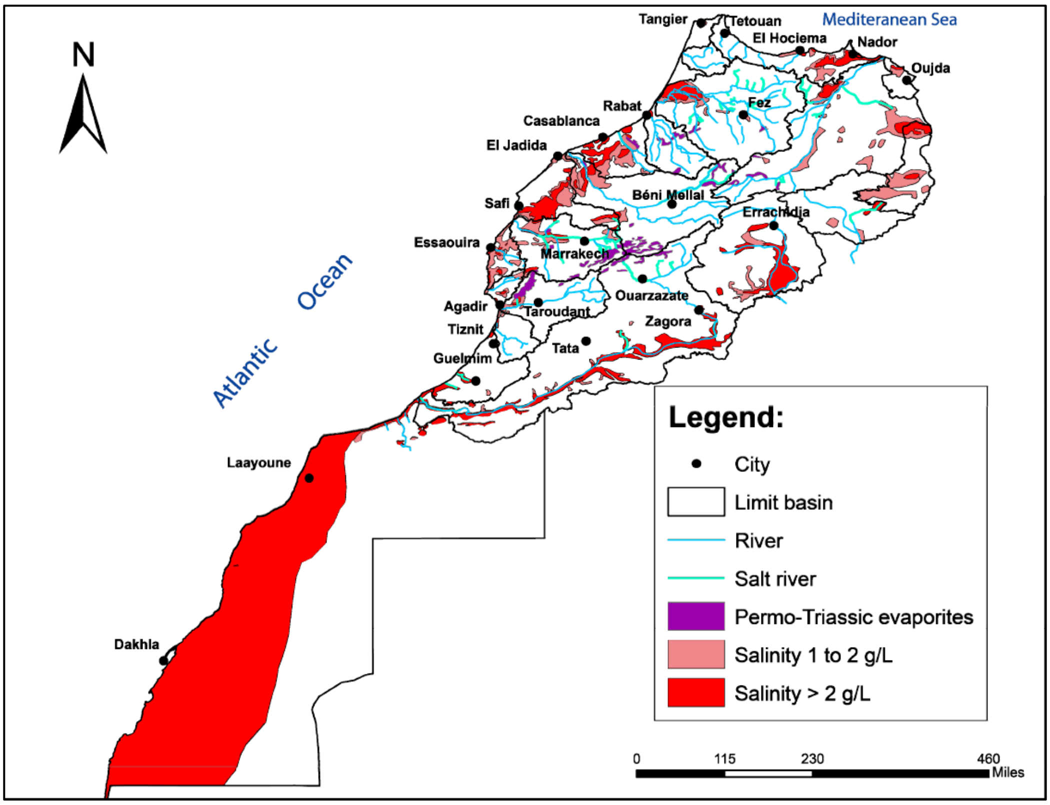


Figure 4-12. Spatial distribution of saline aquifers and rivers in Morocco. Figure from Hssaisoune et al. 2020

Water quality in coastal areas

In the aquifers located along the Mediterranean coast, high mineralization of the groundwater is caused by dissolution processes of (Miocene) evaporitic rocks and carbonates and human impact from agriculture (Re *et al.*, 2013, Fetouani *et al.*, 2008, Fekkoul *et al.*, 2013). In this area, agricultural activity, and resulting high nitrate levels, is the main contributor of groundwater contamination. Seawater intrusion into the Martil and Triffa aquifers also contributes to contamination (Boughriba *et al.*, 2018, Fekkoul *et al.*, 2013).

Along the Atlantic coast, many aquifers suffer from seawater intrusion and anthropogenic impacts. The Bouregreg-Chaouia basin is a vital water source for the regional population. The groundwater is intensively pumped for irrigation, which increases its vulnerability to salinization and affects its quality (Hssaisoune, 2020). The quality of Chaouia groundwater is affected by high mineralization from seawater intrusion and anthropogenic activities (Najib *et al.*, 2016). Over-pumping and over-utilization of fertilizers has led to groundwater degradation (I.e., a high electrical conductivity, and high levels of total dissolved solids, chloride and nitrate), which has made most of the water unsuitable for drinking.

In the coastal area of the Oum Erbia basin, Mountadar *et al.* (2018) found that the groundwater is contaminated by seawater intrusion and ion exchange based on the hydrogeological layers present. In the central Tensift-Haouz basin a deterioration in groundwater quality was observed: an increase in salinity from seawater intrusion and nitrate contamination from intensifying agricultural activity (Bouchaou *et al.*, 2009; Ouhamdouch *et al.*, 2019). The Souss-Massa coastal aquifer shows high salinity mainly along the estuaries of the Souss and Massa rivers (Hssaisoune, 2020).

In the southern part of Morocco, along the coastal edge of the Sahara, there is high salinity from seawater intrusion and evaporation (e.g., Foum El Oued aquifer).

Water quality in inland aquifers

Inland areas show variable salinity values of different origins. Water quality on the Tadla plain (Oum Er-Rbia basin in Figure 4-13) deteriorated due to excessive use of organic and inorganic fertilizers and irrigation wastewater. In the Middle Atlas and on the Saïss plain, water contamination from anthropogenic sources was identified (Gamar et al., 2018), but even though, agricultural activity has caused nitrates to increase (up to 180 mg/L) in the Saïss aquifer, water sources from the Middle Atlas still have good quality. In the Tensift-Haouz basin (see Figure 4-13) studies found that the groundwater on the Tensift plains is relatively degraded as a result from the local geology and anthropogenic activities (Hssaisoune, 2020).

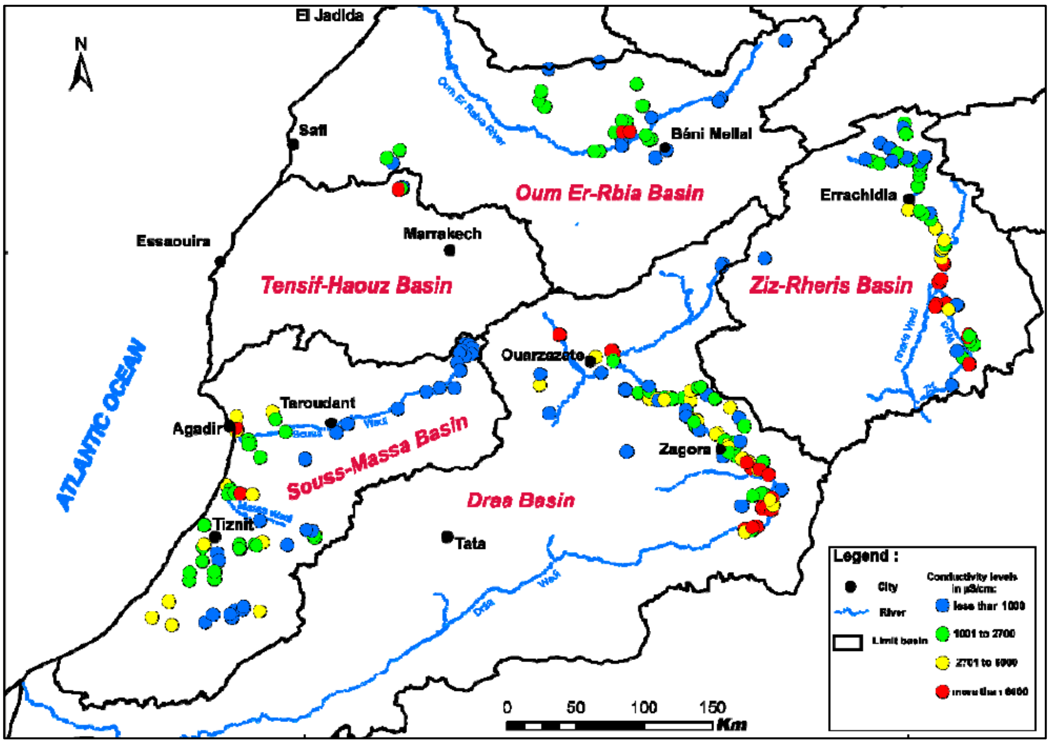


Figure 4-13. Detailed information on the conductivity levels (µS/cm) in four major basins in Morocco. Figure from Hssaisoune *et al.*, 2020. Legend: blue: less than 1000, green: 1000 – 2700, yellow: 2700 – 6000. Red: more than 6000. In general, upstream areas has good water quality and moderate recharge; Downstream (e.g., coastal and agricultural areas) areas have poor water quality as a result of high salinity from various sources and a long groundwater residence time.

To support the arid central regions of Morocco in their water availability a plan for a water highway was developed. In this project, a water transfer system will be constructed to transfer water from the northern dams to dams in the central region or Morocco. Project implementation is ongoing (see also Figure 4-14).

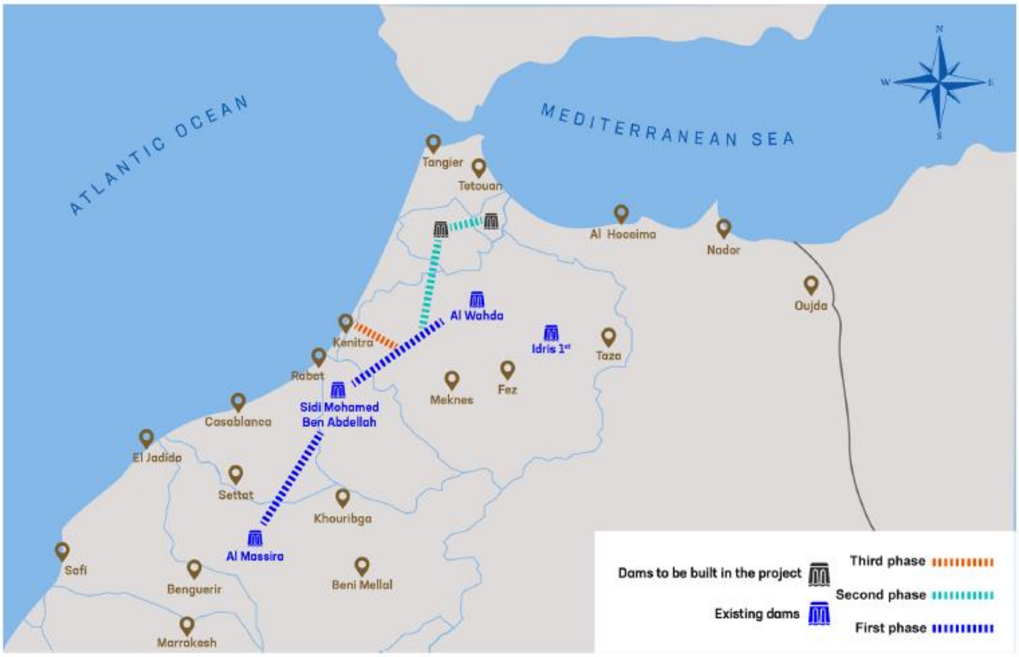


Figure 4-14. The planned water transfer (Source: El Mocayd *et al.*, 2019). Project implementation is ongoing. The proposed north–south water transfer project (Water Highway) aims to supply water to the arid southern regions from the watersheds in the north.

At a national scale, the water degradation has the highest environmental cost, amounting to 1.4 billion dollars (11.6 billion dirhams), i.e. 960 dirhams/capita/year, 1.26% of the national GDP and 35.9% of the total Cost Of Environmental Degradation (COED; see fig. -415). Key drivers are urban and industrial (i.e tanneries, olive industry, fish industry) wastewaters, sea water intrusion and fertiliser and pesticide use.

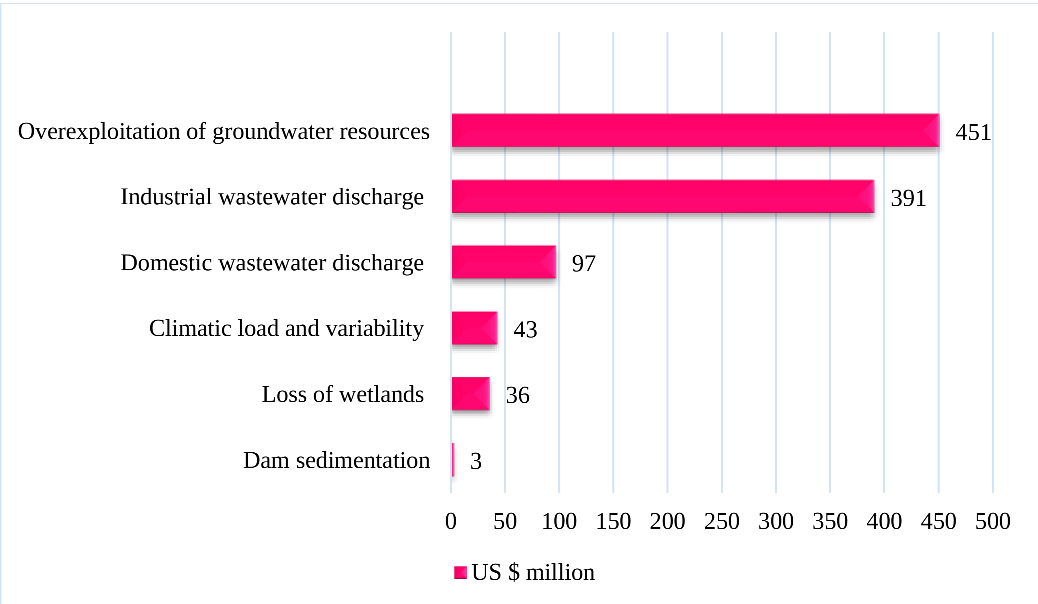


Figure 4-15 Total environmental cost of water resources degradation in Morocco.

4.1.5 Developments in irrigation

Currently farmers use the following good agricultural practices:

- Drip irrigation: Over 500.000 ha are using this technology. Because of subsidies by the government an increasing number of farmers are using drip irrigation.
- Substrate culture: Over 4.000 ha greenhouse production are using substrate culture (sand, coconut, peat) for growing tomatoes, red berries, blue berries, black berries and strawberries).
- An SMS irrigation warning system: the first use was in the Souss Massa/Agadir region and now farmers want to apply it in the Oum Rabiaa Bassin in the region of Beni Mellal (Choukr-Allah, personal communication).

The overall efficiency of the use of water in irrigation, including the conveyance of water to, and application on the fields is currently in the order of 40%, which means that less than half of the water delivered to farms currently reaches the crops (World Bank, 1998). Faced with the evidence that few farmers yet have the capacity to invest (although at the same time private investments without subsidies were taking place, like in the coastal Chaouia), in 2006 the government raised the rate of subsidies by 60%. However, the Prime Minister declared that "efforts to establish an efficient demand management did not live up to [our] ambitions" and that "the government was ready to launch a large national program for water savings, a key measure of which would be the expansion on a large scale of efficient irrigation techniques" (MAPM, 2007a). In 2007 the National Program for Water Savings in Irrigation (PNEEI) was established. The PNEEI adopted ambitious targets. It seeks to achieve the conversion of 550.000 ha of land irrigated by gravity or sprinkler to drip irrigation in 15 years, at the cost of 37 billion Dirhams (~3.7 € billion). Of this conversion, 72% would involve large-scale public irrigation (including some individual farm conversions and the modernization of the collective distribution of pressurized water through pipes), with the remainder being devoted to private individual irrigation.
With regard to water savings, in 2016 the Ministry reported that the conversion to drip irrigation so far had yielded savings estimated at 800 Mm^3, and that "*farmers had been able to diversify their production systems and achieve up to three times more production with half the water*" (quoted in L'Economiste, 2016).

Plan Maroc Vert and the Green Generation Plan

The Green Morocco Plan (Plan Maroc Vert) was launched in 2008, aimed to make the Moroccan agricultural sector a real lever of socio-economic development in the Kingdom, through the acceleration of growth, poverty reduction and the consolidation of the integration of agriculture into national and international markets. The Government is planning a new 10-year Agriculture development Plan called the Green Generation (GG) Plan.
In this plan, the priority focusses on the human element, and it aims to develop a social protection system in the countryside. The objective of this plan is to develop an agricultural middle class, able to play an important role in the socio-economic balance of rural areas.

The outcomes of the Green Morocco Plan were:

- An increase of export by a factor of 2.4
- An increase of export of Red fruits by a factor of 18
- An increase of export of Tomatoes by a factor of 3
- An increase in the production of Argan by a factor of 5
- An increase in the Agricultural GDP by a factor of 2

- An increase in the irrigated area using drip irrigation by a factor of 3.7. The area increased from 160 000 ha to 585 000 ha
- 450 000 ha were planted with trees
- The creation of 19 associations of farmers
- The decentralization of the budget of the Ministry of Agriculture

The intended outcomes of the new GG Plan are:

- To increase the middle class by 400.000
- To increase exports by a factor of 2
- To increase the agricultural GDP by a factor of 2
- To create 350.000 new jobs
- The aggregation of 1 Mha, 180.000 new young farmers
- New Entrepreneurs: 200.000 including 45.000 young entrepreneurs
- 150K new young people trained with 10K with official diplomas
- 20% of land irrigated by wells will be solar pumped
- To improve crop yield by factor of 1.5
- Diffusion of technologies to preserve soil health and improve water use efficiency
- To stimulate the development of electronic services and digital agriculture
- To increase R&D expenses by a factor of 1.5-2

As mentioned above, because of the subsidies provided by the state, more farmers use drip irrigation now. The state may contribute up to 100% subsidies for small farmers with less than 5ha of land to finance their conversion from furrow irrigation to drip irrigation. This includes the drip lines, a PVC network, and a fertigation unit and the installation of it all.

4.2 Water governance

The Rivers Basin Agencies (ABH, "Agence du bassin hydraulique") are responsible for the Monitoring of both surface water and ground water as well as the quality of these water resources. Data is available on the websites of the ABHs. Every basin has its own website: http://www.agriculturalsystem.net/agences-des-basin-hydraulique/

Considering the objective to secure Morocco's water supply, the government plans are to build 50 water reservoirs by 2050 (Takouleu, 2020) due to investment of 35 billion euros. The water storage capacity should thereby increase from 18.7 billion m^3 of water to 32 billion m^3 of water. Moreover, water use for irrigation will be regulated with the intention to save 2.5 billion m^3 by 2030. Furthermore, in January 2020 the Priority Programme for Drinking Water Supply and Irrigation launched aiming to build 20 dams to store rainwater during the period 2020-2027. This programme will require an investment of 10.7 billion euros in the seven years of the program. It will make it possible to build three seawater desalination plants in coastal areas to produce nearly 515 MCM/yr in 2030 (PNE).

In terms of drought, there is no unit responsible for drought management (no independent body). There is a lack of comprehensive early warning systems and an inadequacy in sharing information on droughts. Thus, Morocco's national preparedness for water scarcity and drought can be enhanced. (Areikat, 2013).

4.2.1 National and regional plans and policies

In all river basins the governance is the same, as all the administrative structures (ABH, ORMVA, ONEE, REGIES) are existing. However, their efficiency differs between existing cropping systems, and it also depends on the type of urbanisation and industry developed in that basin.

The institutional framework for water management is defined by the Constitution 41 and by the law (the Water Act No. 10-95), including for the national consultation frameworks (i.e., the Superior Council for Water and Climate and the National Council of the Environment), 42 other public institutions, including at the subnational level (i.e., water basin agencies and irrigation agencies (ORMVAs) and decentralized representative structures such as Water Users Associations (WUAs). Mobilization of this institutional framework depends mainly on agricultural policy. More specifically, the Ministries of Agriculture and of Water activate evaluation functions and the implementation of programs in accordance with the law and guidance from stakeholder representation and consultation mechanisms.

The passing of Law 10-95 in 1995 was a breakthrough in Moroccan water policy. The law's main objective was to rationalize water use, to provide universal access to the resource, to reduce disparities between cities and villages and to ensure water security across the country. Since 1995 after passing the Water Law as an instrument to manage the water sector for sustainable development, Morocco has made significant efforts to establish an effective integrated water resources management strategy that includes key elements such as a national water masterplan, a national water quality protection plan and a national flood protection plan. The master plans of integrated water resources management at river basin level (PDAIR) and the National Water Plan (PNE) were established for a period of 20 years, based on principles of decentralized and concerted integrated water resources management (EMWIS, 2011).

The National Water Plan (NWP) was launched in 2010 as the vehicle of the National Water Strategy, combined with the regional water master plans. It is based on an optimal mix of both a vigorous demand management strategy, involving comprehensive reforms and actions to make better use of existing supplies, and a supply management strategy, involving highly selective development and exploitation of new water supplies (conventional or non-conventional such as desalinated water and reuse of sewage water). Moreover, the NWP pays more attention than in the past to the protection of water resources and the natural environment, as well as adaptation to climate change.

Achievements include the establishment of an institutional framework; improving the government's capacity for water resource planning; improving water use efficiency; increasing effectiveness of existing hydraulic infrastructure; and introducing water pollution control measures (Choukr-Allah, 2011).

4.2.2 Important government programs

The circular economy is rapidly rising up political and business agendas. In contrast to today's largely linear, 'take-make-use-dispose' economy, a circular economy represents a development strategy that enables economic growth while aiming to optimise the chain of consumption of biological and technical materials.

The government of Morocco is using circular economy strategies to reduce its carbon footprint. Morocco is developing its Low Emission Development Strategy (LEDS). Morocco submitted its national climate contribution (INDC) to the UNFCCC in June 2015 as one of the first countries in the region. In its submission Morocco proposed to reduce the

country's GHG emissions by 13% (unconditionally) and up to 32% from "business as usual" conditions by 2030.
The implementation of Morocco's INDC covers five main sectors: energy, waste (both solid and liquid), agriculture, buildings and forestry. Among the targets are (i) achieve a collection rate of urban household waste of 100% by 2030 and improve recycling, (ii) connect all urban households to sewers by 2030, including 100% wastewater treatment by 2030 and 50% reuse of wastewater by 2020, (iii) modernise the agricultural sector and promote a sustainable use of resources.

The prospects of the Argan (*Argana spinosa*) Biosphere reserve conservation under the scope of the 2012 National Charter for Environment and Sustainable Development is part of the activity of the circular economy with the Souss-Massa Watershed. In fact, the rate of degradation of the Argan ecosystem and the unfair benefit sharing along the value chain of local products continues to threaten social wellbeing of the rural populations that live within the Argan ecosystem. To address this disequilibrium, a project endorsed by the GEF and supervised by UNDP is being implemented by the Moroccan Ministry of Agriculture and Fishing. The project aims at introducing the circular economy approach through Payment for Ecosystem Services (PES), as a market-based instrument, in order to conserve agro-biodiversity and promote local products in the Souss-Massa Region. Identified pillar products of local and global importance are Argan and honey. Several opportunities and challenges related to the development of contractual agreements between the rights holders and end users of ecosystem services.

Wastewater reuse in agriculture has been identified as a way to alleviate water scarcity, improve crop productivity and improve environmental sustainability. Since the sixties, Morocco has largely contributed to the mobilization of its hydraulic capacities in order to face the demographic increase and sustain its social and economic development. Nonetheless, and in addition to the continuation of the efforts directed to mobilization, and the control of the demand, the limited hydraulic potential requires the resort to unconventional resources. The use of treated wastewater in irrigation is necessity for a better water resources economy.

The diagnoses of the wastewater reuse situation in Morocco converge on a major finding residing in the fact that, to date, no project for the reuse of treated wastewater in agriculture (on a full scale - nature) has come into being. Only pilot projects, in particular those of Ouarzazate, Ben Sergao, Drarga, Attaouia, have been carried out and have made it possible to develop, through agronomic trials, some fairly well documented technical standards.

For other uses, since 2012, we have witnessed a development process of two types of flagship projects: the reuse of treated wastewater for watering golf courses and green spaces in the cities of Agadir and of Marrakesh and reuse for industrial purposes, in particular washing phosphates at Khouribga and Benguerir.
Following the start of the National Liquid Sanitation and Wastewater Treatment Plan (PNA) in 2006, the purification rate increased substantially to exceed 40% in 2016. At the same time, several projects for the reuse of treated wastewater for the irrigation of crops, were tied up and/or planned but did not succeed/materialize for various reasons. This results in a significant gap between the objectives stated by the national water sector strategy (SNE) set up in 2009 and by the ten-year plan broken down by the master plan for the reuse of treated wastewater in irrigation developed by the Department of Agriculture in 2015. These initiatives are motivated by the fact that the reuse of wastewater constitutes

both an alternative to help reduce the growing water deficit, a model of adaptation to climate change, and a measure to mitigate environmental impacts rejections because reuse allows nutrients to be diverted to plant biomass. It can thus be considered as being a "quaternary" treatment.

Box 3. An 'Aquifer management contract' in the Souss region

A convention for the preservation and development of water resources in the Souss region was established in the form of an 'aquifer management contract'. It was the result of a process of intensive consultations with all the stakeholders: government and local authorities, water users' associations, farmers' organisations, and credit institutions. The action plan under this contract covers control on the digging of wells and boreholes, control on the expansion of orchards and irrigated areas, adopting water-saving technologies (drip irrigation coupled with irrigation scheduling services), and awareness-raising of farmers and the general public in the region on issues of saving water and preventing pollution. A commission was formed by representatives of all the stakeholders to enforce the implementation of the aquifer contract. To date, more than 50 water users' associations in agriculture, covering an area of 12,300 ha, have benefited from the programme. The commission has played a key role in the development and adoption of legislative amendments to adjust the fees paid by farmers for the use of irrigation water

4.2.3 Implementation and Water Resource Management

With regards to the implementation of the PNE, the body of relevant legislation and regulations continues to be strengthened, notably with the adoption in August 2016 of a new Water Act (No. 36-15) that pursues the objectives of water act 10-95, with a view to guaranteeing the right to water. Thus, this new law introduced reforms aimed primarily at consolidating and strengthening decentralized, integrated and participatory management and planning of water resources, strengthening consultation and coordination bodies and organizations through the establishment of river basin councils and legal foundations to diversify supply through the use of unconventional water resources including desalinated seawater, implementing water-related information systems, strengthening the institutional framework and mechanisms for the protection and conservation of water resources, and strengthening financial instruments for the development of the water sector based on the principle of user pays/polluter pays.

The latest strategies (New Law 36/15) and national plans undertaken show a political commitment towards the integrated water resources management approach. Examples of water-related strategies are the above mentioned Green Morocco Plan (2008), which includes a crosscutting initiative for the modernization of irrigation systems; the National Irrigation Water Saving Programme (2007); and the National Water Strategy and National Water Plan (2009), which focus on the role of complementary water management actions to address water problems and achieve coordinated management of supply and demand, while ensuring equitable distribution between rural and urban areas.

Despite the importance of the achievements made in integrated water resources management through the promulgation of the Water Law 36-15, there is a need to consolidate and reinforce these achievements. In fact, the corresponding application texts are not published, in particular those related to liquid sanitation, seawater desalination, the preservation of aquatic environments, the fight against floods and the participatory management of water.

Furthermore, recently the main acting policies aim to strengthen harvesting more water in the dams, the use of non-conventional water resources, such as desalinated seawater and brackish water and treated wastewater (Houzir *et al.,* 2016), as well as the preservation of groundwater resources (Groundwater Contract).

Agriculture is the fourth sector highlighted in the Green Investment Plan with investment needs budgeted at estimated 11.12 billion MAD (1.2 billion USD) in order to improve the resilience of Morocco’s agricultural production.
Morocco elaborated a National Plan against Global Warming (PNRC)43, which it presented to COP15 in Copenhagen in 2009. This plan contains a portfolio of actions as well as detailed programs for both mitigation and adaptation and is a first attempt in addressing the need for an integrated approach with coordination of sectoral policies. This includes National Plan on Domestic Waste Management (PNDM) and actions concerning emissions reduction from transportation. Adaptation actions listed represented sectoral strategies in relation to climate change challenges and constraints (such as the National Water Plan, the Green Morocco Plan).
The Morocco Climate Change Policy (PCCM) developed in 2013 describes the main principles, defines global strategic priorities for mitigation and adaptation and traces systematically the sectoral actions to address climate change by different sectors in Morocco.
The PCCM established a time horizon until 2030 with specific deadlines and goals for the majority of sectoral and inter-sectoral national strategies, and aims to be a dynamic and flexible instrument, with a monitoring and evaluation mechanism that allow for the necessary refinements.

In the water sector, the following adaption measures are recommended at the national level:
1. Improve planning and foster integrated management of water resources by strengthening the synergy between the different national strategies and plans related to water and the institutionalization and operationalization of Water Basin Councils for big watersheds.
2. Strengthen the conservation of water resources mainly through widespread and quick implementation of so-called “watershed contracts” and the intensification of the fight against illegal drawing of water resources. The latter could be ensured by utilizing the human power and material capacities of the water police. Another means to conserve water is to encourage the use of non-conventional water resources in all regions of Morocco, but especially in basins suffering from water scarcity. The extraction of those water resources could be coupled with the use of renewable energy sources.
3. Strengthen the protection against the pollution of water resources through (i) the acceleration of the implementation of the National Sanitation Program and Liquid and Wastewater Treatment (PNA, 2005), (ii) the development and implementation of a National Plan for Rural Sanitation, (iii) the acceleration of the implementation of standards for industrial waste, (iv) the acceleration of the application of the polluter-pays principle as contained in water law No. 10- 95, (v) the effective establishment of the perimeters of protection against pollution around catchments and capturing fields of drinking water (surface and groundwater) and (vi) the establishment of a permanent coordination between the water police and other protection bodies environment at each water basin.
4. Strengthen education, research and awareness in the areas of water and climate change through the establishment of a National Centre for Research, Innovation and Expertise in the areas of water and climate comprising all national experts and areas of competence,

in order to optimize human and material resources available and to build the awareness of the public and different user group for the rarity and scarcity of water resources water, water saving (including in agriculture) and the fight against pollution through textbooks, media, audio-visual media, civil society engagement, etc.

Improved governance comes mainly from the new institutional arrangements governing the water sector, with the reinforced role of the High Water and Climate Council as an apex body for national water policy and programmes, and the creation of river basin agencies. At the sub-sectorial level, the Moroccan irrigation agencies are unique, as they integrate the provision of production services to farmers with water supply, an approach that is crucial for enhancing water productivity and farm output.

4.3 Exemplary developments and inspiring partnerships

4.3.1 Sector innovations through Souss Massa case

Details on the successful story on the Souss-Massa region are provided in Box 1. It represents an ambitious action plan to improve governance and water productivity. A convention for the preservation and development of water resources in the Souss region was established in the form of an 'aquifer management contract'. It was the result of a process of intensive consultations with all the stakeholders: government and local authorities, water users' associations, farmers' organisations, and credit institutions. The action plan under this contract covers control on the digging of wells and boreholes, control on the expansion of orchards and irrigated areas, adopting water-saving technologies (drip irrigation coupled with irrigation scheduling services), and awareness-raising of farmers and the general public in the region on issues of saving water and preventing pollution. A commission was formed by representatives of all the stakeholders to enforce the implementation of the aquifer contract. To date, more than 50 water users' associations in agriculture, covering an area of 12,300 ha, have benefited from the programme. The commission has played a key role in the development and adoption of legislative amendments to adjust the fees paid by farmers for the use of irrigation water. The Rivers Basin Agencies (ABH) are responsible for the monitoring of both surface water and ground water as well as the quality of these water resources.
The uptake and adoption of new technology is high and a large share of farmers adopt them easily. Nevertheless, there is demand for more vocational training for farmers and technical staff and access to finances, other support, etc., in particular for greenhouse structures, soilless culture management, and recycling of the brine from demineralisation units.
Farmers also use technologies allowing them to adapt to more saline conditions of the soil and irrigation water. They seem aware of the impacts of salinity problems and use several approaches when growing crops under saline conditions such as the use of organic amendments, sand amendments, by using more salt tolerant crops, and by using drip irrigation while they alternate irrigating with fresh and saline water.

4.3.2 Water-agriculture partnerships

The Souss Massa is the most developed region and has several running partnerships with European growers. In these partnerships, most of the farmers are using technicians and engineers educated at the Horticulture centre of IAV Hassan II.
Also, the farmers' association that has developed a Center of transfer of technologies to test different varieties, irrigation system, plastic greenhouses, substrates, and pest control products is of great support.

Several foreign companies and/or institutes are active in Morocco who provide services or support to improve the water use efficiency and/ or sustainability of agriculture. These companies are mostly French and Israeli.

Dutch companies are mainly in the seed business. They offer hybrids for vegetables (KAMPS Bean) and also companies involved in pest management using predators and parasites (Biological control). Finally, there are few Dutch companies producing vegetables in the Souss Massa for Export (Quality Citrus), but none that are active in the water sector even though technologies and experience on water efficiency for good agricultural practices is very high in Morocco. Additionally, they are active in the climate control of medium technology greenhouses throughout the country. Herein lie more possibilities, as the greenhouses could be more water use efficient.

GIZ organization

Moreover, opportunities for the Dutch business sector are also to cooperate with the GIZ German organization, which has an office in Morocco. Therefore, they have a bigger network of trustworthy partners in the country. There are opportunities for the Dutch to strengthen and supplement current and future projects of the GIZ, resulting in bilateral cooperation.

5 Tunisia

Table 5-1. Summary table for Tunisia

Country overview	Tunisia
Water availability and use	-Most of the demand is concentrated in the populated coastal zone. -Irrigated agriculture is the most consuming economic sector with about 80% of the water resources exploited. The irrigated perimeters of the North make particular use of surface water. In the Centre, groundwater supplies the majority of the irrigable surfaces. In the South, it is the deep-water tables that are not very renewable that are solicited. - For the deep aquifers, the total exploitation of deep aquifers reached 1895 Mm3 in 2016. This exploitation represents 133% of the total deep water resources estimated at 1422 Mm3. - Surface water storage in dams indicate a decrease in their total useful capacity of about 20% due to silting
Future water availability	- Recent climate projections show a decrease in rainfall from -5% to -20% by 2050 depending on the region, which would gradually increase to reach -10% and -35% in 2100. -Successive periods of drought will cause a decrease in the natural recharge of groundwater and limit the possibilities of artificial recharge by dams. -The losses due to salinization of the coastal aquifers due to the expected rise in sea level would be about 50% of the current resources of these aquifers by 2030, i.e. nearly 150 million m3. -Projections of changes in salinization at the level of coastal aquifers clearly highlight the increasing and irreversible salinization of these underground resources by 2100.
Water quality	-Surface water has low salinity levels, but groundwater is badly affected with 84% of all groundwater resources having salinity levels of more than 1.5 g/l and 30% of the shallow aquifers more than 4.0 g/l. -Salinisation of groundwater is widespread in Tunisia, linked to intensive exploitation; to the geochemical nature of geological deposits; and sometimes to leaching of irrigation water.

	-Saline intrusion in the coastal aquifers is problematic -TWW plants are present in many cities and villages. -The use of TWW for irrigation remains weak in irrigated areas but shows potential
Irrigation types	Surface irrigation (with pressurized pipe networks), Drip irrigation and Sprinkler irrigation. -Drip irrigation is becoming more important.
Trends in irrigated agriculture	- Regional specialization in irrigated areas in production systems. - Newcomers in the top ten are watermelons, chilies and peppers, potatoes, onions and shallots and carrots and turnips.
Trends in greenhouse cultivation	-Greenhouses with geothermal energy -Developments in desalinization for greenhouse production
Trends in livestock	-There is a significant decrease in the number of heads of cattle in Tunisia. -The number of camels and pigs are decrease significantly, only the number of cattle is stable.
Water productivity & efficiency	- The subsidy by the Tunisian State of photovoltaic installations for pumping in agriculture (promoting renewable energy), has contradictory effects to the preservation of water resources by making the resource completely free.
Trend in governance	-Water resources mobilization (Strategy of 2001–2011). aims to mobilize 95% of conventional resources by building dams, reservoirs and flood runoff infrastructure, and to develop non-conventional resources such as recycled and desalinated water. - Tunisia's National Adaptation Plan was launched in August 2018. It aims to strengthen the adaptive capacity of agricultural activity, to ensure food security, coastal protection and water resources. Adaptation in the watersector has a prominent place. - Water saving is promoted and implemented under Tunisia's water saving program: Programme National d'Economie d'Eau en Irrigation, PNEEI. Drip irrigation has become more important in Tunisia and is subsidized.
Water pricing	The price varies between 0.048 and 0.162 Tunisian dinars (1 dinar = about 0.3 €) for 1 m^3 when the perimeter is equipped with water meters. Otherwise, for each crop and season, the water supply is estimated on a flat-rate basis. This price does not vary according to the year but according to the region and for each perimeter and sometimes according to the crop. However, the price is adjusted in some northern perimeters with a lower price to encourage complementary irrigation of cereals in winter.

Focus region: Gabes-region in Tunisia	-Production of dates and vegetables (tomatoes) with geothermal energy. - An est. 17 Mm^3 is recovered annually by recharging ground water tables. - Exploitation of groundwater is estimated at 28.3 Mm^3/year. -The water table of one of the deep aquifer layers shows an average annual decrease of 2 m. -The mediocre quality of shallow groundwater (salinity between 4 and 8 g/l) pushes farmers to use the deep water table whose waters are less loaded with salts (3 g/l).

5.1 Water and agriculture

5.1.1 Topography and climate

The eastern end of the Atlas Mountains and the northern reaches of the Sahara Desert are part of Tunisia. The rest of the country's land is fertile soil bordered in the north and east with 1,300 kilometres of coastline. Rainfall is a major, though variable, factor, ranging from an average of less than 100 mm/year in the south, to over 1000 mm/year in the extreme north of the country. About 80% of the rainfall is concentrated between October and March. The annual potential evapotranspiration ranges from 1200 mm in the north to 1800 mm in the south (source: Aquastat). In the northern part, the topography is more undulating, leaving relatively little cultivable land in areas of relatively high rainfall. Tunisia's Mediterranean climate with mild winters and sunny springs are suitable for most vegetables.

Due to its geographical position, Tunisia is subject to a strong climatic variability with marked droughts but also the occurrence of torrential rains, and in recent years droughts have become more frequent and more severe, lasting for longer periods. The repeated drought events, combined with the depletion of the aquifers, are causing acute water shortages, affecting the social life of the country, its economy, and the environment (Gaaloul, 2008). It is expected that climate change will result in a significant reduction in rainfall and an increase in the frequency of droughts (Besbes *et al.*, 2010).

Annual average rainfall in the Gabes region is 180 mm. In the North-eastern peninsula of Cap Bon (Nabeul), the average annual rainfall varies between 450 and 600 mm.

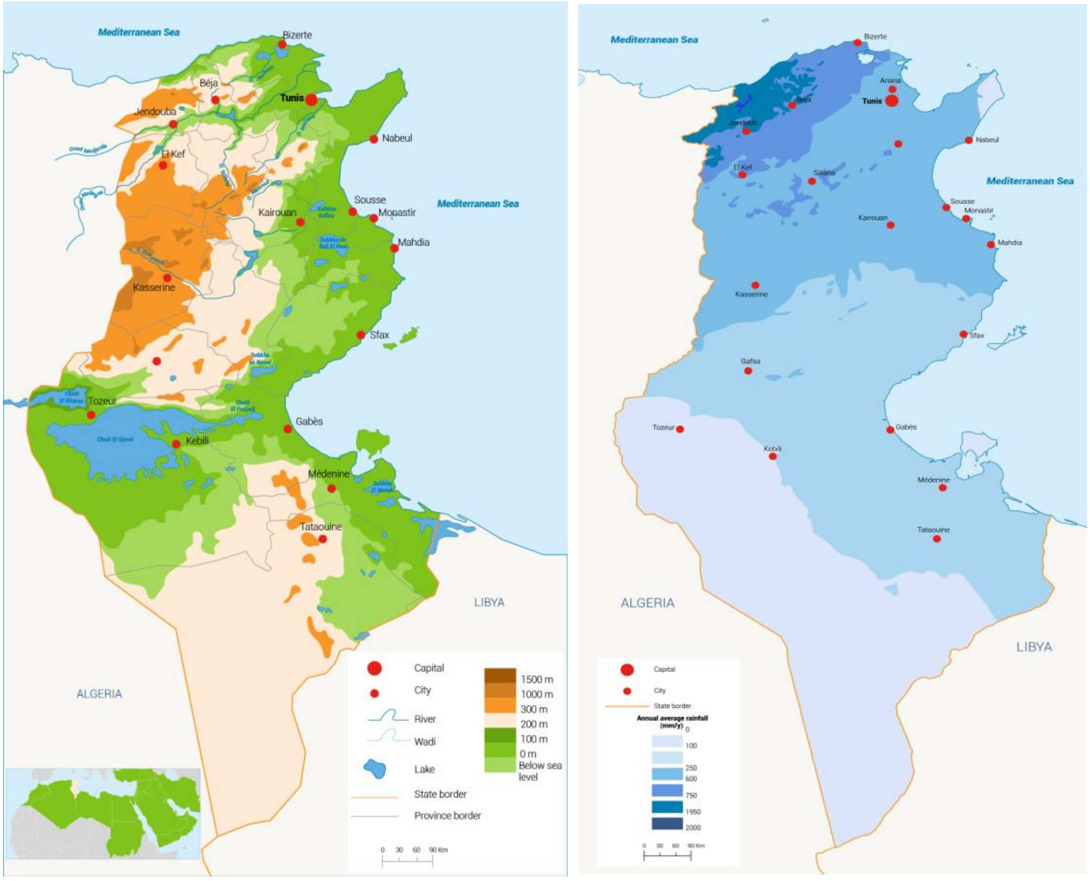


Figure 5-1 Topographic map (m elevation) and annual average precipitation map (mm/y) (Source: fanack)

Climate change

Recent climate projections show a decrease in rainfall from -5% to -20% by 2050 depending on the region, which would gradually increase to reach -10% and -35% in 2100. This reduction in rainfall, combined with an increase in the average intensity and frequency of drought, should result in the exacerbation of pressure on water resources, accentuated by human exploitation, which will increase under the effect of the rise in temperature which would be 1.2 to 2.3˚C by 2050 and reach 2.9˚C and 4.3˚C by 2100 depending on the region. This development will aggravate, in the coming years, the situation of structural water stress that Tunisia is experiencing, with a decline in conventional water resources estimated at about 28% by 2030.

The decrease in surface water would be around 5% on the same horizon, leading to a decrease in stocks in dams and an increased reduction in their capacity following a less frequent completely dried out reservoirs during droughts. Successive periods of drought will cause a decrease in the natural recharge of groundwater and limit the possibilities of artificial recharge by dams. In addition, the losses due to salinization of the coastal aquifers due to the expected rise in sea level would be about 50% of the current resources of these aquifers by 2030, i.e. nearly 150 million m^3.

Water quality will likely decrease, with salinization and greater levels of pollution being the main threats. This means that even in irrigated areas where the reduction in the availability of water in quantity and quality will lead to a reduction in crop yields.

5.1.2 Landuse and agro-ecological zones

In Tunisia, 33% of land is exploitable, 33% are forests and rangelands, and 34% of non-agricultural land. 92% of agriculture is rain-fed and 8% is irrigated (WOCAT, DS-SLM project). Agriculture plays a leading role in Tunisia's economy; however, the sector faces major challenges and Tunisia still depends on food imports. The government of Tunisia is looking for opportunities to increase national food production fitting the current and future climatic conditions. The landuse and agro ecological zones are corresponding to the topography and climate in the region (see also Figure 5-3). The mountains are covered with forests. In the North in less sloping land is cereal production. More downstream towards the coast are the irrigated agricultural lands. The southern part is mostly arid rangeland with a sparse oasis.

The irrigated areas are 435,000 ha in 2018, including 242,000 ha of public land and 193,000 ha of private land. Irrigated land represents about 8.2% of the total suitable agricultural area. Figure 5-2 shows where the irrigated agriculture is concentrated. The vast majority of the area of public irrigated land is equipped with pressurized pipe networks, most often operating on demand and with sprinkler or localized plot irrigation systems. This concerns 75% of the public irrigated land. The surface area of privately (small-scale) irrigated land varies from one year to the next depending on climatic conditions.

Figure 5-2. Locations of irrigated agricultural lands in Tunisia (FAO – AQUASTAT, 2015).

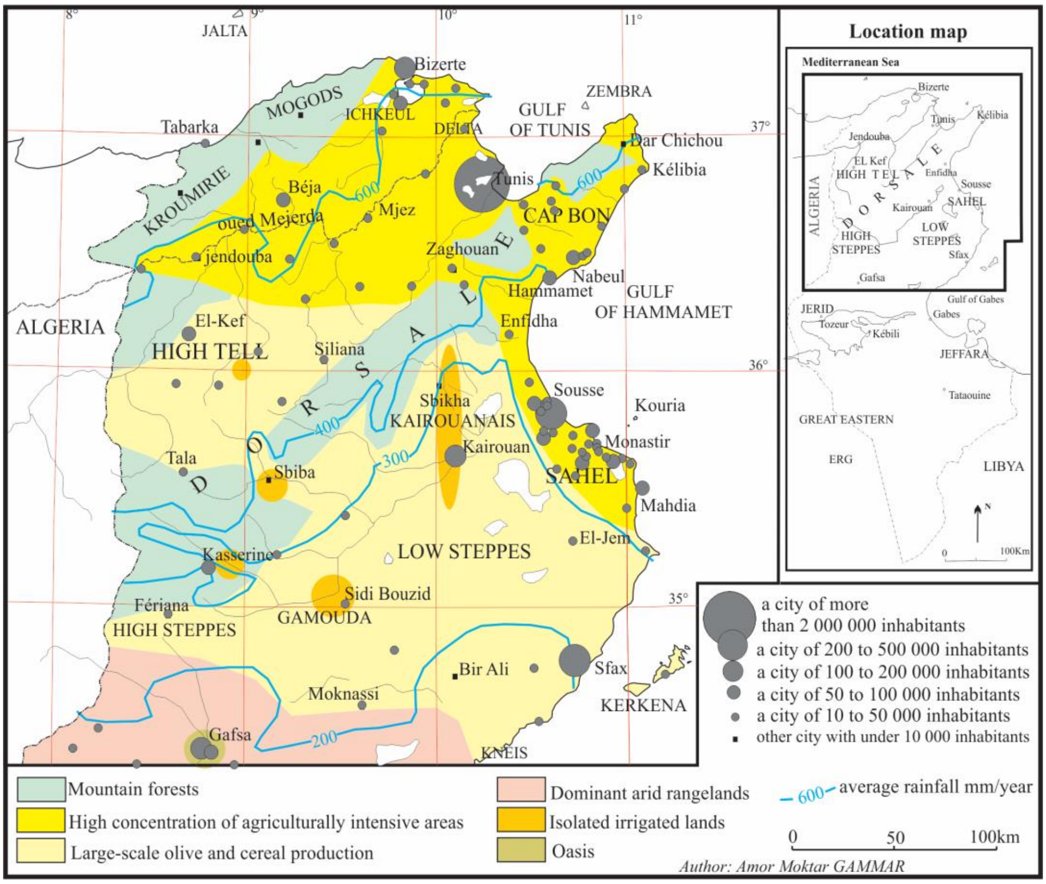


Figure 5-3. Agricultural spatial differentiation in northern and central Tunisia (Gammar, 2019)

Beside the arid oasis agricultural system of the Gabès region based essentially on groundwater irrigated agriculture, the agricultural system of the Cap Bon (Nabeul, north east) region is completely different with irrigated /rainfed agriculture. Thus, the Cap Bon region covers an area of 2,822 km. It has a population of about 787,920 inhabitants (2014) and accounts for 15% of national agricultural production for a useful agricultural area of about 246,000 hectares, or 4% of the country's total. In addition, one sixth of this area is irrigated (41,000 hectares), which enhances the productivity of the agricultural sector which is high. The main agricultural products are (in tons per year): Field crops; Citrus fruits; Spices; Tomatoes; Strawberries; Potatoes; Olives. The region stands out especially for the production of grapes and wine.

Land degradation

Tunisia is troubled by degradation of the land and resources. There is of course the imbalance between water use and renewable water resources. But the main forms of degradation in Tunisia are: 1) erosion (due to rainfall), 2) reduced vegetation cover, 3) salinization, 4) reduced soil fertility. This information was gathered by the 2015 – 2019 project Decision Support for Mainstreaming and Scaling Out Sustainable Land Management (DS-SLM) to help combat Desertification, Land Degradation, and Drought (project financed by GEF and coordinated by FAO; see Figure 5-4).

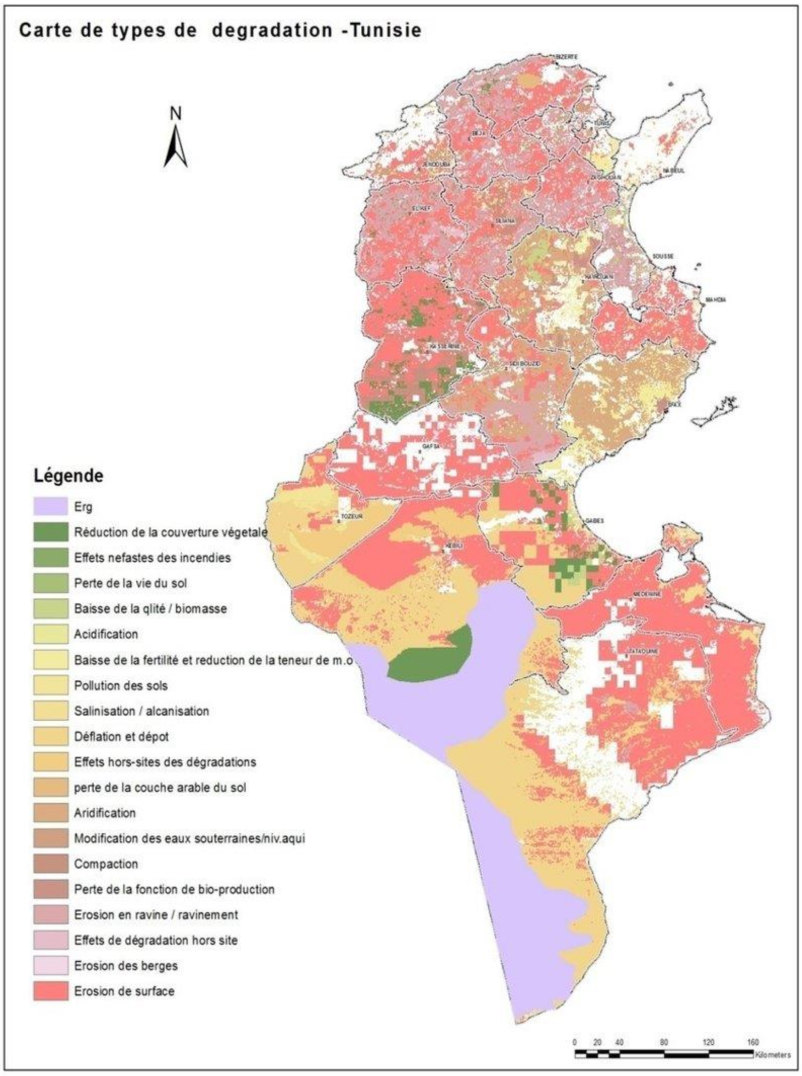


Figure 5-4. Map developed in 2019 by the DS-SLM project indicating the main types of degradation in Tunisia (WOCAT, DS-SLM). Main type of degradation is surface erosion, or (top) soil erosion.

5.1.3 Agriculture and crops

The main crops grown in Tunisia are shown in Figure 5-5. The top ten crops grown by cultivated area averaged over 2016-2018 (latest available data on FAOSTAT) are compared with the top ten crops grown ten years before that (i.e. 2006-2008). The numbers above the bars indicate the yield in t/ha. Table 5-2. The changes in cultivated area and yield of the top ten crops as shown in Figure 5-5. Ranking is based on the mean cultivated area in hectares over 2016-2018 shows the trends in area cultivated and in yield over the ten years presented here.

One of the most noticeable patterns is that of the top ten crops types grown in 2006-2008, only five are still in the top ten 10 years later. The crops that have fallen out of the top ten are almonds, broad beans and horse beans, pistachios, grapes and cereals[2]**.** Newcomers in the top ten are watermelons, chilies and peppers, potatoes, onions and shallots and carrots and turnips. As we can read below, Almonds consume very large

[2] Including inter alia: canagua or coaihua (Chenopodium pallidicaule); quihuicha or Inca wheat (Amaranthus caudatus); adlay or Job's tears (Coix lacryma-jobi); wild rice (Zizania aquatica).

quantities of water in Tunisia, so it is probably a good thing that they are not so widely cultivated anymore.
Even though all the new crops in the top ten are all still relatively minor in cultivated area, there is a clear shift in crops. Of the five that are not in the top ten anymore in the period 2016-2018, all are mainly produced under rainfed conditions. The five crops new in the top ten however are all produced under irrigated agriculture.

Yields of most of the five crops that allow us to compare have increased, most notably barley and dates. The decrease of yield in olive production is also noticeable, especially given the fact that olive yields have increased over the same period in the other two Maghreb countries discussed in the report, Algeria and Morocco.

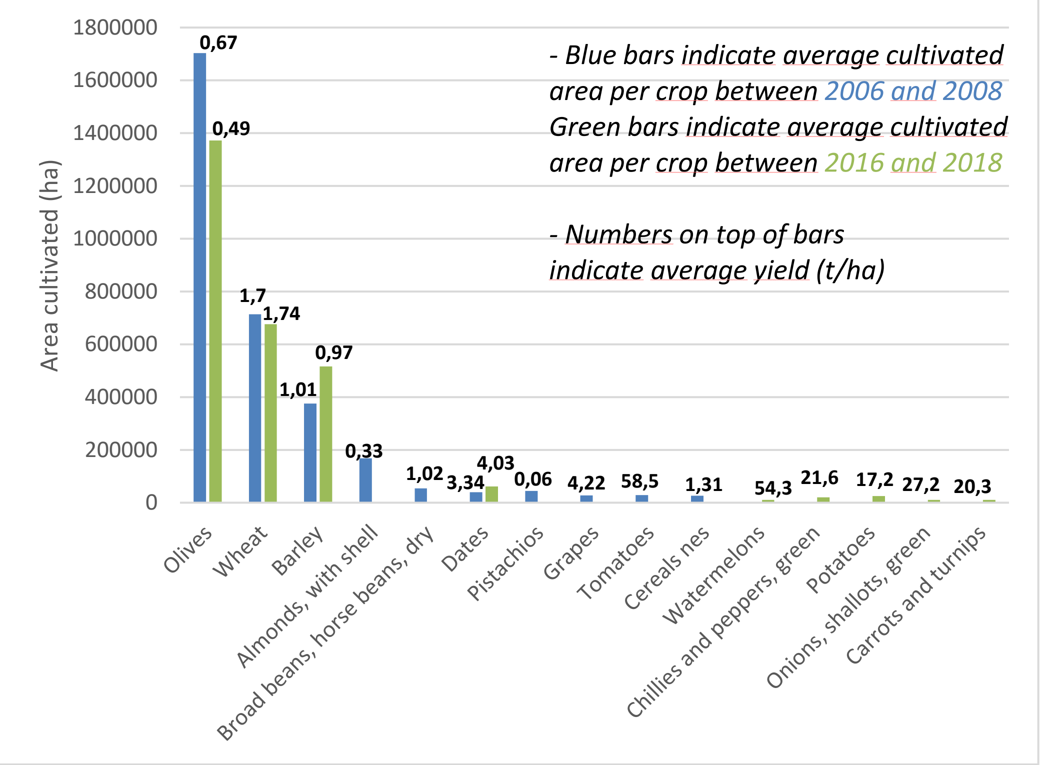


Figure 5-5. Top ten crop production in Tunisia 2006-2008, compared to the top ten crop production ten years later (2016-2018). Bars indicate the total area cultivated in ha, numbers on top of the bars indicate the yield in t/ha over the respective periods. Data from FAOSTAT (2018-2018 most recent available data).

Table 5-2. The changes in cultivated area and yield of the top ten crops as shown in Figure 5-5. Ranking is based on the mean cultivated area in hectares over 2016-2018.

Crop	Change in area over ten years (%)	Change in yield over ten years (%)
Wheat	-5,2	2,5
Tomatoes	-21,3	60,7
Olives	-19,4	-26,0
Barley	37,5	-3,7
Watermelon	N/A	N/A
Chillies and peppers, green	N/A	N/A
Potatoes	N/A	N/A
Onions, shallots, green	N/A	N/A
Dates	53,5	20,8
Carrots and turnips	N/A	N/A

Agricultural water footprint

Vegetable crops and citrus fruits require large quantities of water, especially in summer, and also of good quality. This is the case for tomatoes, strawberries, and citrus fruits. The improvement of water management at the plot level is underway to ensure the needs of the crops in terms of water quantity and quality. The average consumption per hectare varies from 7000 m^3 for a summer cycle of a market garden crop such as tomatoes, to about 10000 m^3 for shrub crops such as citrus fruits. These average figures vary between regions, soils and years

Chouchane *et al.*, (2013) assessed the water footprint of agricultural production in Tunisia and states that the total water footprint of production in Tunisia was, on average, 19 Gm^3/yr in the period 1996-2005. The water footprint of crop production gave the largest contribution (87%). Analysis for different crops types were made and showed that Tunisian almonds have the largest water footprint (WF) per unit of weight, about 20820 m^3/ton, which is more than twice the global average for almonds. Tomatoes have the smallest WF with 120 m^3/ton, which is below the global average. Dates, almonds, figs and grapes are the biggest (blue) water users and show that there is potential for improved water efficiency with these crops (Chouchane *et al.*, 2013).

Looking at economic values of the products per water use, tomatoes and potatoes were the main crops with relatively high economic water productivity, with a Tunisian average of 1.08 and 0.87 US$/$m^3$ respectively (Chouchane *et al.,* 2013).

5.1.4 Water resources

Irrigated agriculture is the most water consuming economic sector with about 80% of the total water resources exploited. The irrigated sector consumes about 2.40 billion m^3 per year of which 80% comes from groundwater and 20% from dams. The irrigated perimeters of the North make particular use of surface water. In the Centre, groundwater supplies most of the irrigable surfaces. In the South, it is the deep-water tables that are not very renewable that are solicited. The use of groundwater and overexploitation is intensifying, due to the spread of illicit wells.

The potential water resources are estimated at 4.8 billion m^3 per year in 2014, of which 4.38 billion m^3 per year are renewable (OSS, 2015). Groundwater represents a significant share of the renewable resources for Tunisia, and the transboundary NWSAS aquifer system is the main source of groundwater for the country. Current withdrawals from the aquifer (by Tunisia, Libya and Algeria combined) exceed three times its recharge capacity (3.2 billon m3 in 2016) (UNECE, 2020). For Tunisia, the non-renewable used groundwater resources was estimated at 0.65 billion m^3/year in 2014, and the withdrawal for irrigation at 2.3 billion m^3/year (OSS, 2015).

Surface water

At the end of 2018, Tunisia has 37 dams with a total reservoir capacity of 2,285 Mm^3, 258 hill dams with a total capacity of 365 Mm^3 and 913 hill lakes with a total capacity of 58 Mm^3. Of the 37 dams, 32 are still in operation. A platform for remote management of the dams is under way with the installation of telemetry equipment, the implementation of a real-time teletransmission system, data centralization and the visualization and management of the teletransmitted information.

The hydraulic situation of the dams indicates a decrease in their total useful capacity of about 20% due to silting. For example, the silting of the Mellègue dam has led to the construction of a new dam on the same basin. The silting of the Sidi Salem dam is silted at about 34% of its capacity with an annual loss of 8.31 Mm^3/year. The dams of Siliana (52% silted), Sidi Saad (36%) and Nebhana (32%) are in a similar situation. Concerning the hill lakes, the initial capacity was 94.5 Mm^3. The capacity in 2018 is reduced to 51.5Mm^3. Figure 5-6 shows the interconnectedness of the dams in Tunisia.

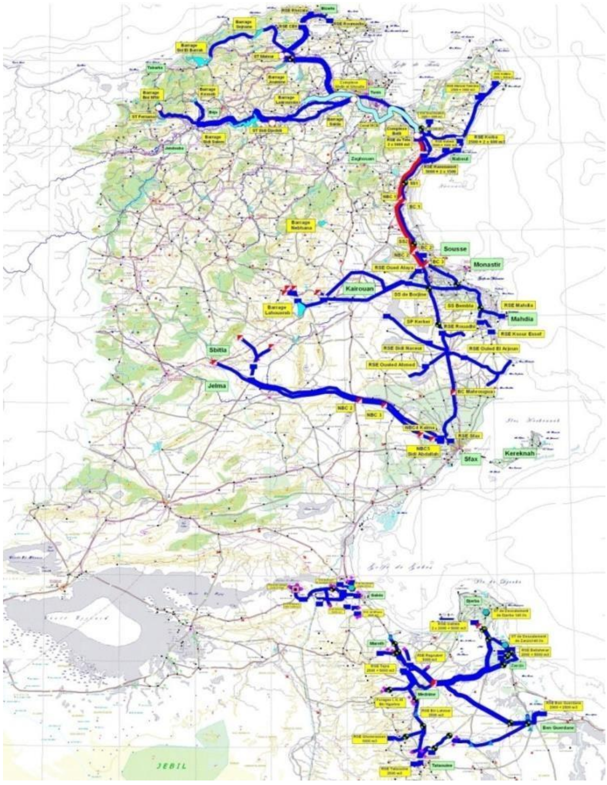


Figure 5-6. Map of water transfer networks (channels) by which the largest dams in the North are interconnected. The channels make it possible to carry out regulations according to the available stocks in each reservoir and to control their salinity. This transfer is done by costly pumping.

Groundwater

The groundwater resources are estimated at 2150 Mm^3/year, out of which 745 Mm^3 come from shallow aquifers (depth less than 50 m) and 1380 Mm^3 from deep aquifers weakly renewable from deep aquifers in the South. An estimated 610 Mm^3/year are non-renewable (Hoekstra, 2013). The north of Tunisia is distinguished by its richness in shallow groundwater. The north has access to 55% of the shallow ground water resources, the central part 30%, whereas the south contains only 15%. Regarding deep aquifers, the south contains 58% of resources, the Centre contains 24%, whereas the north contains only 8%, so very comparable numbers to the shallow ground water resources.

The South of Tunisia shares large groundwater reserves with Algeria and Libya. These water resources are only partially usable and partially renewable. Groundwater exploitation continues to increase, with an overall exploitation rate of 117% in 2015. For the deep aquifers, the total exploitation of deep aquifers reached 1895 Mm^3 in 2016. This exploitation represents 133% of the total deep-water resources estimated at 1422 Mm^3. 60% of the total exploitation of the aquifers is located in the South.

The aquifers of the North and the Sahel are under-exploited in relation to their resources. This could be due to the use of surface water in the North and the poor quality of the deep groundwater in the Sahel, which is mostly brackish water. Overexploitation accentuates the threat of water quality degradation, whether through salinization or pollution from agricultural sources. The contribution of (artificial) groundwater recharge to the reduction of this exploitation rate remains insufficient.

Trends in water resources

In the region Chott Fedjej springs are located that are fed by the aquifer of the Continental Intercalaire (CI). Since 1974, the discharge of the springs was monitored annually. The flow has been steadily on decrease since the 1950 and are stable around 50 l/s since the year 2000 (Figure 5-7). The same reduction in flow from springs can be seen in springs that are fed by the Complexe Terminal (CT), only these springs have dried up completely since the 1980s.

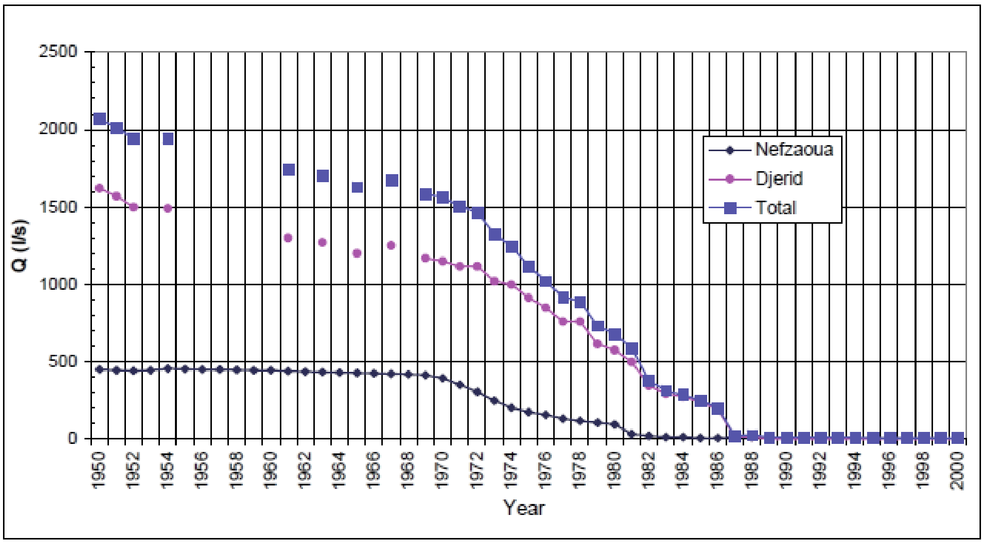


Figure 5-7 Record of the flow of the Complexe Terminal springs in Tunisia from 1950s to 2000. Source OSS, 2004.

A clear trend of lowering groundwater tables is perceptible in the deep groundwater of Tunisia. There are zones of for example Nefzaoua – Djerid where it is clear that exploitation of aquifers is intensive by grouped wells in several well fields (OSS, 2004). In the deep groundwater aquifers, the effect of abstraction is clearly visible in lowering groundwater tables (Figure 5-8). Chapter 2.2.2 provides more detail about the drawdowns in the CI and CT layers of the NWSAS.

In the Gabes region, it is estimated that 17 Mm3 of groundwater is recovered annually by recharge. Exploitation is estimated at 28.3 Mm3/year. Here, the water table of the CI is captured by all the drillings on depths varying from 720 to 1200 m. The piezometry of this water table shows an average annual decrease of 2 m.

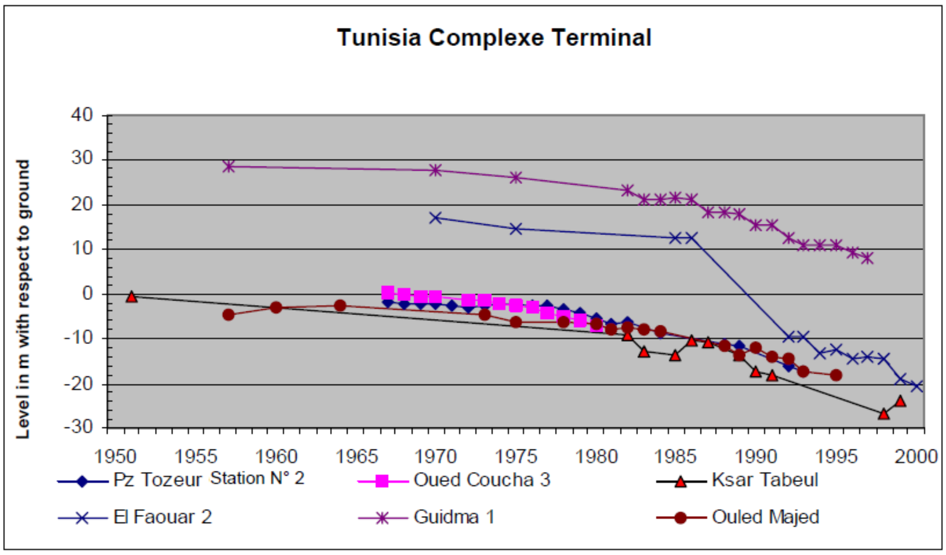


Figure 5-8. Examples of drawdowns of aquifers from the Complexe Terminal in Tunisia, an aquifer of the NWSAS system. Source OSS, 2004.

Another interesting development in groundwater abstraction is the subsidy by the Tunisian State of photovoltaic (solar powered) installations for pumping in agriculture, with the aim of promoting renewable energy. This has led to contradictory effects to the preservation of water resources, with unlimited abstraction by making the resource completely free.

Trends in Salinity

Salinisation of groundwater is widespread in Tunisia, linked to intensive exploitation; to the geochemical nature of geological deposits; and sometimes to leaching of irrigation water. In Tunisia, the values of total dissolved salt of the water of the CI aquifer range between 1500 and 7020 mg/l.

In Tunisia the salinity of the CI aquifer is relatively high compared to other regions of the Saharan basin. This seems to result mainly from the lithological nature of the aquifers, that contain more clays and gypsum. Salinity generally increases towards the south and in older (fossil) groundwater: much of the groundwater in the south and parts of the centre of the country has total dissolved solids (TDS) of more than 3 g/l; and in much of the centre and north groundwater TDS is typically between 1.5 and 3 g/l. The lowest salinity values are found in the least deep aquifer layers. Saline intrusion in the coastal aquifers is also problematic (British Geological Survey, 2021, and OSS, 2004). Also, near the inland salt lake Chott, a rise in salinity values is visible. For example, Figure 5-9 shows the rise of salinity in a well in the waters of the CT in the Kebili peninsula of Nefzaoua.

The mediocre quality of shallow groundwater in Gabes region (salinity between 4 and 8 g/l) pushes the farmers to use the deep water table whose waters are less saline (3 g/l). Most water is used for irrigated agricultural lands. The piezometry of this water table shows an average annual decrease of 2 m. The waters of this nappe present a total mineralization varying from 2.7 g/l to 4 g/l and a high temperature ranging from 63 to 70°C.

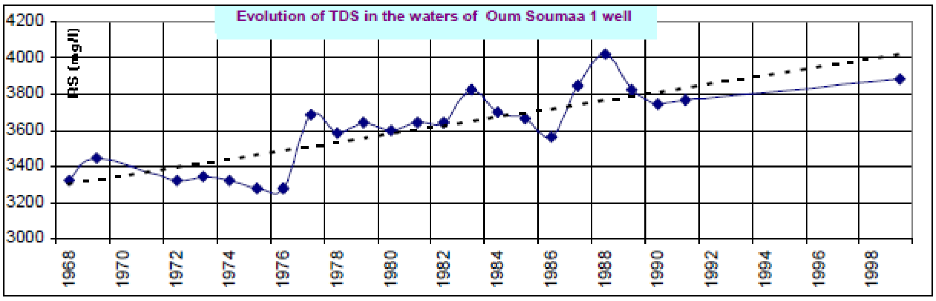


Figure 5-9 Example of the evolution of water salinity of the Complexe Terminal in the Kebili peninsula (Nefzaoua- Tunisia) for a well of Oum Soumaa (Source OSS, 2004).

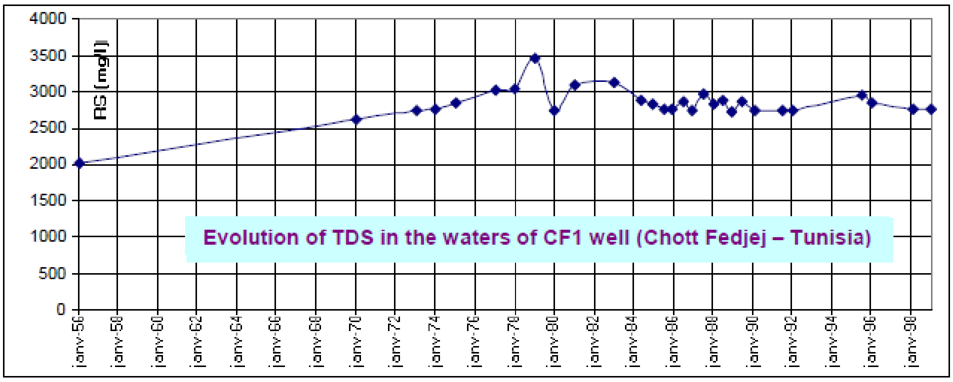


Figure 5-10 Example of the Evolution water salinity of the Continental Intercalaire in Tunisia In Chott Fedjej. Source (OSS, 2004). There is no clear trend visible over time for the evolution of water salinity.

There is no clear trend visible over time for most wells (see also example Figure 5-10). Small variations in salinity levels may occur as it is a multi-layered aquifer system. However, the salinity is expected to increase to a certain salinity level (ceiling) with the intensification of groundwater abstraction due to homogenisation of water from different layers (OSS, 2004).

In the framework of the "Coastal Resilience" project "Addressing climate change vulnerabilities and risks in vulnerable coastal areas of Tunisia" with the support of UNDP, projections of changes in salinization at the level of coastal aquifers in highly vulnerable sites were established. They clearly highlight the increasing and irreversible salinization of these underground resources by 2100, even for a moderate climate change scenario. These consequences are further aggravated by the increased pressure of withdrawals from the resource due to the increased needs for drinking water and for irrigation, all the more so as Tunisia's resilience to climate change is limited by the low water reserves.

5.1.5 Developments in irrigation

The following irrigation techniques are applied in Tunisia:

- Surface irrigation is applied on 23% of the irrigation area. Efficiency is in the order of 70% for improved gravity irrigation.
- Drip irrigation has become more important in Tunisia (49%), and is subsidized by the government. Efficiencies are around 90 to 95%, but the uniformity of watering depends on the choice of equipment and its hydraulic characteristics.
- Sprinkler irrigation (28%). Sprinklers are frequently used for irrigation of cereal crops, forage and some vegetable crops. The hydraulic efficiency is around 85 to 90% (so low water losses in the conveyance system). Water efficiency for field application will be lower (around 50-60%).

The new technologies introduced on irrigation equipment are improving the efficiency, while reducing the proportion of labour in the works. These technologies become more widely adopted by farmers as Tunisian agriculture is in a transition phase from traditional agricultural systems to innovative sustainable agricultural systems. The focus of the government is mainly on the smallholders as they present the majority of the farmers and are therefore the biggest future challenge. Technological advances in the manufacture of pumping equipment, supply and distribution pipes, sprinkler and localized irrigation equipment have clearly catalysed their expansion. These advances are regularly presented to the various stakeholders in the sector at various events, exhibitions, workshops and demonstration days.

Regional specialization

Currently, the trend in the production of irrigated perimeters in Tunisia is towards regional specialization which optimizes the advantage of seasonal climatic and pedological differences. Thus, we find the fruits in the Sahel, along the coast and in the south of the country. Apples and pears are produced mainly in Kasserine and Kef. In Cap Bon citrus fruits, strawberries, tomatoes, vines, and potatoes are produced. Winter vegetables and tomatoes are often grown in Sidi Bouzid and Kairouan. Dates and vegetables are produced in Tozeur, Gabès and Kébili. In the latter in greenhouses also geothermal water is used for oasis irrigation and heating, irrigation, and soil disinfection with augmented production compared to normal greenhouses.
Northern productions include milk, meat, cereals and winter or summer vegetables.

The Governorate of Gabes is characterized by a lower arid climate for the coastal areas and Saharan inland. Surface water is partially used for small facilities (tabias, jessours, majel and cisterns) but a good part is discharged towards the sea or the Sebkhet (a salt lake). Olive trees, date palms, almond trees and pomegranate trees are part of arboriculture in the Gabes region. All the perimeters are monitored by the agents of the CRDA of Gabes (*Regional Commissariat for Agricultural Development of Gabes* or *the Commissariat Régional au Développement Agricole de Gabes*). About 73% of the irrigated perimeters are equipped with water saving systems with 66.3% improved gravity surface irrigation, 32.4% localized drip irrigation and 1.3% localized sprinkler irrigation. Intensive cultivation is practiced with high profitability.

Desalinization

Water desalination is strategic for Tunisia. But there are some constraints for desalinization for agricultural production: the high cost, the high energy consumption, the desalination processes are energy consuming, and the impact on hydro-ecosystems. To lower the cost and consumption of energy, photovoltaic (solar energy) processes are being developed. In terms of environmental impact, solutions are being sought to reduce the discharge of water with a high salt content, which can lead to the sterilization of the receiving environment (the salt concentration of discharged water is about three times that of the water used). These constraints are less intense when the water to be desalinated comes from groundwater with about 5 g of salts per litre. This is not the case for sea water with about 35 g of salt per litre. However, groundwater is already overexploited and often affected by the intrusion of salt water from the sea. As a result, water desalination is carried out in Tunisia with great caution.

The desalination currently underway in Tunisia is based on increasingly large plants when the water is intended to supply populations and small units when it comes to satisfying the needs of high commercial value crops such as greenhouse and nursery crops.

Desalination is practiced particularly in the South East to meet the drinking water needs of large cities and tourist areas. Several large farms are also equipped with desalination facilities to reduce the salinity of irrigation water. However, the discharge of brine poses a major problem with negative impacts on hydro-ecosystems. Desalination is practiced particularly in the South East (also Gabes region) to meet the drinking water needs of large cities and tourist areas.

Government support

The irrigated sector has become in recent decades a strategic component for the country's food security and its economic development (job creation and exports). The State has widely supported and continues to support its development, now opting for the rehabilitation of infrastructure, the optimization of its management and the control of water consumption by restoring irrigation systems, in a context of confirmed scarcity of the resource.

Modern technologies such as remote sensing and satellite data are used very little by the government and are limited to a few studies to estimate crop yields and floods. These studies are mainly conducted by or with the National Remote Sensing center (Centre National de Télédétection, CNT). Research is underway for their use on a larger scale for monitoring soil surface and water status and estimating crop water needs and consumption in some regions. Trials are also being conducted on the use of UAVs (drones) for the detection of plant diseases, among other things.

Agricultural Development Groups

Irrigation schemes are managed by the *Agricultural Development Groups* or *Groupement de Développement Agricole* (GDA,). At the end of 2018, there were 2,703 GDAs. The GDAs have difficulties that limit their financial autonomy and the effectiveness of their management. Among these difficulties are the lack of involvement of end users, the limits of volunteer work, variable and often weak technical expertise, and failures in the administrative and financial management of the GDA. A specific plan provides several actions to improve the governance of the GDAs and their operation.

National irrigation water saving program

The national irrigation water saving program has enabled 405,000 ha to be equipped with water saving equipment, i.e. 93% of the perimeters. Localized irrigation has gradually replaced other equipment and now accounts for 49% of the equipped areas (198,000 ha), compared to 8% in 1995. Over the same period (1995 - 2018), sprinkling increased from 28% to 47% (113,000 ha). Improved gravity-fed irrigation is applied for the irrigation of 23% of the perimeters (94,000 ha). With the entry into force of the new Investment Incentive Law in 2017, subsidies for water saving equipment have begun to increase significantly.

5.2 Water governance

Historically, Tunisia's agricultural system was based on small family farms that grew subsistence crops with little market integration, but larger agricultural enterprises are increasingly prominent. Public land may be leased by the government to private farmers or managed directly by the Ministry of Agriculture. Foreigners cannot own agricultural land but may obtain long-term leases.
The government of Tunisia is looking for opportunities to increase national food production fitting the current and future climatic conditions. This would strengthen national food and nutrition security, generate employment and income, and save costs through import substitution. To achieve this, the Tunisian government launched an agriculture and rural development strategy

The Ministry of Agriculture and Hydraulic Resources or Ministère de l'Agriculture et des Ressources Hydrauliques et de la Pêche (MARHP) sets policies concerning conventional water resources in Tunisia, while the Ministry of Environment and Sustainable Development governs sanitation, wastewater and environmental planning.

5.2.1 National and regional plans, policies

Essentially, there is the Water Policy (Water Code, Code des eaux), which covers all aspects related to water. Alongside this code, there are sectoral strategies, specific national programs, regulations, and standards. There is also a National Water Council which defines the main strategic direction of the water sector.

For nearly three decades, awareness has been raised on the limits of a policy focused on the development of supply. Indeed, this water supply can no longer meet the qualitative and quantitative demand in certain densely populated and/or structurally water-deficient regions. Since the 1990s, Tunisia has thus developed a demand management policy, working for this purpose to carry out a series of institutional, economic and technical reforms concerning the revision of the water code dating from 1975 and the saving of irrigation water within the framework of the National Irrigation Water Saving Program started in 1995. This program is promoted by the decision to increase the investment subsidy granted to modern irrigation equipment.

The to-be-developed new water code takes into consideration the current major stakes of the water sector:

- Implementing demand management
- Ensure more sophisticated water governance
- Controlling extreme phenomena: floods and droughts
- Progress towards sustainable groundwater management
- Improve the development of irrigated perimeters while controlling water savings
- Relaunch rain-fed agriculture
- Protect water resources against degradation
- Controlling energy consumption

The new water code is in its final phase. A first draft has recently been transmitted to the Presidency of the Government for approval, which has submitted it to the Parliament. The institutional aspects of the water code treasure the evolution towards demand management. Since its independence, Tunisia has established water resource strategies according to an approach essentially based on supply management.

The elaboration of the new Water Code, particularly in the area of improving governance: regulatory body, bringing decision-making levels closer to the local level (regional water councils). Water Police is one of the tools for implementing the new Water Code. A twinning project has been initiated for the organization of the water police and the possible prospect of the evolution of a current structure into a water agency whose missions should promote the preservation and management of water resources and the cooperation of water stakeholders. Its full implementation will probably still take time.

Strategic plans

In Tunisia, the National Water Program was adopted by the government in 1995. This program aims at efficient and economical valorisation of water use and maintaining water demand to a compatible level with regard to the available resources. The program includes the improvement of water use efficiency of collectively irrigated areas and the improvement of individual irrigation systems. A master plan for water use has been implemented for each of the country's three natural regions the north, the centre and the south. The master plans include provisions on the transfer of surface and groundwater and on flood protection for large urban centres. Three main strategic plans were implemented:

- The 10 years strategy of water resources mobilization initiated for the 1st time in 1990, the Decennial Water Resources Mobilization Strategy (1990–2000),
- It's complementary strategy for water resources mobilization (2001–2011). The strategy 2001-2011 aims to mobilize 95% of conventional resources by building dams, reservoirs and flood runoff infrastructure, and to develop non-conventional resources such as recycled and desalinated water.
- The long-term strategy (Water Strategy 2030) mainly builds up on the Water Master Plans for the north, centre and south of Tunisia. The Water Strategy 2050 is under preparation.

Water saving is promoted and implemented under Tunisia's water saving program: Programme National d'Economie d'Eau en Irrigation, PNEEI (described above). PNEEI promotes the use of more efficient techniques at field scale, where the *Water sector investment program* or *le Programme d'investissement dans le secteur de l'eau* (PISEAU) addresses the irrigation perimeter scale (infrastructure). The programme PISEAU is a series of investment projects in the water sector that started in 2001. The programme focuses on infrastructure and rehabilitation of existing irrigation perimeters and the development of new perimeters. The programme is financed by the World bank and KfW development bank. The follow-up of PISEAU, project PISEAU II (2009-2013), aimed at an integrated water resources management and the improvement of rural living conditions.

5.2.2 Important Government project on reuse of treated wastewater

Circular economy combines significant growth and employment opportunities with an intelligent consideration of the environment and resources. It aims to reduce resource use and waste while continuing to generate economic wealth. This is the case with the reuse of treated wastewater (TWW). The use of TWW in Tunisia is part of a national strategy to mobilize and use the water, where it contributes to the protection of the environment, the sustainability of agricultural production, the save water and the expansion of irrigated areas. It also contributes to the reduction of saline water intrusion in the coastal areas through groundwater recharge. On the other hand, it provides nutrients to the soil and plants and thus reduce the total needs of chemical fertilizers and increased economic returns to farmers.

The first Tunisian experience with the use of TWW for irrigation in 1965 was implemented in order to protect the citrus region of Soukra affected by the overexploitation of groundwater and the subsequent decrease of the piezometric level. With the success of this experiment, and due to the increasing amounts of available TWW, the government increased the number of projects that uses TWW for irrigation, and to water golf courses, whenever it is technically and economically feasible.

The current TWW comes from 122 Wastewater Treatment Plant (WWTPs) located in many cities and villages (ONAS, 2018, Figure 5-11). TWW quality is subject to regular and ongoing monitoring by the National Sanitation Utility (ONAS) as well as other intervening structures, namely: the National Agency for the Protection of the Environment (ANPE), the Ministry of Public Health and the Ministry of Agriculture. The estimated TWW volume was about 270 million cubic meters (Mm^3) in 2018. TWW exploitation remains weak as about

75% of this water is disposed into the sea and valleys, and the rest is used for various purposes:

- Agricultural areas: 32 WWTPs irrigate 33 irrigated perimeters, 8530 ha in total of which only 30% is actually irrigated with TWW. The volume exploited for irrigation was 14 million m^3 in 2018.
- Recreational purposes: 8 WWTPs irrigate 10 golf courses (1040 ha); In addition, 27 green spaces (parks, gardens and roadside green spaces; 450 ha) are irrigated.
- Reclamation for resource conservation: 2 WWTPs for groundwater recharge.
- Industrial valorisation: it is still very marginal, and little considered; 1 WWTP (Gafsa) for irrigated area and industrial use (Chemical Group).
- Environmental valorisation: 33.5 Mm^3 for the benefit of wetlands / agroecological zones.

The use of TWW by the agricultural sector has increased from 33% to about 63% in the North. The use of TWW for irrigation remains weak in other irrigated areas, for several reasons, such as the absence of adequate facilities for the storage of water due to the inconsistency of irrigation peak periods and periods of significant exchange of water treatment.

With the intensification of irrigated areas by TWW legal and legislative texts were developed for the use of TWW to organize for the different uses. There is for example a list of crops that can be irrigated with TWW and norms were developed for the maximum level of chemicals and biological quantities for agricultural purposes.

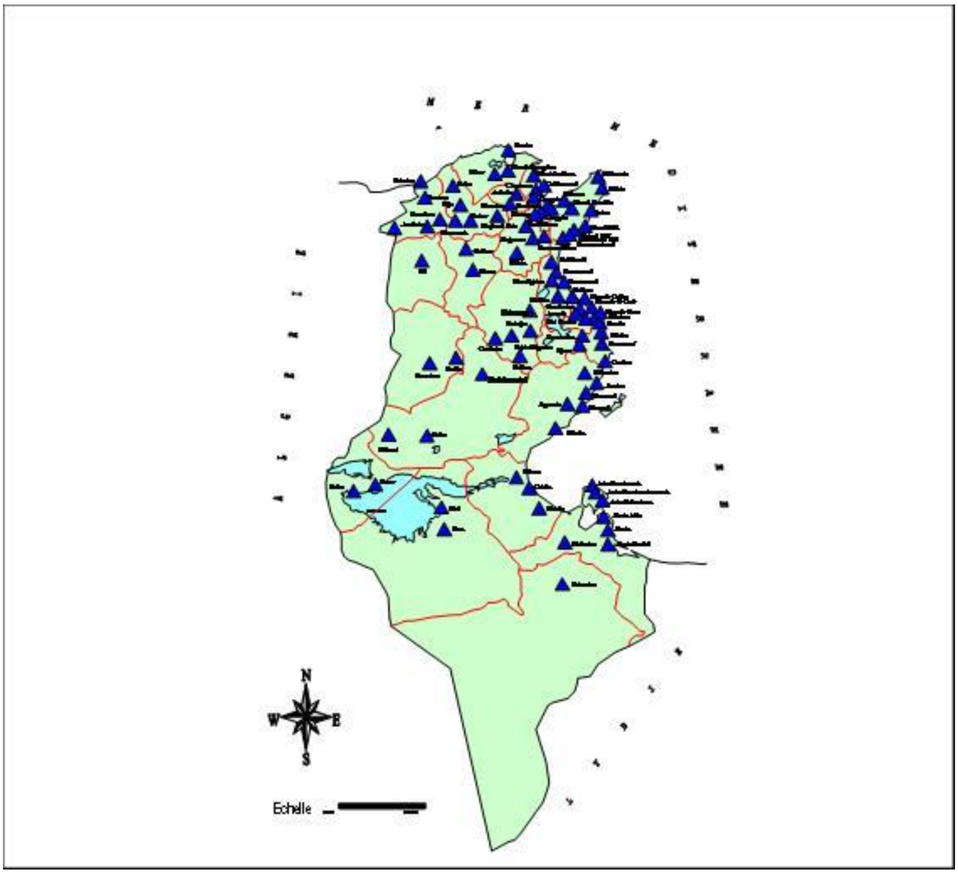


Figure 5-11 Location of Wastewater treatment plants (ONAS, 2013).

5.2.3 Implementation and Water resource management

Tunisia has begun to implement the commitments of the Paris Agreement. At the institutional level, it has set up an objectives-based management unit to carry out the program for monitoring and coordinating activities relating to the implementation of the "Paris Agreement" on climate within the framework of the United Nations Framework Convention on Climate Change. Its missions are described in Government Decree No. 2018-263 of March 12, 2018. They place great emphasis on coordination between stakeholders to implement the Agreement by 2030.

At the operational level, the process of developing the National Adaptation Plan for the second component of the plan relating to food security and adaptation to the agricultural sector was launched in August 2018. It aims to strengthen the adaptive capacity of agricultural activity, to ensure food security, coastal protection, and water resources. Adaptation in the water sector has a prominent place in the communication.

The National Portfolio of Adaptation Projects includes projects in the water sector: Renewable Energy, Desalination, Early Warning System (EWS) for Flood Management, Development of the Intelligent Drinking Water Network, Development of a large-scale program on the use of non-conventional water in irrigated agriculture (desalination and reuse water), Adaptation of Rainfed Agriculture and Watershed Management to Climate Change, Assessment of Erosion Status and Inventory of Water and Soil Conservation Works.

5.3 Exemplary developments and inspiring partnerships

The demand for tasty, high-quality tomatoes continues to grow and tomatoes are eaten more and more frequently not only in summer, but in winter as well. To overcome lower winter productions, Agro Care BV with support of the Tunisia government and support from the Dutch entrepreneurial bank FMO, have now 10 hectares of greenhouses complex according to high Dutch standards and the JV organisation is still expanding.
Again others like the Dutch companies like the Rijkzwaan (the no. 4 vegetable breeding company in the world) have subsidiaries and distributors in Tunisia for developing new markets on new varieties and top-quality seeds.

Most experts reported that they are not much aware of involvement of Dutch companies active in Tunisia that provide services related to improving water use efficiency and/or agricultural sustainability.
But there are some like the Dutch company Hoogendoorn that provide sustainable and user-friendly automation solutions for different kind of horticultural business worldwide. Including the integrated greenhouse management of water, energy and cultivation where they cooperate closely with their customers, partners and universities on sustainable horticultural solutions that deliver added value to crop production and profit. Together with their local partners they deliver solutions, training, recommendations, service and support. The company is currently busy implementing more sustainable organic production at several locations, also in Tunisia.

6 Maghreb challenges

6.1 Facing the challenges

That water is scarce and will become scarcer in the three Maghreb countries in the near future is not a new finding. The challenge lies in making smart use of the available water in a more efficient and sustainable manner and to minimise water losses. In addition, other (non-conventional) water resources have the potential to be exploited more. For example, considerable amounts of brackish water are available. This water can of course be desalinized, but this would make the water expensive and could therefor lead to excessive food prices. Perhaps preferable is to explore the potential for direct use of saline water, as already happens in the Maghreb countries to some extent when there is no other water available to farmers. Also, treated waste water could be used more broadly and effectively.

Below, we elaborate on important challenges that all three countries face to a greater or lesser degree. Once the challenges and some of the underlying reasons are known, the opportunities also become visible. Those will be outlined in chapter 7.

6.1.1 Over-exploitation and deteriorating quality of groundwater resources

In general, groundwater resources are over-exploited throughout the Maghreb region. This means that groundwater levels drop, i.e., more water is consumed then is replaced by natural recharge.

With falling ground water levels, the water quality of the groundwater also declines. Several regions experience groundwater quality declines mainly due to seawater intrusion, the dissolution of evaporitic rocks and carbonates, nitrate pollution and increases in natural salinity.

The resulting deficit and reduced water quality is mainly due to ineffective groundwater management, and a lack of understanding of the resource. An increase in the number of unregistered and poorly managed wells along with inadequate coordination between water authorities in some regions, further decreases groundwater levels and hamper tackling the various challenges efficiently.

6.1.2 Climate Change and regional differences

Current climate change projections suggest an increase in the frequency, intensity and duration of droughts accompanied by a decrease in precipitation for all three countries. As described in the earlier chapters, there are considerable regional differences in climate, transitioning from a Mediterranean climate in the north to arid climates in the south. As a result, water-agri challenges are perceived differently and investments in certain agricultural practices differ as well. For example, in the north, water is not considered to be a limited resource as much as it is in the south, and as such, farmers hardly invest in water-use efficient farming techniques.

6.1.3 Sedimentation, siltation and dam performance

The governments mobilise considerable resources to secure water resources by building large and small dams, reservoirs, transfer pipelines, river defence works, drinking water treatment stations, wastewater treatment stations and water desalination stations, agricultural drainage systems and so on.

The performance and efficiency of dams and reservoirs deteriorate due to high sedimentation rates upstream and structural leakage. Additionally, they suffer from high rates of evaporation. Sedimentation due to upstream soil erosion often leads to increased siltation of particles of sand, mud, and other materials in the dam reservoir, consequently lowering storage capacity but also water quality in the reservoirs. For example, due to the silting up of dam reservoirs, to date Morocco has lost 2,411 million m^3 of the total capacity of its dams.

With more than 100 large and small dams and reservoirs planned for 2050 in the three countries (ICOLD, pers. comm.), these drivers of change signify major challenges for current and future dam, reservoir and water infrastructure.

6.1.4 Water losses between dam and farmer

Significant water losses can also occur between the water infrastructure listed in the previous section and the location of water use. Indeed, various experts from the Maghreb indicate the immediate need to tackle these losses from dam to farmer/crop.

Adoption rates of newly introduced water-saving technologies (see chapter 7) are proving to be slow. There is good knowledge at universities in the countries, but it has proven difficult to get the right knowledge of water-saving techniques and how to manage crop water requirements to the farmers (Michielsen, personal communication, 2020).

6.1.5 Salinisation of groundwater

Most aquifers in all three countries contain saline groundwater. Salinity levels have increased over time and will most likely rise further in the future. Generally, the salinisation comes from the parent material (evaporitic rocks & carbonates) and near the coast, from seawater intrusion.

6.1.6 Over-irrigation of crops

Even though not quantified in this study, there are reports that it is likely that farmers frequently over-irrigate their crops in all three countries. This is caused in part by too low water pricing combined with limited available knowledge on crop water requirements. In addition to water loss and lower water-use efficiency, over-irrigation can also result in lower yields and increased disease pressure on the crop.

Over-irrigation is a challenge in achieving efficient water use that cannot be straightforwardly mitigated by improved irrigation techniques. For example, it has been shown that in Morocco, farmers that used drip irrigation applied up to five times as much water to their crop as was required. In Morocco, with improved water management practices, i.e. a combination of efficient water technologies and preventing over-irrigation, ~30 to 50% of the water used in open field irrigation could be saved.

This shows that capacity building concerning water problems and how to use water resources more sustainably is of crucial importance.

6.1.7 Energy

Many of the technological advances in the water and agriculture sector are energy-intensive. The Maghreb faces challenges in terms of controlling energy consumption in relation to water and food security.

This is already noticeable in regions characterized by limited energy resources availability, growing energy demands and the continued rise in energy costs. The production, treatment, transfer and distribution of water requires large quantities of energy, mainly electric.

The energy market has shown tremendous growth over the last decade, and, in Morocco, this market is progressively opening up to private investment (RVO, 2018). Direct electricity consumption in the agricultural sector is growing steadily (5-10% on average), of which a fair share is energy consumption of irrigation schemes. The specific energy consumption was not quantified in this study and varies between regions, but in general the increase in consumption can be attributed to deepening wells and boreholes following the lowering of the piezometric level of overexploited groundwater resources.
Hence, there are great challenges for the respective governments to address the Water, Energy, Food Nexus to consolidate the reforms currently underway described in the country specific chapters, on a long-term perspective of the Maghreb region.

6.1.8 Post-harvest processes

Insufficient quality of transport, storage and processing lead to post-harvest losses. The quality of agricultural products is sometimes insufficient for export, and even on internal markets farmers may get lower prices for their products due to inconsistent quality. It remains a challenge to optimise value chains, food storage, reduce waste and improve export quality. When storage of vegetables improves, farmers can improve the value of their products since the sale of a single product, for example potatoes, can be spread over a longer period of time. That would be beneficial for the farmers, who now harvest and sell all their potatoes at the same time of year, decreasing the value.
There is a challenge in the provision of technical support in the after-sales business process (of cold stores, greenhouses, etc) in Morocco. For the installation of for example a cold store, often a (Dutch) technical team visits Morocco or another Maghreb country for the installation process. But in the likely event of a (minor) technical difficulty after installation, local technicians should be able to fix the problems quickly. Such technical staff is available, but not in large numbers. They are also expensive. This is another potential direction for capacity building.

6.1.9 Legal system and implementation

For many stakeholders we talked to, it was unclear how the legal system in their respective countries operates in practice. It is believed that legal policymaking and cooperation may improve by defining the coordination between various ministries and organizations relevant for the water-agriculture better. This can increase the efficiency of joint action between ministries.
Although there seems to be a well-operating legal system in place, the everyday practice is rather different. For example, in some regions it was noted that the construction of wells requires a permit, but that the abstraction of water often does not seem to be restricted, creating challenges in making steps towards fair water distribution.
It is important to realise that the Dutch business sector has to deal with unclarities in the legal system operations and policymaking which can lead to a misuse of trust during dealings.

6.1.10 Doing business

The main challenges related to doing business in the Maghreb region seem to be related to communication. The different ways of doing business, the language barrier (French/Arabic vs. Dutch/English), differences in work ethics and culture make it more challenging to do business.
There is furthermore a variety of operational challenges depending on region and crop. To point out one example, the challenges in the potato sector proved to be: 1) dependent on import of seed potatoes, 2) variability in supply, 3) fluctuation in the price system, 4) low level of mechanisation and 5) yield losses. Often prices are too low to offer farmers a good return on investment, while imported potatoes can be even cheaper. Weak points

that complicate the potato chain were insufficient transparency, mistrust, no long-term perspective, parallel illegal chains, little organisation and no registration.
For all three countries it was noted that doing good business should go hand in hand with building and retaining capacity on improved water use in agriculture. The Dutch expertise can be of help in this, both in protected agriculture as well as in open field agriculture. These will be discussed further in the Opportunities chapter.

6.1.11 Local partners

Finding a good local partner can be challenging and requires time and investment before starting operations in a Maghreb country. Doing business in Algeria, Morocco or Tunisia will be greatly facilitated and more opportunities will appear when a good local partner is obtained. A good local partner is trustworthy, has a broad network, is familiar with the environment, culture and legal system operations, and can reach the right people.
When doing business in selling equipment, seeds, etc., (from the Netherlands) in for example Morocco, it is best to work with a local distributor. For the development of new business in Morocco it is a challenge to find a good local partner or local distributor that besides sales, also has knowledge about the agricultural sector. A matchmaking event (supported by the Embassy) at the annual agricultural fair could be a way to facilitate meeting potential partners.

7 Maghreb opportunities

7.1 Opportunities common to the three countries

The three Maghreb countries face many challenges, but there are also many opportunities. Opportunities that arise when land productivity needs to increase by improving:

1) available water resources and the quality thereof;
2) water productivity and water use efficiency in rainfed and irrigated land;
3) soil fertility;
4) plant material and crop cultivation management;
5) micro-climate;
6) capacity building and improved monitoring and forecasting practices for sustainable water management and good agricultural practices.

In this section, we will discuss the opportunities in each of these fields based on the desk research, the country expert reports and the outcomes of the interviews. To provide the reader with an overview, the main categories of opportunities have been listed in Figure 7-1 with an indication of the associated likelihood for Dutch entrepreneurs to be successful in picking up on these opportunities. Opportunities have been weighed and colour-coded for each country according to the demand and need, and the likelihood of successful new activities (see legend below for an explanation of the three different colours) based on expert judgement. More details on the specific technological and other opportunities are given below Figure 7-1.

Table 7-1 Various opportunities and associated specific technologies for the three Maghreb countries. Colours indicate the likelihood of successful Dutch entrepreneurship on a relatively short term. Blue: Clear demand for Dutch expertise and with local support, Grey: Likely demand for Dutch expertise, Orange: Medium chance, but uncertain and Red: Little to no support (legend below).

Opportunities	Specific technology	Algeria	Morocco	Tunisia
Waterefficient technologies	1. Climate smart irrigation			
	2. Drip irrigation			
	3. Crops under greenhouses			
	4. Hydroponics			
Smart water capturing	5. Rainwater harvesting			
	6. Dew yield			
Catchment interventions	7. 3R approach			
	8. Protection, restoration and management			
	9. Soil and water conservation (SWC)			
	10. Off-stream water storage			
	11. In-stream water storage			

	12. Managed aquifer recharge			
Capacity building & skills	13. Bridging the knowledge gap			
	14. Digitalization, geo-data, satelite data			
	15. Good local partner			
	16. Improve post-harvest processes			
Innovations	17. Salt tolerant crops			
	18. New tolerant cash crop types			
	19. Solar energy in agriculture			
Using non conventional water resources	20. Saline farming			
	21. Desalinized water			
	22. Treated waste water			

	Clear demand for Dutch expertise and with local support.
	Likely demand for Dutch expertise.
	Medium chance, but uncertain.
	Little to No support.

7.1.1 Water-efficient technologies

1. Climate-smart irrigation

There is a growing demand for sophisticated scheduling, innovative equipment and precision techniques (UNECE, 2019). More and more irrigators are encouraged to procure irrigation systems that increase irrigation efficiency and preserve resources (through the integration of soil moisture warning systems for the optimal use of irrigation water, information on crop type and developmental stage and local climatological data. This way, farmers can optimise volumes of water given and the timing thereof for crops, and reduce evaporation losses, as well as work towards water conservation and good environmental practices (e.g. crop selection based on their water needs, improved drainage, sustainable soil management). Governments can help by making investments more accessible and cost-effective (e.g. incentivising the use of locally manufactured material adapted to irrigation) and by providing training to use, operate, and maintain better irrigation systems. Climate-smart irrigation was demonstrated to be effective in increasing both yield and quality of potatoes in multiple demo projects on sustainable management in Algeria and is now being promoted.

- In Algeria, some innovations in the field of irrigation are reported, with farmers trying to move away from less water-efficient furrow irrigation.
- In Morocco there is clear demand for more water-use efficient technologies. Since drip irrigation (see below) is adopted already in nine broad areas in the country, some areas of which apply drip irrigation on more than 50% of the agricultural area, it is now time to take the next step to combine water efficient irrigation techniques with other technologies. Additionally, farmers are interested and successful implementation has been reported. Multiple packages with sensors, mobile phone apps etc. now exist, ready to be implemented. Funding from the government is present as are several Dutch service and technology suppliers. However, in the north of the country, where there is sufficient rainfall and thus

currently sufficient water availability, farmers are not aware of future water shortages that are predicted to occur under climate change scenarios and are therefore not investing in water-saving technologies.
- In Tunisia, climate-smart irrigation practises have been implemented and may act as a billboard for more efficient approaches that are needed to move away from traditional irrigation methods, which are still widely used (Green Climate Fund, 2019). There, Dutch technologies and experience are still limited apart from involvement in some EU research projects and projects that are part of the Orange Knowledge Programme (funded by Dutch government and implemented by Nuffic).

2. Drip irrigation

Some promising innovations brought forward rely on improving the water use efficiency of crop production. The first and perhaps most obvious improvement to be made are changing irrigation systems to drip irrigation or sub-surface irrigation. The conversion to modern irrigation systems and improvement of existing irrigation systems can potentially save billions of m^3 water annually in the three countries (World Bank, 2017).
This significance fuels a clear demand for drip irrigation in all the three countries: the techniques are being promoted and some public subsidies are available for making the transition at larger scales. There seems to be a willingness by farmers to adopt this technique to scale, although a lack of sufficient knowledge and skills hamper tech uptake and upkeep thereafter, or the use of the improved technique to its full potential.

- Morocco has invested heavily in promoting drip irrigation and there are now nine main regions where drip irrigation is rather common.
- In Algeria, there are innovative practices in the use of drip irrigation to irrigate cereals, durum wheat, on an experimental basis in the commune of Loutaya, north of Biskra. The first results of this project are positive. Drip irrigation is becoming more important in other regions of Algeria as well, and is partly subsidized. Combining drip irrigation with the installation of subsurface drainage, especially in clay soils, can considerably lower the salinity after rainy periods (Hartani, 2001).

These developments create good opportunities for the Netherlands, where sophisticated smart irrigation systems have already been implemented that optimize the amount of water and fertilizer use by combining soil moisture monitoring, subsurface irrigation and fertigation. Examples of successful implementation of this type of system is the Deltadrip project, where per 10 ha of potatoes, ca. 3200 m^3 of water was saved compared to traditional irrigation.

3. Crops under greenhouses

The production level of greenhouse setups like the single-span tunnels, Canarian and multi-chapel greenhouses and multi-span tunnels can be increased by optimising different factors. The Netherlands can play a role in optimising production and the water and energy efficiency in an integrated manner for different levels of greenhouse agriculture. In addition, there are good opportunities in the fields of crop protection and fertilisation. There is a demand for knowledge of and technology for more durable applications from Dutch companies supplying greenhouse technologies and management services. Especially in the northern and coastal regions of Algeria, but also in the areas where protected cultivation is common in Morocco, there are good opportunities. In the coastal zone of Algeria there is still limited use of multi-span greenhouses and this offers opportunities where the availability of land and the current low greenhouse performance are an issue. In addition, the postharvest situation and marketing of greenhouse vegetable products in Algeria is not yet optimal (van Os et al., 2012). Here, crop diversification and improved post-harvest processes (cool storage, grading, packaging, transport) could greatly improve produce and stimulate export.

- In Morocco, the last decade has seen improvements in the protected culture operation and technologies include fertigation, the use of long shelf-life cultivars, bumblebee pollination, geothermal heating, mulching, substrates culture, and integrated pest management. These improvements are increasingly being recognized as regular greenhouse practices.
- In Tunisia, new partnerships with Dutch companies in the field of greenhouses could improve farmer production. These partnerships could concentrate on smart water management for cultivating safe crops in greenhouses. For example, the tomato is very important in terms of surface area, production, consumption and export. Tomato consumption in Tunisia is the highest in the world with about 70 kg/year/person. It is also a crop with high water consumption. The loss of tomatoes estimated at 6% is also a loss of water. Tomatoes are cultivated both in the open fields in summer, as well as in greenhouses in winter. Apart from some very successful expansions of for example the Agrocare in El Hamma, Dutch companies still have a timid presence that can be extended. Vegetable and floral crops are promising niches.

Furthermore, the fertigation at farmer scale for more efficient application of water and fertilizers, especially with saline water, integrating modern IT technologies, is in demand. These can be even augmented in excellent climatic conditions at geothermal areas allowing export to the EU during winter (Soethoudt *et al.*, 2018).

The greenhouses that are built often perform suboptimal shortly after the service or technology supplier leaves the region. There is a lot to gain by improving maintenance to structures. A greenhouse system integrating water, energy, nonconventional water use and rain/dew water capturing is an interesting niche, especially combined with sustained and applied knowledge building (e.g., precise monitoring and control of greenhouse by e.g., the IIVO system of the company Hoogendoorn and the LCA method of AZURA).

4. Hydroponics

Hydroponic systems have a high water use efficiency, potentially reducing water losses through evaporation by up to 90% compared to conventional agricultural practices. The most efficient systems are those based on a non-soil substrate principle. When a circulating system is used, it is also highly efficient in the use of nutrients. Additionally, higher yields can be achieved than with open field cultivation for some crops (Euvelink and Marcelis, 2016). The systems can be used in combination with water harvesting techniques as described in this report.
Hydroponics systems can also be designed using brackish water. Production of various vegetables such as various Brassicas and lettuce have been shown to be very viable using water with an EC between 6-8 dS/m (The Salt Doctors). Yields that are very close to the maximum yield potential under field conditions have been achieved. In fact, yields in a hydroponics system can be higher than can be achieved under open field conditions due to improved oxygen availability.
Currently, a project is being reviewed in Morocco that aims to develop a cheap and easy-to-use hydroponics system. The ‘brine’ produced from the production of certain berries such as strawberries, blueberries and raspberries has a relatively low salinity because the producers desalinize lightly brackish water in central and southern Morocco. This ‘brine’

could feed into a hydroponic system based on brackish water because salinity levels are commonly well within the range for use and is therefore still a valuable resource.
Although the latent demand seems to be present (especially in Morocco), the clear benefits from hydroponics are not well known in Algeria and Tunisia and systems are hardly being implemented. The Netherlands has extensive experience and expertise with this type of systems.

7.1.2 Smart Water capturing

5. Rainwater harvesting

There is a considerable potential for rainwater harvesting in the Maghreb countries. The additional water captured by small scale (e.g., 1 house) or large scale set ups (e.g. from a greenhouse, roof systems or other infrastructure) can be used for all kinds of purposes such as domestic use, hydroponic crop production, small scale open field crop production, kitchen gardens, backyard crops and horticultural tree production. The collected water can be stored in surface and subsurface tanks. Open reservoirs are less favourable due to the high evaporation rates. The roof area used for collection, the rainfall regime, the size of the storage facility and the water demand/use determine the requirements of equipment and storage space needed as well as impact on downstream ecosystems and other water users. For a hydroponics production system, a rainwater reservoir of 1000 m^3/ha is recommended in the Algiers region (Van Os *et al.*, 2017).
Rainwater is free of charge and when captured from air directly it is of good quality and can be used for drinking water purposes and high quality agricultural production. It is recommended to integrate collected rainwater into the greenhouse management as an additional source, not to be solely dependent on it. Rainwater can be blended in with other water streams for the greenhouse crops allowing lowering of harmful nutrient concentrations and salinity.
The rainwater amount that can be collected from the roofs of greenhouses, schools, and residential areas is substantial. In Algeria there are several programs on rainwater harvesting. It is reported that, for the coastal zone of Algeria, 75-90% of the 500-600 mm/year can be collected. For the drier regions, the potential for rainwater collection is less because of reduced rainfall (<250 mm).
Judging from the precipitation patterns in Northern Africa, the coast of Algeria, a large part of Morocco and the northern part of Tunisia are most suitable for rainwater harvesting.
With the standard type of greenhouses in the Maghreb region (common tunnel systems), no rainwater collection is possible. On the other hand, the multispan tunnels can collect rainwater, but it is not commonly done (Van Os et al. 2017). With the proper incentives and slightly adjusted tunnel design precipitation can be drawn into the greenhouse improving on crop production rates and sustainable water management can be made.

6. Dew yield

There is potential for the collection of fog and dew in the Maghreb countries for household use (Lekouch *et al.*, 2012 and Mirleft & Id Ouasskssou, 2014). The location of the cities with respect to the Atlas mountain chain, which controls the circulation of the humid marine air, is the main factor that influences dew production and therefore the potential for dew water harvesting. The implementation for dew yield technology as add-on to water capturing is still in its infancy.

7.1.3 Catchment interventions

An integrated landscape management with optimised hydrology increases water quality and availability in up and downstream areas. This optimisation includes interventions that are mostly based on increasing the Recharge, Retention and Reuse (3R of water, See Annex

2 and figure 7.2) of groundwater, surface water and rainwater that in turn enhance the movement, distribution, and management of water in the catchment, including the water cycle, water resources, and environmental watershed sustainability.
The type of 3R intervention most suited at location depends on biophysical factors, such as topography, soil, geology, land cover and land use, water use, but also sociological aspects such as land ownership, conflicts and upstream vs downstream users.
For the Maghreb it is important to realise that in the same catchments there are numerous dams and reservoirs planned, especially in the upstream areas as part of the water supply and energy system, interventions could start pragmatically by tackling a number inefficiencies already encountered in the current water supply systems.
For example, reducing the leakages of dams, basin banks and distribution systems must be a priority and offer opportunities for Dutch expertise in dams and water infrastructure technology but also flood control, see Gardar Dam in Algeria (Benfetta, 2017).
Also, the siltation of the reservoirs is a key issue with regard to water supply. Reportedly, most of the siltation and sediment deposited in reservoirs originate from the erosion of the wadis. In the case of the SMBA Dam, 90% of the sediments come from the Wadi Haddad and Wadi Mina upstream of the dam (Faiza & al, 2018). Creating bunds, discontinuous terraces, and in general landscape restoration techniques on the wadis will significantly reduce this siltation problem.
A list with the measures for countering reservoir sedimentation in Moroccan catchment, reservoir and at the dam in Figure 7-1 shows its urgence and again opportunities for Dutch expertise for water infra structure optimisations.

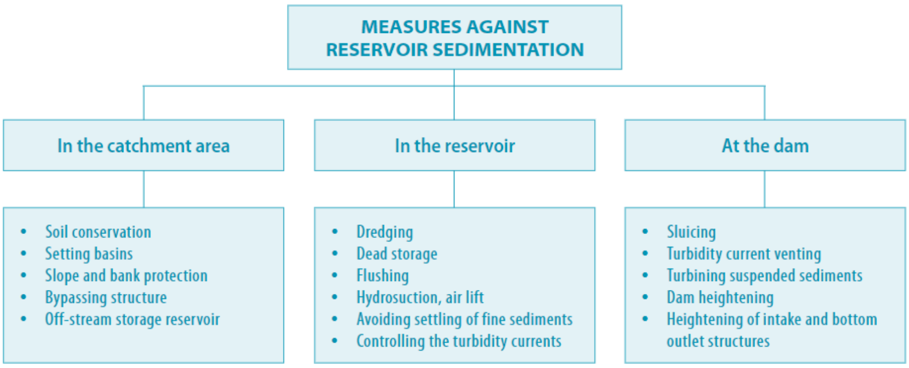


Figure 7-1 Measures for countering reservoir sedimentation . (Liu, 2017).

There is a high potential for the future development of a more resilient landscape and sustainable water resources in the Maghreb countries making use of the right catchment interventions such as the 3R or MAR approaches or other scalable conservation techniques, off- and in-stream water storage, elaborated on in the following chapters. All in all interventions that are beneficial for energy and food production since they increase the water quality and availability by:

- reducing erosion and sediment runoff towards reservoirs,
- increasing recharge rates of groundwater resources,
- capturing peak flow and flash floods during the rainy season for later use
- improving soil moisture content for agriculture and ecosystems.

7. 3R approach

The 3R approach and related techniques and applications, provide a sustainable way for land and water resources management. In general, the 3R interventions are scalable, low cost, and do not negatively impact the environment. They are predominantly nature-based and frugal solutions that store water in the wet period and make it available for use in the dry periods. The selection of suitable 3R interventions depends on the intended use. For drinking water, closed storage in tanks or groundwater storage are most suited. The demand for cattle or irrigation water requires a lower quality, which broadens the range of possible 3R interventions with open water storage and soil moisture.

Contrary to Tunisia and Morocco, Algeria does not yet implement the 3R landscape approach yet according to the WOCAT database. However, several 3R landscape interventions at catchment scale are already applied in all three countries, at varying scales and under various approaches. Examples are Sustainable Land Management (SLM), Soil and Water Conservation (SWC) and Soil Defence and Restoration (SDR), or the programme Desert Ecosystems and Livelihoods Programme (DELP). Morocco and Tunisia are both involved in the Decision Support for Mainstreaming and Scaling Out Sustainable Land Management (DS-SLM) programme.

Four main categories of interventions can be distinguished within the 3R Landscape Approach, based on their functioning, location in the landscape and main purpose. These categories are described below. Other potential interventions is presented in more detail in Annex 3.
Each category of intervention has its applications and techniques for a certain purpose, strength, and weaknesses. Whether interventions aim at improving vegetation cover and biodiversity, promoting soil formation, storing water or any other purposes, and the rate at which this happens differs per category, and even per specific intervention. Some examples are given in Table 7-2.

8. Protection, restoration and management

Protection, restoration and management of mainly upstream areas is an effective measure to reduce erosion rates and siltation of reservoirs downstream. Areas closures will prevent overgrazing of upstream areas. Restoration or revegetation of hillsides could lower the erosion rates significantly. Successful implementation and upscaling of activities is facilitated when governments are already aware of the sustainable land management approach; proof of concepts have been established and the intervention benefits are known to the government and local communities.

In Tunisia and Morocco, the LiFE programme[3] was started entitled 'Establishment of pilot systems for monitoring desertification in two countries on the southern shore of the Mediterranean: Tunisia and Morocco' coordinated by the OSS, aimed to set up indicators and desertification monitoring systems integrating satellite data and field data. A map server containing all the information from the project is currently accessible to all partners. To support effective implementation and upscaling of interventions, it is important to have a spatial data for prioritization of intervention areas and ongoing monitoring of for example vegetation cover. In the LiFE programme, maps of change in the state of vegetation and maps of the location of areas sensitive to degradation were thus produced.

Also in Tunisia, from 2015 – 2019, a project for Decision Support for Mainstreaming and Scaling Out Sustainable Land Management (DS-SLM) was ongoing to help combat Desertification, Land Degradation, and Drought (project financed by GEF and coordinated by FAO). The programme is part of the WOCAT network. A map was developed in 2019 by the DS-SLM project indicating the main types of degradation in Tunisia (WOCAT, DS-

[3] https://crts.gov.ma/thematiques/desertification/indicateurs-pour-suivi-de-la-desertification

SLM). This map can support the implementation of Protection, restoration and management interventions. In Morocco also a DS-SLM coordinator was appointed, but no programme results have been published yet.

9. Soil and water conservation (SWC)

There are techniques and interventions that support soil moisture conservation in the root zone. Part of the retained water can be used by crops and a part percolates deeper to recharge the groundwater. Examples include grass strips, soil bunds, deep ploughing, and conservation agriculture. For example, for SWC there are opportunities in Algeria for no-till farming techniques. No-till farming decreases the amount of soil erosion that tillage causes in certain soils, especially in sandy and dry soils on sloping terrain. Other benefits include an increase in the amount of water that infiltrates into the soil, soil retention of organic matter, nutrient cycling and biodiversity.

Table 7-2 shows an example of a WOCAT database entry for the SWC intervention soil bund in Morocco, which supports rainwater harvesting in tree plantations. In the reference plot without bunds, drip irrigation is done daily. In the field with the dikes, only every third day irrigation is necessary. The WOCAT database shows that in Morocco and Tunisia, implementation of SWC measures is ongoing.

10. Off-stream water storage

Off-stream water storage comprises interventions that store water outside of the river system in the landscape. Examples are small ponds, hillside dams or rock catchments. The downside is often that open water storage has high water losses due to evaporation. But if off stream interventions are combined with groundwater recharge (e.g. infiltration ponds), a significant improvement of water resources is perceptible.

Water harvesting interventions are often integrated in headwater catchments of rural semi-arid and arid regions to reduce runoff, increase infiltration, and reduce flood risk downstream. Intervention in the landscape (e.g. off-stream water storage), have a high impact on the reduction of surface runoff and (top) soil erosion. Al-Seekh and Mohammed (2009) showed for example that runoff in the West Bank is reduced by 65–85% with stone terraces and semi-circle bunds compared to a control site.

Monitoring of the dam capacity (hill dams, reservoirs etc) in the Maghreb countries showed high siltation rates. Off-stream water storage interventions can greatly contribute to lowering of siltation rates and improve aquifer recharge in the Maghreb countries. Tunisia and Morocco are already active in the WOCAT network, that supports sustainable landscape interventions.

11. In-stream water storage

In-stream water storage comprises intervention in the riverbed and surrounding riparian areas. Sand dams, gabion dams and check dams are examples of instream interventions. These structures harvest sediments and streamflow in the wet season. The harvesting water in the stream, replenish groundwater. This is conserved and stored to be re-used for extending growing periods and/or for supplementary irrigation during dry periods. In-stream intervention also benefit the surrounding and upstream natural resources due to the improved water availability.

Sand dams and permeable gabions dams are examples of relatively low-cost instream structures that can greatly improve groundwater recharge. Morocco and Tunisia alrealy have permeable gabion dams in place (Table 7-2).

Table 7-2. Some examples from the WOCAT database (https://qcat.wocat.net/en/wocat/) of successful landscape interventions in Morocco and Tunisia. No interventions for Algeria were documented in the WOCAT database. Pictures are from the WOCAT database project information sheets.

Picture	Examples catchment interventions
	**Permeable Gabion dams in wadis** Morocco This intervention allows part of the runoff water to pass through the walls and storing sediment (and water) behind the wall. This contribute to baseflow, groundwater recharge,
	**Rainwater harvesting in tree plantations (with drip irrigation) through soil bunds** Morocco In the reference plot without bunds, drip irrigation is done daily. In the field with the dikes, only every third day irrigation is necessary.
	**Stabilization of terraces along the wadi with trees** Morocco The, in this case, poplar trees are planted in tight rows along the banks, and as soon as they have grown enough to stabilize the land, transformed into the edge of terraces.
	**Area closure and reforestation with native tree species of Acacia** Tunisia Rehabilitation of degraded drylands and restoration of the original forest-steppe ecosystem in the Bled Talah region, which suffered from overexploitation of natural resources and intensification of agricultural activities.
	**Gabion check dam** Tunisia To slow down the water flow in the wadi courses and improve its infiltration into deeper soil layers and geologic formations, small check dams are installed on the wadi beds, usually in series.

Recharge well

Tunisia

A recharge well comprises a drilled hole, up to 30-40 m deep that reaches the water table, and a surrounding filter used to allow the direct injection of floodwater into the aquifer. Recharge wells are used in combination with gabion check dams to enhance the infiltration of floodwater into the aquifer.

An opportune intervention would be to capture more frequent and intense flash floods as well as the excess of water via roofs, small basins, khettaras/fogarras and ditches so that it can be infiltrated in Aquifer Storage Recharge systems as described in more detail under 12. These systems could be controlled locally by small communities of farmers, like it is done with the khettaras/fogarras. Solutions to the losses in the distribution systems elsewhere may be mitigated by the re-introducing/recovering and upgrading of the traditional khettaras/fogarras, which were abandoned due to overexploitation of the aquifers. In Morocco, Tafilalet, for example, since 2005 many communities are acting collectively to resurrect the khettaras/fogarras with more than 20 working khettaras/fogarras in use for hundreds of small farmers. (El Faiz & Ruf, 2010). An identified business case (see chapter 8.2) could be the combination of the existing old khettara/fogarra systems with an Aquifer Storage Recharge system that makes use of the abandoned wells that usually surround the khettaras/fogarras (see figure 8-1 and 8-2). This solution would be inexpensive and The National Water Plan of Morocco already considers using the aquifers to store water.

12. Managed aquifer recharge

In order to store harvested rainwater or surface water in the ground and make it available for later use, water can be stored in the aquifer. Water needs to be infiltrated actively in order to make the most use of the storage capacity of the aquifer. This way of recharging the aquifer is called Artificial Recharge (AR) or Managed Aquifer Recharge (MAR or when used for agriculture, AgriMAR..

Managed Aquifer Recharge is a term for a wide and growing range of measures to support active management of groundwater resources at the local and basin level, to make more efficient use of water resources, assist conjunctive management of surface and groundwater resources, to buffer against increasing intensity of climate extremes, particularly drought, and to protect and improve water quality in aquifers (see Dillon et al., 2019). AgriMAR shows potential for the coastal zone of the Maghreb region, as AgriMAR provides a low-cost solution for storing freshwater in a saline environment to be used for irrigation during the dry season. As pointed out, there is a potential to combine the use of the traditional water harvesting systems (so-called foggaras, ketharas) for Managed Aquifer Recharge. Important advantages of these techniques consist of (1) high recharge rates utilizing relatively small surface areas; (2) the transformation of unreliable, often polluted surface water into safe quality groundwater; and (3) subterranean storage which protects the water against evaporation losses, algae blooms, atmospheric fallout of pollutants, and earthquake hazards.

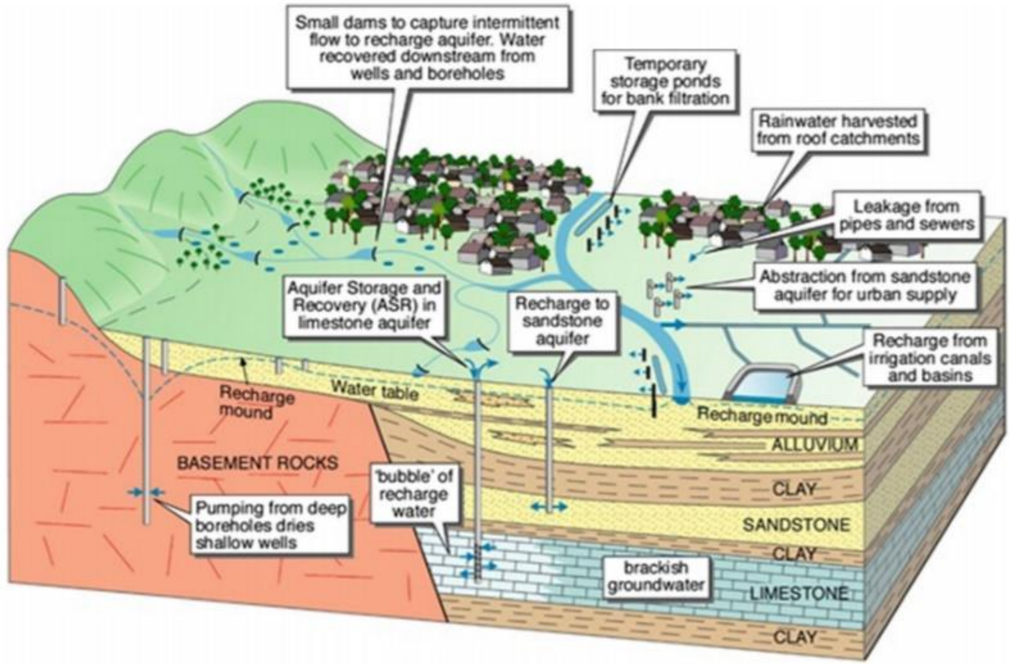


Figure 7-2. Managed aquifer recharge is adapted to the local hydrology and hydrogeology, and is usually governed by the type of aquifer, topography, land use, ambient groundwater quality and intended uses of the recovered water. This diagram shows a variety of recharge methods and water sources making use of several different aquifers for storage and treatment with recovery for a variety of uses. An understanding of the hydrogeology of the locale is fundamental to determining options available and the technical feasibility of MAR projects. Recharge shown here occurs via streambed structures, riverbank filtration, infiltration basins and recharge wells. Source: Dillon (2019).

7.1.4 Capacity building and skills

One common pattern that emerged from this study is that small-scale farmers are often not aware of e.g., improved farming methods, good agricultural practices, (mechanization of) precisions farming, new crop varieties, using renewable energies for irrigation, the development of solar and wind pumping for small-scale agricultural irrigation, etc. As pointed out by most experts interviewed, improving basic practical skills by providing training sessions, showcasing opportunities and technologies, and durable, affordable and integrated tools for farmers on how to implement technologies is a clear demand.

Herein lie opportunities for the Dutch business sector and applied knowledge institutes with vocational training, to reduce the gap between research, development and practise and to generate new promising partnerships developing new products and services, mitigating current trends in water availability and agricultural performance.

To this end, it is important that more demo sites are created, that can serve as an example for local farmers and also work together with local farmers. There are initiatives that aim to achieve such partnerships. Some of these like the Orange Knowledge Programme are funded by the Netherlands government on e.g., institutional collaboration projects, group training (Tailor-Made Training - TMT, TMT Plus, refresher courses), individual scholarships for mid-career professionals, and alumni activities, also NUFFIC's TVET (Technical and Vocational Education and Training) provides knowledge and skills for employment. In these programmes, local partners such as universities and farmer associations, team up with Dutch partners to create a training programme to share information on topics such as improving the sustainability of your farming practices, or to improve crop yields under saline conditions. Several such projects are currently running in Africa, including one in Tunisia.

Other science and technology cooperation that seek the further sustainable development and management of agriculture, health, land and water resources, and interactions with climate change are for example the Sahara and Sahel Observatory (OSS), and the affiliated joint EU-Africa project AFROMAISON, a Tunis-based international Association with an African vocation for arid and fragile regions.
This type of programming has proven very successful as a way to demonstrate, and as such for capacity building, to show in a practical way the possibilities that exist to improve yields in a sustainable fashion across a much wider audience across water-energy-food troubled regions.

13. Bridging the knowledge gap

Across the region the bridging of knowledge gaps seems to be of high importance.
This includes improving on the general knowledge on relevant agricultural tools and techniques, a better knowledge on soil characteristics, crop cultivation management, good agricultural practices and precisiosn farming. In particular knowledge is required on water requirements, since current approaches often lead to over-irrigation behaviour (this goes hand in hand with lack of recording of the quantities of water consumed).
There is opportunity for great improvement of water-agriculture performance by training of farmers and technical staff in particular in demoing crop irrigation using climatic and soil data, or in the management of the fertigation of the crop as well as the management water and nutrients for soilless cropping in different substrates. Reportedly in Algeria there is a strong need in reducing the gap between research and practise through focused trainings (in Arabic/French).
There is also insufficient knowledge on fertigation rules, insufficient skills for e.g., installing irrigation equipment. E.g., the Tunisian Union of Agriculture and Fisheries (UTAP) has therefore launched a training project for 150 farmers from several Tunisian governorates (Afrik21, 2020) to address proactively these gaps.
For the development of innovation capacities it was felt that new institutional framework could be needed in which universities and research centres work together towards an inter-sectorial framework with an increasing role of the private sector. This could help by establishing a market orientated research framework by linking vocational training and university programmes (especially in science, engineering and technical studies) with activities of the WEF-industry, for example through joint education-industry clusters (R&D platforms) or partnerships (joint lectures, internships etc.), as well as increasing the role of universities and its researchers of transferring international knowledge to the domestic labour market by fostering exchange programmes with the international scientific community.
Furthermore, sustained capacity building and retention on in particular the organisation and management of the integration of water, energy and production efficiencies can provide additional advantages for in particular the Netherlands. The Netherlands are unique in having a long history of combined water, energy and agriculture optimisations, in open field as well as in greenhouses.
These are competitive advantages the Dutch companies must further develop and explore by for example investing in services and material that enhances the capacity building and the realisation power of new bilateral cooperations for the long term (e.g., https://www.plantempowerment.com/ .

14. Digitalization

There is a clear demand for relevant remote sensing and geo-water – agriculture data applications and information products. This was pointed out by many questioned of being of high importance. R&D initiatives are underway and new ones are being developed. Nonetheless, the RS technologies and other modern surveillance for following geological

and hydrological status and trend are used sparsely, mostly limited to a few studies to estimate crop yields and floods. Providing real opportunity for required improvements.
A wide range of RS techniques with better spatial and temporal resolution is improving fast including satellite imagery, aerial photography, Synthetic Aperture Radar (SAR), ground-penetrating radar, airborne and terrestrial LiDAR, and Unmanned Aerial Vehicles (UAV) imagery. Based on that, new approaches are noted on e.g., measuring growth and biomass yields in time and determining energy balances in and around crops as well as water content in top soil as well as evapotranspiration allowing precision cultivation on e.g., the continued high sugar production with optimised irrigation and fertiliser use. A number of older and newer open access data and information sharing platforms are available. (e.g., https://wapor.apps.fao.org/home/WAPOR_2/1).

- In Algeria, and also for Morocco, RS for improved knowledge on water resources and crop water requirements are reportedly demanded as well as improved knowledge management system and proper use with good agreements on data usage and privacy. There are investments in practical but precise technology that are user friendly and has the ability to co-create new applications and information products (e.g., from Digital farming to hydrological drought or yield index insurances).
- Also, in Tunisia, and with support of the government, there are good opportunities for Dutch entrepreneurs in RS techniques to disseminate through applications information directly to farmers on the ground on e.g., actual water demand and availability so they can optimise their farming practices.

It remains however for all three countries an opportunity to design or finetune, preferably through open source data and information platforms, new useful RS information that is able to provide the real solutions for the specific requirements of the farmers, agriholdings and also basin organizations on the ground. It is felt that the mentioned demo-sites would be an good place to, on a continuous basis, bridge proactively the gap between the increasing supply of possibilities with the actual local demand.

15. Good local partner

Although all three countries acknowledged the need for improved and successful bilateral cooperation, most impact might be gained in Algeria and Tunisia.
A partnership with a local trusted partner is rather a prerequisite for doing good business and provide the best solutions within official and jurisdictional settings of the three respective countries. Simply put, if you have a good trustworthy local partner to partner with, there are a lot of opportunities for doing good business. For productive partnerships a more equal level playing field is commendable. Recognising and respecting the significant differences of the different parties' cultural and language settings. Important there is to set and officially agree on clear long-term objectives carried by both parties with moments of genuinely celebrating success of the achieved. Especially in a region that in terms of the water and agricultural practices needs to accelerate its transition from traditional to modern.
There is a potential for the involvement of agronomists or sales persons with a combined Dutch-Moroccan (or Tunisian/Algerian) nationality in capacity building programs or employment in local business development.

16. Improve post-harvest processes

During several expert discussions and interviews it was pointed out that there is much to gain when improving on post-harvest losses (estimated at 20-30% of total production across Maghreb). This seems especially relevant for export produce for Algeria with challenging logistics, and long and thus complex water-agri-food value chains. For Morocco it was mentioned that often the type of low or high tech investments in water-

agri is also depending on certain EU restrictions that has quota for imports during the months EU countries harvest. Additionally, Morocco has much to gain from improving the storage of agricultural produce, to ensure a better spread in time for releasing the products to the markert, improving the prices farmers will receive.
In Tunisia attention was drawn to upgrading so-called collection centers, where ca. 70% of fresh tomatoes is aggregated, and where improving and adding value determines quality price relations. A need for logistics design, technology organization, scale and improved business models of these centers may signify new opportunities for Dutch entrepreneurs. Soethoudt et al. (2018) reported a waste stream of ca. 60.000 tons of tomatoes annually. These streams could be processed into concentrate, natural dyes or dried produce for local use and EU market.
Also, as reported by Blom-Zandstra (2018), it appears that the potato value chain is not fully developed in Tunesia. The main focus of the potato chain is primarily on production. Most of the produced potatoes are directly consumed, while processing of potatoes hardly occurs. Currently, future perspectives for small holders appear to be unfavorable. Thus, the need to rectifying post-harvest losses by targeting local markets with locally produced products may provide more benefits for entrepreneurs (including social value) than solely focussing on export quality.
In Tunisia the use of Dutch technologies and expertise are still limited apart from involvement in EU research and Orange Knowledge Programme projects. More involvement there with the production and export of vegetable and floral products, helps to develop the sector further, providing a range of new opportunities.

7.1.5 Innovations

17. Salt tolerant crops

Another way to adapt to the low water availability, high salinity conditions in most of the Maghreb region is the adoption of salt tolerant crops. Breeding for salt tolerance can help to improve the tolerance levels, but research by The Salt Doctors (De Vos *et al.*, 2016), among others, showed that more tolerant varieties can already be identified by large scale screening. These more tolerant varieties can often withstand salinity levels in the range of 6-8 dS/m (ECe, soil salinity level) and suitable varieties have been identified for potato, cauliflower, carrot and beets (among others). These tolerance levels are in the range of common salinity levels found in shallow wells in the Maghreb area (see Table 2-3). Also, the salt tolerance levels of common cultivated crops in the Maghreb, like barley, olive and dates are also, in general, well within this range. So, based on the salinity levels of various water resources in the Maghreb, there are opportunities to use these non-conventional water sources for crop production. There are opportunities for Dutch breeding companies to supply seeds of robust, salt tolerant crop varieties, especially for crops like potato and different vegetables.
Breeding for salt tolerant crops is a somewhat latent demand. Farmers acknowledge this as an opportune solution (pers. Comm. Merdaci staff member of ITDAS Biskra). There is a general consensus that replacing e.g., alfalfa by forage mays and limit the production of Banana crops in the Souss Massa will allow to save over 100 million m^3 and reduce the water deficit in the region. Farmers already have a certain amount of (historical) mastery of salinity management and this includes the use of plants adapted to salinity. So, the use of robust, salt tolerant varieties is already recognized as an opportunity, making adoption of these varieties relatively easy, especially varieties of crops that are already being used by the farmers.

18. New tolerant cash crops

Especially needed are drought-tolerant crops that do not suffer too much in times of drought (e.g. current potato types are not very tolerant to high temperatures and water stress). In order to use saline resources safely and sustainable and with changing climatic settings, the right crops and crop varieties should be chosen. So, besides selecting a more tolerant variety of a specific crop, also the option of introducing completely new crops should be considered. An example is changing to more salt tolerant crops such as quinoa that can help to improve production on salinized lands. Several successful projects to this end have been carried out, mainly in Morocco and Algeria, and quinoa is now becoming more widespread.

19. Solar energy in agriculture

Solar energy use is steadily emerging, but in Algeria still quite limited to domestic use in rural areas far from power grids. No water pumping with solar has been seen so far according by *the Technical Institute for the Development of Saharan Agronomy* or *Institut technique de développement de l'agronomie saharienne*, Biskra (ITDAS). Several governments are willing to or are subsidizing or supporting solar panels for farmers and it is then expected that more farmers will be using solar energy. Several farmers are interested in this energy solution.

7.1.6 Using non-conventional water resources

20. Saline farming

Salt affected lands and brackish water can be used for agriculture when the right crop variety and specific soil and water management is used. There is a demand for saline farming and Dutch expertise therein. It is felt that the use of saline water needs more attention in water-agriculture partnerships. As salinity is an ancient problem in the Maghreb, farmers do already have some experience in dealing with such problems. Currently, farmers in Morocco use brackish water for the cultivation of the following crops: forage crops (alfalfa, Bleu Panicum, sorghum, barley) trees (olives, figs, date palm) and vegetables (artichokes, melon, cabbages, okra).

Crop cultivation under saline conditions requires specific soil and water management, especially when saline water is used for irrigation. Salinity can affect different aspects of soil health (mainly soil structure and mineral balance) and leaching and drainage are vital to control rootzone salinity. When using brackish water for irrigation, periodic leaching is required in order to prevent excessive salt accumulation in the topsoil. Ideally, this leached salinized water should be captured using drainage pipes. However, alternatives are being developed as well. Using salt tolerant deep rooting trees may effectively use the leached water. These trees can be incorporated in an agroforestry design, specifically designed for saline agriculture. Currently, projects are taking place in Egypt to assess the effectiveness of such a saline agroforestry system (DeSalt project, partially funded by RVO).

It is recommendable that only drip and furrow irrigation should be used when using saline water. Sprinklers should not be used as saline water will damage the foliage of almost all crops. When using drip irrigation and when the farmer has good knowledge about his or her crops, the amount of water that should be given each irrigation event can be accurately measured, also when a leaching fraction is factored in. This can be an additional form of water saving, since most farmers use too much water for irrigation. There is a potential for technologies such as sensors and remote sensing to further improve what volume of irrigation water to apply for optimal crop production.

The Dutch experience in the field of hydrology and drainage of agricultural land is recognized in Morocco and Algeria. However, the Dutch companies and the Dutch technologies and experience are still limited in the Maghreb area, apart from involvement in some EU research and short consultancy missions. Bilateral partnerships are possible, for example the fertigation of water at the farmer scale for a better efficiency of water and

fertilizers, especially with saline water by integrating modern IT technologies is an innovative and much demanded aspect.
Much of the land and water in the three Maghreb countries is affected by elevated salinity levels. Especially the moderate saline conditions offer great potential for conventional crop production and these moderate conditions (EC 4-8 dS/m) seem to be widely present in the Maghreb. By combining the traditional knowledge of the farmers with new crop varieties and improved soil and water management, saline agriculture has great potential in the Maghreb.

21. Desalinized water

Desalinisation of seawater is supported by several states. As Moroccan developments clearly show these processes require energy-intensive technology. As a result, in particular Tunisia faces a challenge in terms of controlling energy consumption in relation to water and food security.
Furthermore, these techniques are expensive and used mainly by large farmers and in extensive agriculture. Although ambitious plans are drawn up with support of governments and private sector, especially in Morocco, desalinisation is still in its infancy. Additionally, the produced brine should also be processed in a sustainable way. Sone producers of red fruits that were interviewed for this report mention that they have a deal with the large desalinisation plant under construction in Morocco. According to them, it can be economically viable to produce high value and high-quality products using desalinized water, since this already happens in Spain and the products are competitive in the market.
The Plan National de l'Eau (PNE) in Morocco is ambitious. The PNE proposes the construction of new seawater desalination plants and increase production from 132 MCM/year (2016) to 515 MCM/year in 2030. Almost all desalination plants (96%) operate with reverse osmosis (RO) systems. Markedly the Agadir Desalination Plant is under construction and will produce 36 MCM/year, to fulfil the drinking water and irrigation needs of 800,000 people (123 litre/capita/day). Also, two desalination plants at Jorf Lasfar – el-Jadida and Safi, with a capacity of 75 MCM/year and 25 MCM/year respectively, are under construction and set to produce 100 MCM/year of drinking and industrial water by 2025.
Irrespective the sustainability aspects and despite these developments, the Dutch sector players seem not much active in these developments.

22. Treated waste water

The use of treated Waste Water (TWW) is being promoted as opportune water source across the region. Significant private and public investments are made and some ambitious governance targets for TWW use are set. Nonetheless, and up to now in Morocco, no large project for the reuse of TWW in agriculture has so far come into being. Therefore, throughout the whole region, the use of TWW for irrigation remains weak in the irrigated areas, likely due to the fact that e.g. farmers do not need to use this water for irrigation in areas characterized by high rain. A general lack of understanding of modern TWW irrigation techniques by farmers, hampers the further development of these promising technologies.
For example, the wastewater reuse coupled to managed aquifer recharge (MAR) provides a means to store and reuse treated wastewater (TWW) year-round (figure x.x.).

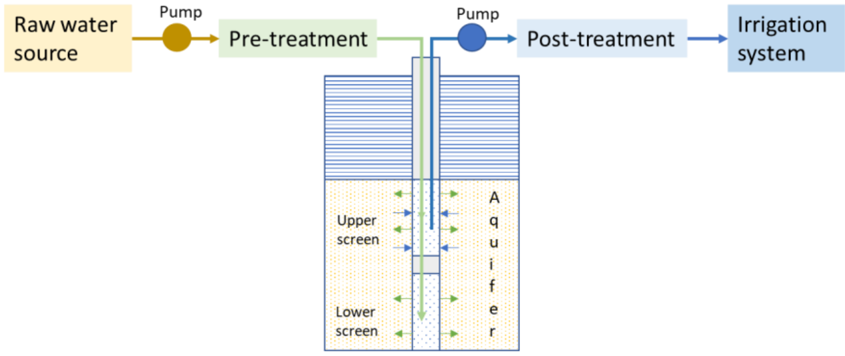


Figure 7-3. Schema of a set-up of Aquifer storage and recovery (ASR) scheme using TWW

- In Algeria the reuse of wastewater is happening on a reasonably large scale. Of 154 treatment plants operated by 'Office National d'Assinissement' across 44 wilayas, 16 plants are concerned with the reuse of purified wastewater in agriculture. During 2019, a volume of 12.325.269 m^3 of purified water was used for the irrigation of 11,045 hectares of agricultural land.
- In Morocco, wastewater reuse in agriculture has been identified as a promising way to alleviate water scarcity, improve crop productivity and improve environmental sustainability. Currently, mainly golf courses are irrigated using treated waste water.
- In Morocco no project at scale for the reuse of treated wastewater in agriculture came into being. The progress made there is coming from pilot projects, in particular those of Ouarzazate, Ben Sergao, Drarga, Attaouia, have been carried out and have made it possible to develop, through agronomic trials, some fairly well documented technical standards. Currently, 25 Mm^3/year of treated wastewater are reused mainly for irrigating golf courses (Marrakech, Agadir, Benslimane, Essaouira, Bouznika, etc.), and for the needs of the industrial sector (phosphate washing in Khouribga and Benguerir) (El Gueddar, 2015).
- Also in Tunisia, the domestic and industrial wastewater treatment and the environment are also subject of partnerships. But despite the opportunities, the Dutch water-agri sector seems not very active in TWW in the country.

8 Business cases

Per country, two of the opportunities are further elaborated in proposed business cases that are considered to have a high potential for successful implementation, and that will therefore contribute to the development of the water-food-energy nexus in the Maghreb countries. One of these business cases revolves around the building of a training and demonstration farm. It may not be directly obvious how building a training and demonstration farm is a business case. However, capacity building is important, as we have seen throughout this report. By showing farmers what can be done, this will ultimately lead to water savings and improved yields, which is beneficial for the region and country as a whole. Additionally, such a location also serves for local authorities, universities, or foreign embassies as a flagship project which can be used to attract further attention from investors and business.

Where possible, also some of the (potential) costs and benefits have been highlighted, but the specific details can only be obtained with in-depth research and pilots.

The assignment of certain business cases to specific countries does not mean that the particular business case is only expected to be successful in that country; on the contrary, we believe that all of the business cases could apply to all three countries, since all three countries are facing similar problems.

8.1 Algeria – Greenhouse Rainwater Harvesting

Location: Coastal zone of Algeria

Key words: Rainwater Harvesting, Climate Smart Agriculture, Pilot, Tanks, Water quality, coastal zone

Brief project description:

There is considerable potential for rainwater harvesting in the coastal zone of Algeria where rainfall ≥ 600 mm/year (figure 3-1). The additional water captured in large scale set ups (e.g. from a greenhouse) can be used for all kinds of purposes such as greenhouse production, hydroponic crop production, small-scale open field crop production, etc. The collected water can be stored in surface and subsurface tanks. For a hydroponics production system, a rainwater reservoir of 1000 m^3/ha is recommended in the Algiers region (Van Os *et al.*, 2017).

Rainwater is free of charge and when captured from air directly it is of good quality and can be used for drinking water purposes and high-quality agricultural production. With maintained collecting system free from contamination and light treatment (filtering and or UV), water quality remains good. It is recommended to integrate collected rainwater into the greenhouse management as an additional source, but not to be solely dependent on it. Rainwater can be blended in with other water streams for the greenhouse crops, allowing lowering of harmful nutrient concentrations and salinity.

The rainwater amount that can be collected from the roofs of greenhouses, schools, and residential areas is substantial. In Algeria there are several rainwater harvesting programs, but often not combined with greenhouses production.

It is reported that, for the coastal zone of Algeria, 75-90% of the ± 600 mm/year can be collected. This means that if an area of half a hectare has rainwater harvesting greenhouses on it, the amount of water harvested is between 2.250 m^3 and 2,700 m^3 of water. A greenhouse producing tomatoes uses around 7,5-10 m^3 per year. This means that around a third of the water requirements of a tomato crop can be harvested as rainwater by the greenhouse itself.
In this project, a proof of concept will be set up for a greenhouse combined with a rainwater harvesting system.

Expected business case results:

- Medium-sized greenhouse farmer provided with rainwater harvesting system in place
- Improved access to water with good water quality for agricultural use
- Showcasing the system for Northern Algeria in dissemination activities (field visits, farmer to farmer visits, etc)
- Clarity on proceedings for the implementation of rainwater harvesting systems in Algeria.

Organisations to involve:

- An agricultural company (medium sized greenhouse farmer) in the coastal zone of Algeria, operational in greenhouse production, needing high quality water.
- EKN for the support on permits for innovative techniques
- Technical partner for the specific design of the RWH system
- Technical partner for the supply and construction of the greenhouse water harvesting system

Costs and benefits associated to this business case:

- Total costs of rainwater harvesting from greenhouse roofs are made up by investment costs, financing costs and yearly recurring operation and maintenance costs.
- Investment costs are all those expended in Year 0 to acquire capital and to install (labour, material, equipment) the system;
- The height of the investment costs depends on the technology level and condition of the greenhouse to be used;
- The height of the investment costs also depends on the to be used method for water storage. The investment costs can vary depending on the way in which the water will be stored. When opting for storage under the greenhouse in crates, the greenhouse and the activities will have to be temporarily relocated and major earthmoving will have to take place; this can cause temporary high costs in year 0; These costs can be avoided when the water is stored in a basin outside the greenhouse. However, in this case, acreage is needed on the farmer's land that the farmer cannot use for crop production. Which means, either way costs need to be made, a cost-benefit analyses helps to conclude on the effectiveness of each choice.
- Irrigation water is applied in the greenhouses through drip irrigation. There could be additional costs for the application of a new drip irrigation system. The farmers might need training on how to cultivate crops in greenhouses equipped with a rainwater harvesting system;
- Rainwater harvesting generates direct benefits to the farmers that invest and can start irrigation without being dependent on depleting groundwater resources or communal water sources which are prone to siltation;

- By collecting rainwater locally, farmers have less chance of salt and drought damage to their crops;
- By collecting rainwater locally, the farmers will have less chance of risk or non-production in the future under climate change because they can meet their water needs themselves.
- Production level and product quality will increase since the grower has high quality water available, producing high quality products

8.2 Algeria – Aquifer recharge with traditional systems

Location: Central zone of Algeria with an abandoned traditional fogarra (ketthara in Morocco) systems

Key words: AgriMAR, Aquifer recharge, Rainwater Harvesting, Climate Smart Agriculture, Feasibility assessment, fogarra

Brief project description: One of the high potential opportunities that has been identified is the upgrading of the abandoned traditional fogarra (ketthara in Morocco) systems with an Aquifer Storage Recharge system (AgriMAR), that makes use of the existing wells that usually surround the fogarras. The traditional fogarras are often abandoned due to overexploitation of the aquifers. Water harvested rainwater by the fogarra system can be stored in the aquifer for later use. The water needs to be infiltrated actively in order to make the most use of the storage capacity of the aquifer. This method of replenishing the aquifer is called Artificial Recharge (AR) or Managed Aquifer Recharge (MAR or AgriMAR). A climate smart solution is reached when the AgriMAR system is combined with water efficient technologies such as a drip irrigation.

Climate projections indicate an increase in the frequency and intensity of flash-floods. This business case provides a climate resilient opportunity to recover this excess of water so that it can be infiltrated in Aquifer Storage Recharge systems. These systems could be controlled locally by small communities of farmers, like it is done with the fogarra & khettaras in the traditional setting. A feasibility assessment combined with business case development is the first step in this process.

Expected project case results:

- Decision-support assessments (hydrogeological, stakeholder, business case) completed
- Business case developed and validated with partners and stakeholders
- AgriMAR proof of concept site selected
- Detailed AgriMAR design and construction steps refined
- Upscaling plan for Algeria developed
- Capacity building and training

Organisations to involve:

- Agricultural company active in the central area of Algeria
- Technical consultancy to carry out the feasibility assessment
- A consultancy to carry out a cost-benefit analysis for implementation
- A technical partner for the supply and construction
- Embassy and government for institutional support

Costs and benefits associated to this business case:

- Total costs of the AgriMAR systems are made up by investment costs, financing costs and yearly recurring operation and maintenance costs. By making use of a traditional fogarra system, investment costs are reduced.

- Investment costs are all those expended in Year 0 to acquire capital and to install (labour, material, equipment) the system. The main piece of equipment is the pump and some tubes.
- Irrigation water is applied to the fields through furrows or drip irrigation. There could be additional costs for the application of a drip irrigation system.
- Operation costs include fuel or electricity and the labour to operate the systems, as well as the additional labour costs for the farmer.
- Maintenance costs consist mostly of repair and cleaning costs.
- AgriMAR generates direct benefits to the farmers that construct the system and can starts off-season production, have improved water availability in the dry season and access to water of good quality. Also, with an AgriMAR system, an underground freshwater bubble can be created in a saline or brackish aquifer.

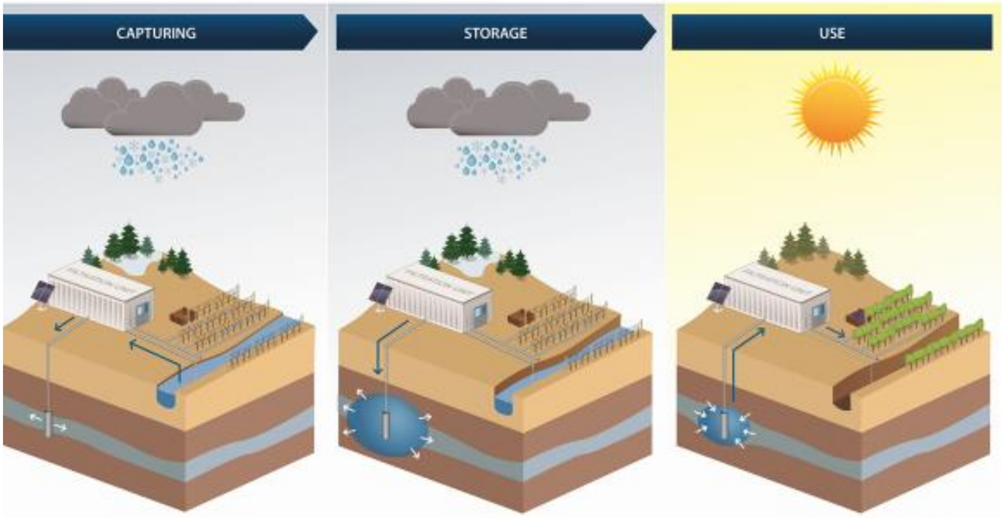


Figure 8-1. Managed Aquifer Recharge: rainwater or floodwater is captured, stored in the subsurface, and recovered for use during the dry season (source: Acacia Water).

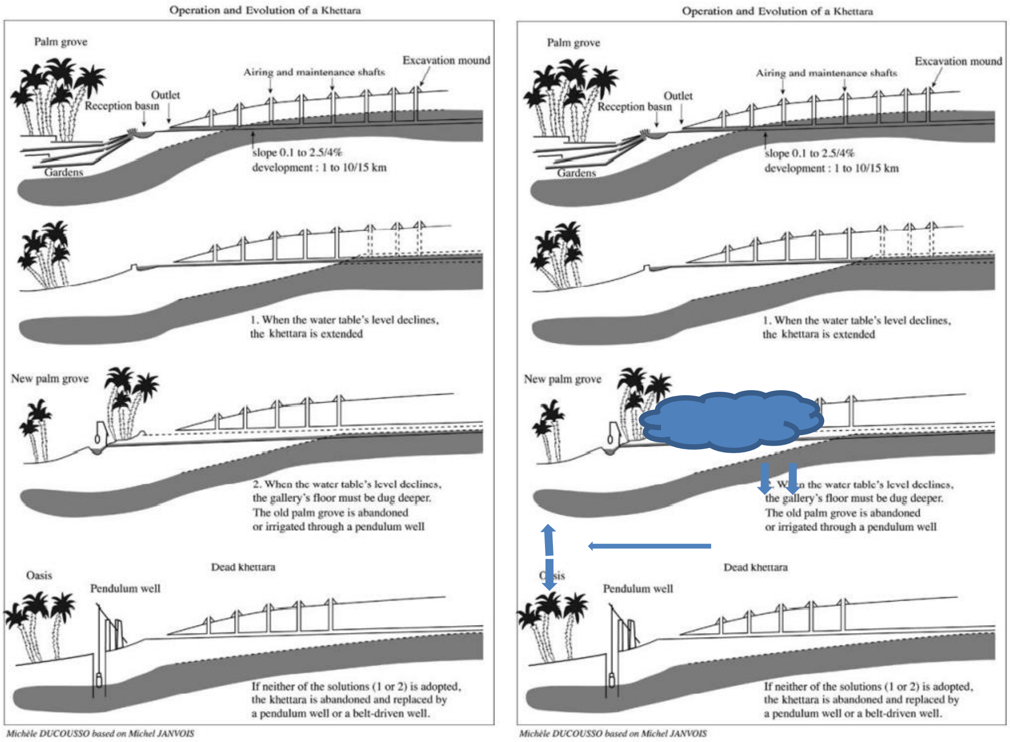


Figure 8-2. Left: Operation and evolution of a fogarra (El Faiz & Ruf, 2010). On the right, the traditional fogarra system combined with a new infiltration and abstraction pump for an AgriMAR system.

8.3 Morocco – Climate Smart hydroponics for smallholder farmers

Location: Different parts of Morocco, with a special focus on the southern region
Key words: hydroponics, smallholder farmers, salinity, water scarcity, vegetable crops
Brief project description:

Especially the southern region of Morocco has to deal with low rainfall, saline groundwater, high soil salinity and poor soil fertility. There is a great need for improving agricultural production, which can be the starting point of poverty reduction, food security and improved nutrition, some of the key Sustainable Development Goals (SDG's). The situation in southern Morocco asks for climate smart and innovative production systems, but at the same time low-tech solutions are needed that are affordable for the smallholder farmers. A potential solution that fits all is hydroponic cultivation of vegetable crops.

In this case the hydroponic cultivation should be low-tech and affordable for smallholder farmers. Pilots in the Netherlands (The Salt Doctors) have shown the potential of open-field hydroponics, using saline water for vegetable production. For this, shallow ponds can be created and the local saline groundwater can be used. Water circulation and aeration can be provided by a solar pump. Special attention is needed to the fertilization and specific crop selection. Although a proof-of-concept has already been developed in The Netherlands, validation in Morocco is needed. Tools, technologies and methods have to be refined for the local conditions, focussing on cost-effective approaches. This method is especially suitable in areas with low fresh water availability, but access to (light) brackish water. Water with an EC of between 2-8 dS/m can produce yields close to its maximum potential when the right crop variety is used.

It is likely that it is possible to accurately predict expected yields under different salinity levels for a number of different crops and crop varieties. This will allow the user to make educated decisions about available water of different qualities (i.e. salinity levels), and

what level of yield to expect. This will help farmers to make smart, informed economic decisions. Crops that can be produced in this way include high value cash crops such as cabbage, cauliflower, kale, spinach beet (chard), lettuce and tomatoes.
Demonstration and training will also be required to ensure farmers are able to implement and scale this climate-smart cultivation strategy. Concerning the costs and potential benefits, this has to be validated under the local conditions.

Expected business case results:

- Improved crop production in southern Morocco for present day use and "climate-proof" for future use
- Development of new business opportunities in the agricultural sector
- An innovative production system and adaptation strategy with potential in many other areas in the Maghreb region and beyond

Organisations to involve:

- Companies to supply input materials for the hydroponic system
- Suppliers of seeds, fertilizers
- Technical partner for the specific development of the hydroponic system under saline conditions, including crop selection and fertilizer strategy
- Local (research for development) partner to develop, validate, and refine the tools, technologies and methods, evaluate cost-benefits
- Capacity building and training on use of hydroponic production system
- Stakeholders to introduce technology to larger group of farmers and ensure scalability

Costs and benefits associated to this business case:

- An initial investment is required to set-up the hydroponics system. This depends on the local costs of materials and labour. A system of ponds of plastic foil is most likely the most cost-effective. Ponds have to be dug, lined with foil, a system of pipelines to add water and a circulation/aeration pump is needed, as well as the floating raft system. Also, seedlings have to be cultivated in a nursery before planting the crops on the raft. Control of pH may be needed and fertilizers need to be added.
- The farmer needs to be trained on how to correctly use the system.
- Validation of the system and growth performance of the different crops has to be done under local conditions. A minimum of two crop cycles will be needed to showcase and validate the results.
- Based on the salinity level of the water used, the farmer can very accurately predict the yield and harvest consistent quantities of high quality.
- Previous results showed an 30% yield increase when salt tolerant crop varieties are used (compared to standard varieties), when using (moderate) saline water.
- Money can be saved in water (up to 90% of reduced water use compared to open field agriculture). Also, (moderate) saline water can be used instead of fresh water.
- Money can be saved in the use of pesticides, since pest pressure is much smaller in hydroponics (no soil borne diseases), and with simple netting many airborne pests can be controlled.
- Yields can be higher than in open field cultivation at comparable salinity levels, possibly due to improved oxygen and nutrient availability for the crop.
- During the pilot in The Netherlands, around 50% less fertilizer was used under saline conditions, achieving similar yields, compared to the recommended amount.

- The growing cycle of a crop is often shorter in a hydroponic system, which also represents a benefit to the farmer who can put his products in the market earlier than his open field growing colleagues.
- Validation at field level is needed, but the principle can be used for large-scale cultivation on relative short term (1-4 years after validation).

8.4 Morocco – Demonstration farm for capacity building

Location: In the area around Oualidia

Key words: Salinity, capacity building, demonstration farm

Brief project description:

The area around Oualidia (the 'Oyster capital' of Morocco) has a strong farming background but is not the leading farming area anymore. This is partly due to problems with saline water and soils. However, because it was a strong farming community historically, there is still a lot of knowledge and there are farmer organisations, as well as the right infrastructure.

To revive the agriculture in the area, we propose to build a demonstration farm, where farmers from the area can come to learn how to improve yields under saline conditions. They can receive training on how to assess the status of their soil and water, how to deal with their specific conditions and which crops and crop varieties best to grow on their land. Drip irrigation is already common in the area, but water use can still be optimized by learning how to determine the irrigation frequency and quantity. This training can also be provided on the farm. Simultaneously, Dutch seed companies can use the farm to test their best performing seeds under the local, saline conditions. Possibly, Moroccan fertiliser companies can use the facility to develop better fertilisers for application on salinized soils, since fertiliser application also raises the EC of the soil.

Through all the literature reading, expert interviews and questionnaires and interviews with other stake holders, one of the recurrent themes was the need for better knowledge transfer. Even though the level of farming in Morocco is rather high, there is still room for improvement. A demonstration farm that can be a hub for information, training and materials (seeds, soil testing materials, sensors, etc.) can help achieving the goal of making the farming system in coastal Morocco future-proof.

Expected business case results:

- Improved crop production in the Oualidia region in Morocco and improve resilience of farmers.
- Improved water en energy use efficiency by farmers in the region.
- Reviving the agricultural sector in Oualidia, already known for its 'saline products'.
- Opportunities for Dutch seed companies to screen and showcase their best varieties.
- Opportunities for Dutch technology companies to test, showcase and sell their products (i.e. soil and water testing materials, soil moisture sensors, solar panels etc.) as well as opportunities for consultancy, training and market development as well as investing.

Organisations to involve:

- Companies that can provide knowledge and training on improved farming methods under saline conditions, as well as companies with expertise in water and irrigation management.
- Companies that can supply the right materials for managing and monitoring a farm using saline resources, such as irrigation and drainage materials, measuring and other diagnostic materials and equipment, sensors, etc.
- Suppliers of seeds.
- (Perhaps) Moroccan fertiliser companies.
- Capacity building and training.

Costs and benefits associated to this business case:

- The demonstration farm needs to be built and maintained. Costs will depend on many factors (completely new location or improve existing location, strong focus on research or more on validation, size of the farm (number of staff needed), number of crops and technologies to be showcased, etc.).
- Staff needs to be trained to maintain the farm in a representative manner.
- Staff needs to be trained on the basics of how to carry out scientific research.
- Local farmers can come and learn about improved cultivation methods and/or the use of alternative water sources. This will improve their yields, ultimately improving their livelihoods and the prosperity of the area.
- Through capacity building, awareness on the necessity to develop and adopt future proof farming methods will become common.
- To start, the focus will be on the implementation at farm level, but many of the tools, methods and technologies can be implemented on a large scale. The benefits on a large scale will take longer to become visible when the initial focus is more on research and training.

8.5 Tunisia – Year-round crop production by using medium tech greenhouses

Location: water-scarce agricultural areas, focus on middle and southern part of the country

Key words: greenhouse, horticulture, water scarcity, water use efficiency

Brief project description:

One of the challenges in Tunisia is how to continue to produce crops in the future under more water scarce conditions. One of the most water efficient cultivation systems is protected cultivation (greenhouses). Although high-tech greenhouses offer full control of the climatic conditions, there is also an increasing opportunity for medium-tech greenhouses. High tech greenhouses are (much) more expensive and require much more experience and expertise for proper maintenance. Thus, medium tech greenhouses have a lot to offer with less (investment) risk than high tech greenhouses pose. The medium-tech greenhouses can provide an early harvest in the winter and, through cooling, cultivation in the summer season is also possible. In short, medium-tech greenhouses can offer year-round cultivation opportunities for farmers, producing in times with high market demand while using less water and other resources. Specific crops for greenhouse cultivation are tomato, lettuce, cucumber, eggplant, pepper, but many other vegetables are suitable as well.

Most farmers however, are not familiar with greenhouse cultivation. Besides the technical aspects of the greenhouse cultivation, also added value can be created by increasing the quality of the products. By means of Good Agricultural Practices it should be possible to increase not only the quantity but also the quality of the product. This can add value to the products for the local market, as well as creating more opportunities for export. Besides the availability of the greenhouse itself, attention is needed to train farmers regarding protected crop cultivation and Good Agricultural Practices in order to achieve high yield of good quality. Post-harvest management and building entrepreneurship will also be vital elements. By doing so, the return of investment can be reduced to a minimum, making greenhouse cultivation cost-effective and scalable.

Expected business case results:

- Improved crop production under water scarce conditions.
- Crop production in the off season, products with high market value.
- Increased production and improved quality.
- New opportunities for export.

Organisations to involve:

- Companies to supply medium-tech greenhouses.
- Technical partner for the specific design of cultivation strategy and provide additional training regarding Good Agricultural Practices.
- Local organization to showcase greenhouse technology, combine sustainable techniques and train the farmers.
- Stakeholders in the value chain to ensure adoption by larger group and create more export opportunities.

Costs and benefits associated to this business case:

- An initial investment is needed to purchase the greenhouses and set up the irrigation and cultivation system. Also, maintenance costs have to be taken into account. This concept is not new and return-of-investments most likely is known already under local conditions.
- Specific training for the farmers is needed.
- When combined with drip irrigation or hydroponics, the water savings can be in the range of 40-90%.
- Greenhouses will enable farmers to produce off-season and year-round (heating in winter, cooling in summer).
- With good agricultural practices and integrated (organic) pest management, the quality of the produce should increase. This can also increase the export opportunities.
- The cultivation area of greenhouses is already increasing in all three countries and can result in increased crop production on relative short term (1-5 years).

8.6 Tunisia – Improving crop yield under saline conditions

Location: Salt-affected farm land with moderate salinity levels

Key words: Salt tolerant crops, improved agricultural practices, increasing crop yield, saline agriculture, climate smart agriculture

Brief project description:

As in the other two studied countries, Tunisia is facing increasing water scarcity and increasing salinity levels of many water resources. Many farmers are already using moderate saline water for irrigation and this can also result in elevated salinity levels in the soil. With increasing salinity, crop yields usually decline. By introducing resilient, robust crop varieties, in combination with smart soil and water management, crop yield under saline conditions can improve. Based on previous results (by The Salt Doctors) it should be possible to achieve 30-40% yield increase, compared to the traditional crop varieties and farming practices.

Improving crop yield under saline conditions starts with the implementation of salt tolerant crops. The crop varieties should not only be able to withstand higher salinity levels, but should also fit the climatic conditions and market needs. This can be validated on a relatively small scale, as long as the conditions are representative for a larger area. Besides the validation of the growth performance under the local, saline conditions, also the cultivation strategy regarding soil and water management has to be fine-tuned according to the specific conditions. In this way, evidence-based, scalable solutions can be developed. The results should be shared with the relevant stakeholders and training of lead farmers, who will implement the cultivation at their own farms. This is often a good way to introduce saline agriculture to a larger group. Special attention is needed to showcase the business model to the farmers in order to ensure that saline agriculture is not only possible but also profitable. In this way, scalable solutions can be introduced and farmers are able to increase their yield and become more resilient to climate change. The focus of this business opportunity will be on creating a network of (lead) farmers who will implement the cultivation of proven salt tolerant crops at their own farms to achieve quick impact (so this approach is different from the demonstration farm concept for Morocco).

Expected business case results:

- Improved crop production under saline conditions.
- Use of salt affected land and non-conventional water resources.
- Strengthening of capacity and knowledge regarding climate smart and saline agriculture.
- More profitable business model for farming.

Organisations to involve:

- Seed companies to provide resilient, robust crop varieties.
- Technical partner for the specific design of cultivation strategy under saline conditions and train-the-trainers.
- Technical partner for the specific design of improved soil and water management and train-the-trainers.
- Local partner to validate growth performance under saline conditions
- Local partner to train farmers.
- Stakeholders in the value chain to ensure adoption by larger group.

Costs and benefits associated to this business case:

- Farmers may need to invest in equipment (irrigation, drainage, soil cultivation machinery) and soil amendments to allow them to improve their yields under saline conditions.
- Farmers need training in the best methods, crops and crop varieties for viable crop production under saline conditions.
- Farmers will see their yields increase, which leads to improvement of their livelihoods. Previous results (by The Salt Doctors) have shown yield increases from 30 up to 100%. Also, by cultivation vegetable crops, not only food security but also nutritional security can be increased (when the crops are used for home consumption).
- Farmers will save (valuable) fresh water which becomes then available for other use. Under specific circumstances, (slightly) saline water can be used (for mixing) for irrigation, saving fresh water. Depended on the salinity level, the fresh water savings can be up to 50 or even 100%.

- Farmers will most likely save water in general, since part of the training on saline farming is about irrigation and the right frequency, most likely teaching the farmer that less water can be sufficient.
- Large areas in the whole Maghreb area are facing increasing salinity levels of water resources and of the arable land. By making use of these saline resources, the amount of available water for irrigation (non-conventional water sources) can be increased significantly and moderate salt affected soil can have high crop potential. However, saline agriculture requires a multi-disciplinary, integrated approach that focusses on crop, soil and water. It will take considerable time to implement cost-effective strategies on a large scale and a multi-year and multi-level approach is needed (4-10 years).

9 Conclusions

Water is scarce in large parts of the Maghreb countries Algeria, Morocco and Tunisia. Since agriculture is the largest consumer of water, it is the sector that is most affected by this scarcity. Through climate change and changing demographics, water will become an even more limited resource in the future, also in areas where currently precipitations levels are sufficient.

This water scarcity has led people to come up with clever interventions to store and distribute water when and where it falls in abundance, so it can be used in dry areas. Throughout the region, structure of sometimes thousands of years old can be found that have been used, and sometimes are still being used, for (underground) water storage and redistribution.

Another problem common in the region is salinisation. With this problem too, farmers have had to deal with it since ancient times- and in many places they deal with this rather effectively.

Thus, it comes as no surprise that many of the solutions proposed in the report to the current and future problems are very closely related to the same type of ancient solutions. Water needs to be captured by landscape changes, stored in existing and new to be build water storing systems such as MAR, and 3R landscape interventions need to prevent the fast silting up of dams and reservoirs that is currently a large problem. Additionally, alternative water sources such as brackish water and treated wastewater should be used more broadly and more effectively.

Even though some of these interventions already take place or have at least been piloted, the region needs to scale up these interventions and solutions to ensure a future proof agriculture. Existing knowledge should be spread more effectively to those who need it, and awareness needs to be improved through capacity building and applied knowledge approaches. To ensure this, government could create an enabling environment, and base their next decisions on proven concepts. This is easier in some countries than in others, but even in countries where the laws and rules seem to be clear and correct, there may still be a lot of room for improvement in the everyday practice. Ideally, the countries can learn from each other, since their problems largely overlap, and sometimes their resources literally do so (i.e. aquifers).

There is expertise in the Netherlands to help establish some of the improvements suggested here. For example, The Netherlands has high quality seed companies that can improve the yields of the farmers, also under adverse conditions. In addition to the seeds, there is just a large amount of water and agriculture knowledge in The Netherlands on best practices for many of the crops cultivated in the region (also under adverse, saline conditions), which can lead to large improvements in yields. This can be achieved by using better starting material such as seeds, but also by flexible, robust and inclusive farming practices and scaling up the mechanisation in agriculture, as well as scaling up the use of data driven (sensory) technologies for managing and improving on water and soil quality and quantity. All of this expertise is present in The Netherlands and can contribute to farmers' productivity.

There is a lot of knowledge on greenhouses, one of the most water use efficient ways to produce food. Greenhouse optimisation can make a big difference in the Maghreb region, also in areas where currently there is enough freshwater present but under climate change conditions, water will become scarce there too like the wetter north with substantial red fruit production.

There are a number of Dutch companies that are specialized in water interventions, with proven concepts for water harvesting, storage and multiple use. This type of intervention will be crucial for the future resilience of agriculture in the region. In general, the interventions recommended all can be seen as a natural and next development on paths taken long ago.

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Annexes

Annex 1 List of specialists interviewed

The majority of the interviews were carried by phone/video call because of Covid-19.

Algeria

Name and Surname	Function / Institution	Email address or contact details
Mohamed Lakehal	Vice general director of the National office of Irrigation and drainage (ONID, Algiers)	lakehal_younes@yahoo.fr
Reda Touaibia	ONID: The management unit for the irrigated areas (GPI) of Mitidja Ouest (Tipaza)	
Benchabane Choukri	Vice president of the Tipaza farmers chamber	
Kamel Bensalah	Head of the research team “smart irrigation” at CRSTRA (Research and Scientific Center for arid regions).	benkam99bis@yahoo.fr
Salim Ouartsi	CEO holding Quartsi : Produits agroalimentaires (importation, exportation)	ouartsi.holding@gmail.com
Mustapha Kamel Fodil	Relizane farmer leader	fodil_99@yahoo.fr
Lakhdar Bahri	Relizane agricultural chamber vice president	
Abdallah Tindert	Entreprise des travaux et équipement agricoles (serres canariannes)- Agrotins Biskra	
Ahmed Hadibi	assistant manager at IBC, an ACI branch specialized in irrigation equipment.	a.hadibi@yahoo.fr
Merabet Amine	Engineer working at AGRIMATCO company with 4 branch offices Biskra, Annaba, Algiers and Mostaganem.	labadi.k.cyp@agrimatco.com

Tunisia

Name and Surname	Function / Institution	Email address
Abdelkader HAMDANE	Former General Director, Directorate General of Rural Engineering and Water Exploitation (DG GREE) Ministry of Agriculture, Hydraulic Resources and Fishing International Expert in the field of water	Abdelkader.hamdane@gmail.com

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Ahmed GHRABI	General Director. Cente des Etudes et des Recherches des Techniques de l'Eau (CERTE, Center for Studies and Research on Water Technology) Ministry of Higher Education and Scientific Research Professor, Specialist in water treatment reuse	Ahmed.ghrabi@certe.rnrt.tn
Ali KCHOUK	Former Director. Planning and Hydraulic Balancing Office (Bureau de Planification et des equilibres Hydrauliques, BPEH) Ministry of Agriculture, Hydraulic Resources and Fishing	alikcouk@yahoo.fr
Jamila TARHOUNI	Professor of hydraulics and hydrology. Former head of the Department of Rural Engineering National Agronomic Institute of Tunis (INAT)	elmaainat@yahoo.fr
Mohamed DOUZI	Regional Manager of the Compagny Générale Conserves Alimentaires (Jouda) Member of the agro-food commission of the Tunisian Union of Industry, Trade and Handicrafts (UTICA)	Douzimohamed75@gmail.com
Faouzi ZAYANI	President of SYNAGRI (Syndicat des Agriculteurs)	Faouazizayani99@gmail.com
Jan Mulder	Senior project manager at Grow Group (Grow Tunisia) and Rainbow Horticulture Tunisia	jmulder3547@gmail.com

Morocco

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Fouad Ababou	Area sales manager Hoogendoorn Growth Management greenhouses and integrated systems	fab@hoogendoorn.nl

Marco Groenewold	Production Director at Van Oers United.	N.a.
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Annex 2 – Shortlist of Dutch parties

A shortlist of Dutch companies, organisations, institutes and service providers in the water – agri sector that are working or have potential interest in business opportunities in Morocco. Algeria and Tunisia.

Consultancy

Name	Website	Email
ACACIA Water	www.acaciawater.com	info@acaciawater.nl
Alterburg & Wymnega	www.altwym.nl	
ANTEA group	www.anteagroup.com	
ARCADIS	www.arcadis.com	
Climate Fund Managers	www.climatefundmanagers.com	
Dacom Farm Intelligence	www.dacom.nl	
Data watt	www.datawatt.nl	
Delphy	www.delphy.nl	info@delphy.nl
Ecorys	www.ecorys.com	
Future Water	www.futurewater.eu	
Gieling consultancy	www.gc-bv.nl	
HKV	www.hkv.nl	
Hydrologic	www.hydrologic.com	
Mott Macdonald	www.mottmac.com	
Nedap Naïade	www.nedap-uv.com	
PNO consultants	www.pnoconsultants.com	
PUM	www.pum.nl	info@pum.nl
SAAF consult	www.saafconsult.com	info@saafconsult.com
Salt Doctors	www.thesaltdoctors.com	bas@thesaltdoctors.com
SWECO	www.sweco.nl	
TAUW	www.tauw.nl	

Knowledge institutes

Name	Website	
Acacia Institute Foundation	www.acaciainstitute.nl	info@boerenmetenwater.com
Deltares	www.deltares.nl	info@deltars.nl
ECN	www.ecn.nl	info@ecn.nl
E-leaf	www.eleaf.com	
IHE Delft	www.un-ihe.org	
KWR	www.kwrwater.nl	
STOWA	www.stowa.nl	
TNO	www.tno.nl	info@tno.nl
TU Delft	www.tudelft.nl	
University of Twente	www.utwente.nl	
Eindhoven TU		
Wageningen Environmental Research (WENR)	https://www.wur.nl/en/Research-Results/Research-Institutes/Environmental-Research.htm	

Wageningen University & Research (WUR)	www.wur.nl	
WETSUS	www.wetsus.nl	

Water Technology Company

Name	Website	Email
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Bluecon	www.bluecon.nl	info@bluecon.nl
Broere	www.broereberegening.nl	info@broereberegening.nl
Colubris	www.colubriscleantech.com	info@colubriscleantech.com
FIXEAU	www.fixeau.com	info@fixeau.com
Hatenboer Water	www.hatenboer-water.com	info@hatenboer-water.com
Hydraloop	www.hydraloop.com	info@hydraloop.com
Landustrie	www.landustrie.nl	info@landustrie.nl
Lenntech	www.lenntech.com	info@lenntech.com
Logisticon	www.logisticon.com	water@logisticon.com
Megagroup	www.megagrouptrade.com	info@megagrouptrade.com
Mobile Water Management	www.mobilewatermanagement.nl	info@mobilewatermanagement.com
Nijhuis Industries	www.nijhuisindustries.com	info@nijhuisindustries.com
Rainmaker	www.rainmakerww.com	sales@rainmakerww.com
Royal Eijkelkamp	www.eijkelkamp.com	sales@eijkelkamp.com
Van Essen	www.vanessen.com	info@vanessen.com

Agriculture

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Agroplant	www.agroplant.nl	info@agroplant.nl
Aquagri	www.aquagri.in	onnoschaap@aquagri.com
Bejo	www.bejo.com	info@bejo.com
De Nijs	www.denijspotatoes.com	Info@nijs.com
DutchGreenhouses	www.Dutchgreenhouses.com	info@dutchgreenhouses.com
Frankort & Koning	www.frankort.nl	info@frankort.nl
GROW group	www.plantise.com	info@plantise.com
Growers United	https://growersunited.nl/	info@growersunited.nl
Havencon	www.havecon.com	info@havecon.com
Hoogendoorn	www.hoogendoorn.nl	fab@hoogendoorn.nl
HZPC	www.hzpc.com	info@hzpc.com
Kamps	www.kamps-sperziebonen.nl	info@kamps-sperziebonen.nl
Meijer Potato	www.meijerpotato.com	info@meijerpotato.com
Messem	www.messem.com	messem@messem.com
Meys	www.meys.eu	info@meys.eu
Netafim	www.netafim.com	Info@netafim.fr
PRIVA	www.priva.com	frontoffice.agro@priva.nl
Prominent	www.prominent-tomatoes.nl	info@growersunited.nl
Rijk Zwaan	www.rijkzwaan.com	info@rijkzwaan.com
Van der Sat	www.vandersat.com	info@vandersat.com
Van Oers	www.vanoers.nl	info@vanoers.nl
A&G van de Bosch	www.vleestomaat.nl	petra@vleestomaat.nl

Energy Technology

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Colsen	www.colsen.nl	info@colsen.nl
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Exasun	www.exasun.com	info@exasun.com
Hydreco	www.hydreco.nl	info@hydreco.nl
Nedisun	www.nedisun.nl	info@nedisun.nl
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Vermillion Energy	www.vermilionenergy.nl	infonl@vermilionenergy.com

Annex 3 – Landscape restoration interventions

A summary of potential interventions is presented in more detail in here. The 3R approach ('Retention, Recharge and Reuse of Water') focuses on the physical landscape analysis to provide some advice about the best manner to store water in the wet period and make it available for use in the dry periods. The selection of suitable 3R interventions depends on the intended use of the water. For drinking water, where high quality is required, closed storage in tanks or groundwater storage are most suited. The demand for cattle or irrigation water may be suited with water from a lower quality, which broadens the range of possible 3R interventions with open water storage and soil moisture.

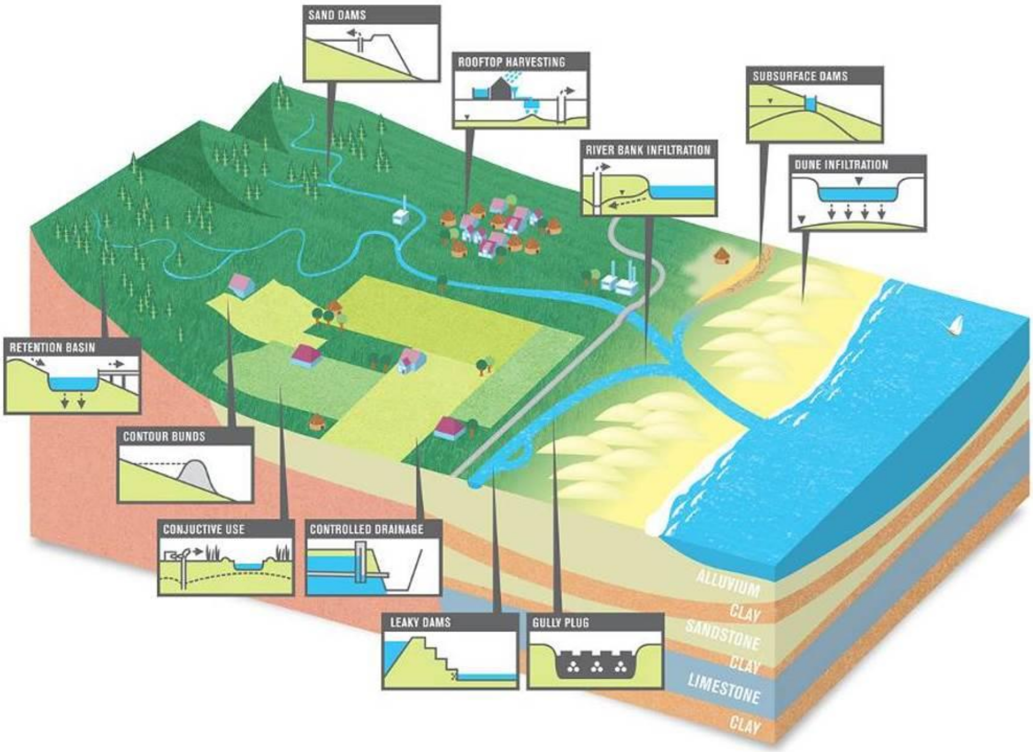

Figure 10-1. Infographic illustrating 3R applications within a river basin (Van Steenbergen & Tuinhof, 2010)

Figure 10-2. Different categories of soil and water harvesting measures

In-stream water storage offers great opportunities for making more water available. Allocation of the different types (and sizes) of in in-stream interventions depends on the location (e.g. upper/middle/lower) in the catchment. The larger the size of the upstream catchment at a certain location, the larger the amount of water that is collected in the river. The higher the slope, the higher the velocity in the river becomes and the higher the risk of erosion and large quantities of sediment transport. The strength and the size of the structure to be placed will depend on these two aspects: how fast is the river water flowing, and how much water is flowing in the river. Important is that all structures need a spillway.

The slope, the catchment size, the amount of rain and surface runoff (partly determined by the rate of degradation of the upstream catchment) determine the type and strength of in-stream structures that can be build:

- Far upstream in the catchment, slopes are steeper and the stream branches smaller, resulting in small but strong structures such as check dams as best solutions. These can be made of stones, and in some cases can be made of gabions. A gabion is a box cage (of a wire mesh/chicken wire) filled with rocks, that can be placed in stream. The advantage of a gabion over a check dam is that the structure is much stronger. With the check dams water is delayed by flowing slowly through the structure, hence sustaining a baseflow downstream of the dam.
- When the streams become bigger, the structure needs to become stronger as well. If the geology is suitable, concrete sand dams with wings in the riverbanks can be constructed.
- Further downstream in the midstream part of the catchment slopes reduce, hence velocity of the rivers reduces. Flow volumes however increase because the upstream catchment increases. Here, riverbeds can become very wide and can contain thick layers of sand. If rivers are still small enough (less than 30 m wide) sand dams can be constructed. If slopes are small enough and the riverbeds are wide, sometimes water can be abstracted directly from the riverbed (called riverbank filtration). Other times however, it is better to build a sub-surface dam to keep the groundwater in the riverbed sediments, and to prevent it from flowing downstream.

- The lower section of the catchment, with flatter areas and streams reduce the chances of erosion, hence make it possible for the water to flow out of the riverbed (naturally or) by application of water spreading weirs.
- At the downstream part, slopes are so low that if large volumes are spread out over large areas no erosion will happen. Therefore, spate irrigation can be applied here.
- It has to be emphasized that the structures should all be strong enough to withstand flash floods and peak flows. Secondly, all these structures should have spillways of the right size, to keep the water in the riverbed, and minimize the risk of failure of the structure during flash floods or peak flows.

Table 10-1. An overview of Water harvesting/storage/usage interventions with indications of the resulting water quantity and quality.

Nr.	Type of water harvesting	3R Interventions	Quantity	Quality	User group		
					Domestic	Livestock	Agriculture
1.	Surface water storage in-stream	Dams/large reservoirs	💧💧 - 💧💧💧	💧 - 💧💧	O	√	√
		Valley dams	💧 - 💧💧	💧	X	O	√
2.	Surface water storage off-stream	Charco dams or small hillside storages	💧 - 💧💧	💧	X	O	√
		Valley tanks	💧 - 💧💧	💧	X	O	√
		Water pans or ponds	💧 - 💧💧	💧	X	√	√
3.	Groundwater storage in riverbeds	Sand dams	💧💧 - 💧💧💧	💧 - 💧💧💧	√	√	√
		Subsurface dams	💧💧 - 💧💧💧	💧 - 💧💧💧	√	√	√
		Permeable dams	💧 - 💧💧	💧💧💧 - 💧💧	O	√	√
4.	Groundwater storage in aquifers	MAR (Managed Aquifer Recharge) / Tube recharge	💧 - 💧💧	💧 - 💧💧	O	√	O
		Riverbank infiltration	💧 - 💧💧	💧💧 - 💧💧💧	√	√	√
5.	Shallow/deep groundwater abstraction	Shallow wells with hand pump	💧 - 💧💧	💧💧 - 💧💧💧	√	√	O
		Drilled deep borehole or tube well with hand pump	💧 - 💧💧	💧💧 - 💧💧💧	√	√	O
		Production borehole/well with motorized pump, solar power or generator	💧💧 - 💧💧💧	💧💧 - 💧💧💧	√	√	√
6.	Overland water storage	Flood water spreading or Spate irrigation	💧 - 💧💧	💧	X	√	√
7.	Hard surface water storage	Rooftop water harvesting	💧	💧💧 - 💧💧💧	√	X	O
		Road water harvesting	💧💧	💧	X	√	√
		Rock catchments	💧 - 💧💧💧	💧	X	√	√
		Underground cisterns/Birkad	💧 - 💧💧	💧💧 - 💧💧💧	O	√	√

	Domestic	Livestock	Agriculture*
√	Good option, check water quality	Good option	Good option
O	Treatment is needed	Treatment might be needed	Limited amounts or high costs
X	Not advised, only consider if no other options are viable, treatment is necessary	Limited amounts, relatively high costs	Not viable

Quantity/quality indication	
💧	Low
💧💧	Medium
💧💧💧	High

* two aspects of the agricultural usage that should be determined in the fields, based on the local situation: the salinity of the used water (especially with MAR in saline areas) and the number of bacteria's in the water, that increases with higher temperatures, and can result in plant diseases.

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