Reconciling resource uses: Assessment of the water-food-energy-ecosystems nexus in the North Western Sahara Aquifer System

Part B: Technical assessment of resources and sectors

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1 Geography, resources and climate

1.1 Location and scope

The North Western Sahara Aquifer System (NWSAS) covers a vast area bounded by Algeria, Libya and Tunisia (Figure 1). The NWSAS is made up of two main overlapping deep aquifer layers that interconnect with the Tunisian–Libyan Djeffara plain: a) the Intercalary Continental, the deepest layer; and b) the Terminal Complex, which is particularly exploited in the Rhir Wadi, Souf, Djérid, Nefzaoua and the Gulf of Sirte. This system covers an area of more than 1 million km², of which 700,000 km² are in Algeria, 250,000 km² are in Libya, and 80,000 km² are in Tunisia.

Figure 1. NWSAS perimeter

Source: OSS.

1.2 Climate, climate projections and adaptation measures

The three countries in which the NWSAS is located have an arid desert climate. Rainfall is scarce and very erratic, sometimes causing flooding. In general, rainfall is less than 150 mm per year, which is well below the annual potential evaporation. Only the northern region of Tripoli (Jebel Nafusah and the Djeffara plain) has an average annual rainfall of between 250 mm and 300 mm, which enables rainfed agriculture. Temperatures are very high in the desert zone, where they exceed 40°C, but are lower in Libya, where they range from 24.5°C in the south of the country to around 20°C in the north.

Over the last 25 years, Algeria has experienced a period of intense and persistent drought, marked by a significant rainfall deficit (almost 30 percent) throughout the country. The reduction rate of rainfalls in the Sahara has been estimated at 28 percent. During the twentieth century, the temperature increased by 1.5°C to 2°C – double the global average increase for the same period.

In Libya, the average annual temperature increased by 0.35°C every ten years between 1951 and 2000. Total annual rainfall increased by 0.03 mm every ten years over the same period, while a decrease of 0.36 mm per decade was recorded over the 1976–2000 period.

In Tunisia, temperatures increased by an average of 1.4°C during the twentieth century. Rainfall patterns are inconsistent and irregular. Rainfall is either very high or very low, and the extent and regularity of this fluctuation varies significantly from one rainfall station to another. Although rainfall tends to increase in the autumn, no spatial homogeneity has been identified. This is particularly the case for the Gafsa station, which is close to the NWSAS perimeter. However, droughts are a concerning and recurrent phenomenon in Tunisia. The so-called 'very dry years' (deficit above 50 percent compared to average) are rare in the north, but more frequent in the central and southern regions. According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), climate projections for Africa, particularly North Africa, indicate a slight decrease in rainfall at the end of the twenty-first century, a significant increase in temperatures, especially minimum temperatures, and a particular increase in heat waves in the Sahara during the twenty-first century.

The report states that throughout the twenty-first century, the impacts of climate change are expected to slow economic growth, hamper efforts to tackle poverty, reduce food security, maintain existing pockets of poverty, and create new ones. In the NWSAS region, this could increase the risk of oases disappearing.

In 2018, downscaling works were conducted in Tunisia as part of the Coordinated Regional Climate Downscaling Experiment (CORDEX) initiative. These were based on two Representative Concentration Pathway (RCP) scenarios: RCP8.5 (pessimistic scenario with high emissions) and RCP4.5 (medium-low scenario with stabilisation at the end of the century). According to RCP4.5 and RCP8.5, the average temperature in the NWSAS region would increase by 1.1°C–1.4°C and 2°C–2.4°C respectively by 2050. Rainfall should be reduced by 0–5 percent according to RCP4.5, and 3–15 percent according to RCP8.5. By 2100, according to RCP4.5 and RCP8.5, the temperature would increase by 2°C–2.6°C and 4.4°C–5°C respectively. Rainfall would be reduced by 0–12 percent according to RCP4.5, and 17–27 percent according to RCP8.5.

It is understood that no recent downscaling works have been carried out in Algeria or Libya. The regional projections for Algeria are therefore based on the work carried out under the country's Third National Communication, in 2010, and the 2001 IPCC IS92a[1] medium scenario. The regional projections for Libya were produced using the World Bank's Climate Change Knowledge Portal.

The table below summarises the projections for the three countries, based on temperature and rainfall:

[1] This is the first generation of IS92 scenarios, developed by the IPCC in 1992.

Table 1. Regional climate projections in NWSAS countries

Area concerned/parameters	Climate scenario	Temperature (°C)	Rainfall (%)	Time frame
Algeria (IPCC Third Assessment Report, 2001)	IS92a	+ 0.8 to 1.1 + 1.6 to 2.2	- 5 to 8 - 15 to 22	2020 2050
Libya (World Bank portal, accessed May 2020)	RCP8.5	+ 2.3	- 7	2050
Tunisia (National Institute of Meteorology (INM), 2018	RCP4.5 RCP8.5	+ 1.1 to 1.4 + 2.0 to 2.6 + 2.0 to 2.4 + 4.4 to 5.0	- 0 to 5 - 0 to 12 - 3 to 15 - 17 to 27	2050 (southern region) 2100 (southern region) 2050 (southern region) 2100 (southern region)

Source: Authors' compilation.

Sandstorms are expected to become increasingly frequent in the NWSAS region, which would have a direct impact on the silting of farms. This is another particularly important parameter for the NWSAS.

1.3 Overview of the NWSAS

1.3.1 Geological description

The NWSAS basin includes a series of aquifers that, over the course of successive reconnaissance studies, have been grouped into two reservoirs known as the Intercalary Continental and the Terminal Complex.[2]

The term **'Intercalary Continental'** refers to a continental episode located between two marine sedimentation cycles:

- the Paleozoic basement completed during the Hercynian orogeny
- topped by the Upper Cretaceous layer.

The **Terminal Complex** is a fairly inhomogeneous body, comprising carbonate formations from the Upper Cretaceous period and detrital episodes from the Tertiary, and mainly Miocene, epochs.

Originally, these definitions were used to analyse and map the hydrodynamic functioning of Algerian and then, by extension, Tunisian aquifers.

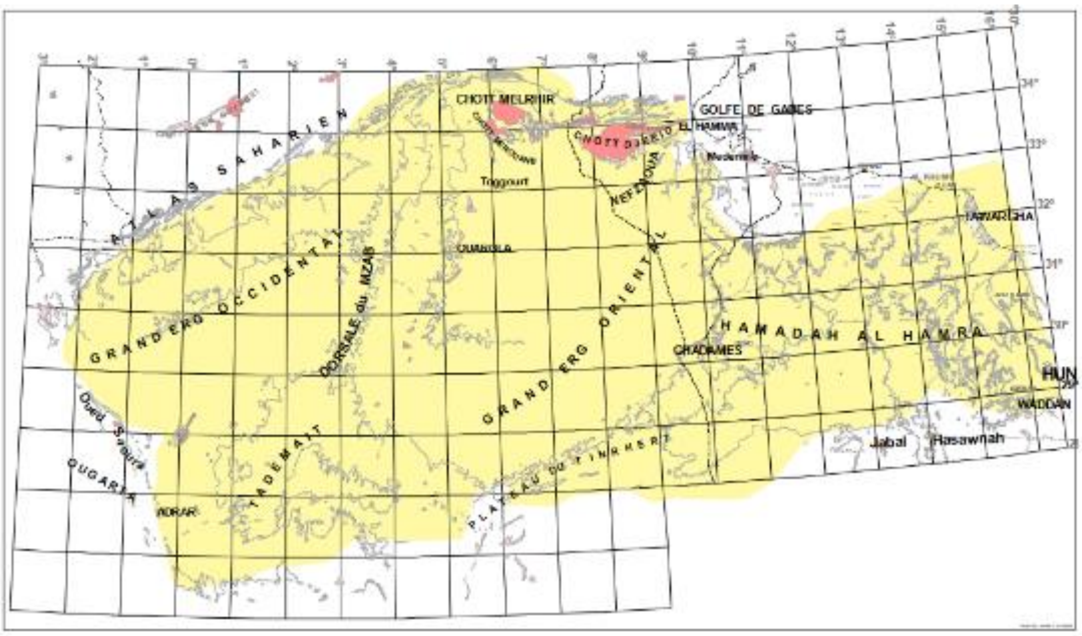
The addition of the Libyan area of the basin to the NWSAS project,[3] required a new analysis of geological, geophysical and hydrogeological information, based both on previous studies and new data collection.

The outcrops of the entire Saharan basin form two basins (Figure 2): the Grand Erg Occidental (Algeria) and Grand Erg Oriental (Algeria and Tunisia) basins, and the Hamada al Hamra plateau (Libya).

[2] OSS (2004).

[3] North Western Sahara Aquifer System project (not to be confused with the aquifer itself), carried out in three phases from 1999 to 2013 and implemented by OSS and other partners.

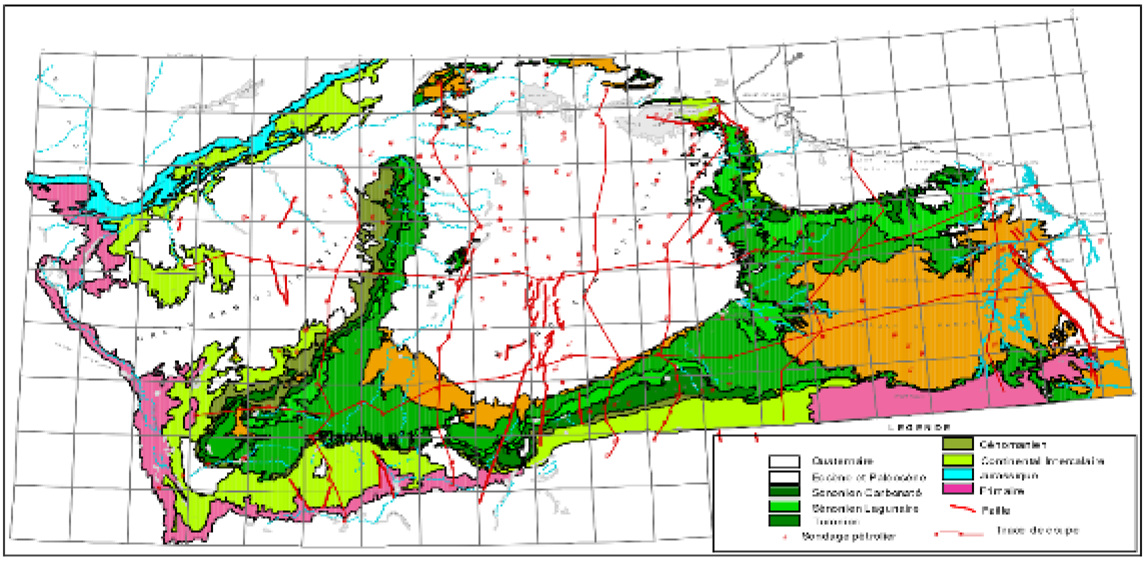
Figure 2. Map of the northern Sahara



Source: OSS (2008).

The oldest formations can be seen in outcrops on the southern and western edges of the basin. The secondary and tertiary sedimentary series thicken in the middle of the two basins and at the edge of the South Atlas flexure (Figure 3).

Figure 3. Map of NWSAS geological outcrops



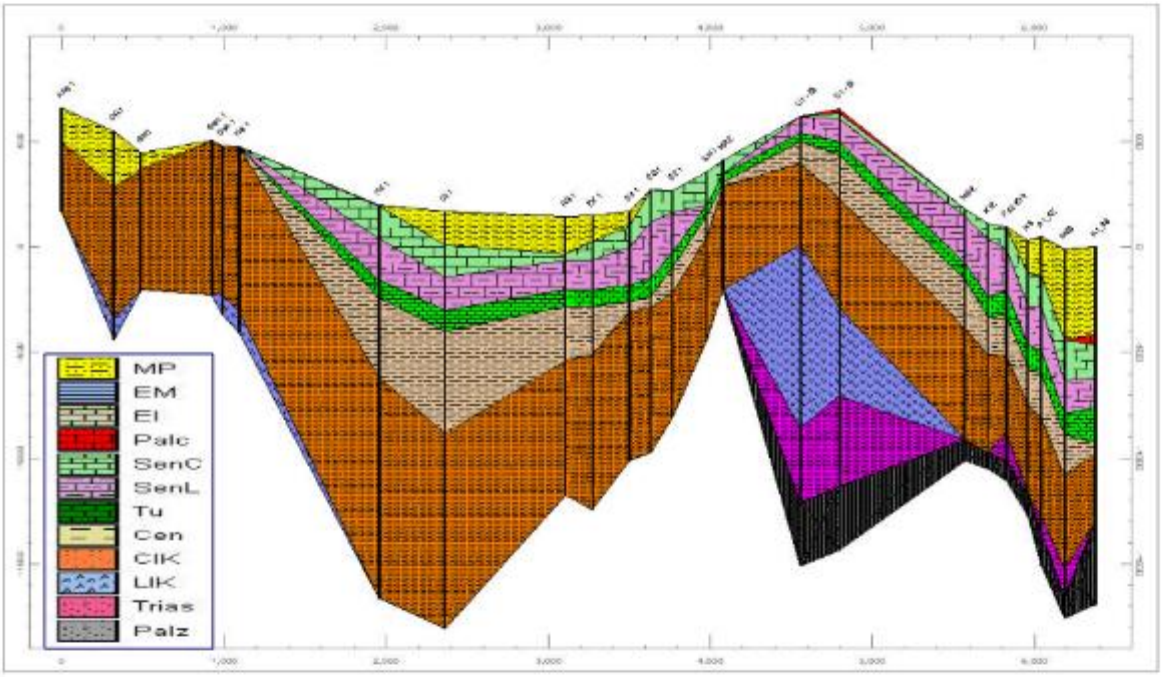
Source: OSS (2004).

1.3.2 Horizontal structure of the NWSAS

The NWSAS is divided into three sub-basins from west to east (see the following Figures 4 and 5):

- The Western Basin, comprising the *foggaras*[4] area to the south, the Grand Erg Occidental and the Saharan Atlas to the north. Most of the Intercalary Continental layer is unconfined and therefore constitutes a groundwater reserve that is easily accessible through structures (*foggaras*, wells and boreholes) of shallow depth (a few dozen metres).
- The central basin, which is the largest and deepest, has the thickest aquifers. Its resources are shared between the three countries. It is bounded by the M'zab Ridge to the west and the Hamadah al Hamra plateau to the east. The Grand Erg Oriental and the Algerian–Tunisian *chotts* (salt lakes) account for a large part of its morphology.[5]
- The eastern basin, characterised by the Hamadah al Hamra plateau, the Hun Graben depression and the accumulation of tertiary sediments.

Figure 4. West to east cross-section of the NWSAS, from the Western basin to the Hun Graben

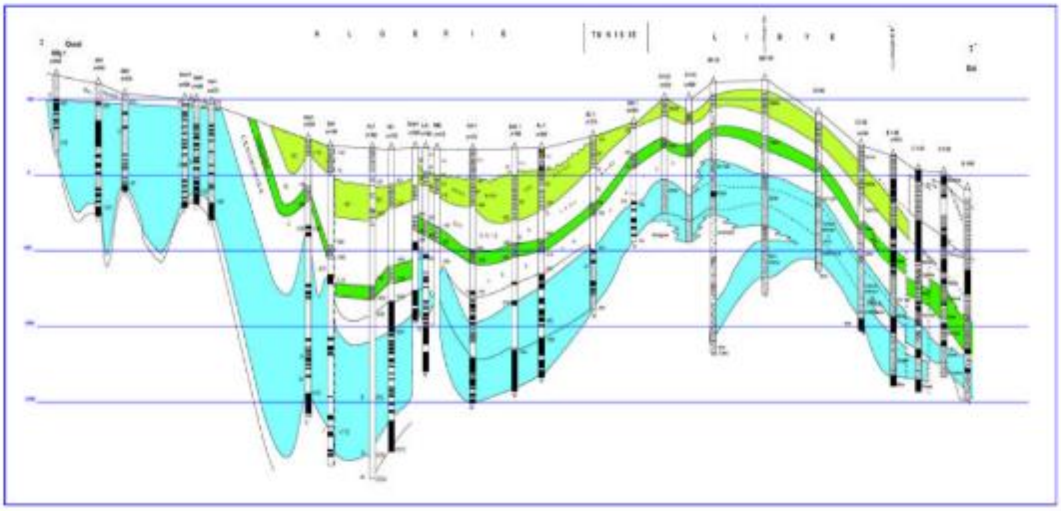


Source: OSS (2004).

[4] *Foggaras* are traditional systems that use gravity to extract groundwater in foothill areas. There are several in Algeria, where they are used to irrigate palm groves in the NWSAS.

[5] A permanent expanse of salt water with changing shores, located in arid, Saharan regions. *Chotts* are fed intermittently during rare rainfall, and often by the deep aquifers for which they serve as natural outflows. They experience high evaporation, leading to the accumulation of salts on the surface of the silt, which are sometimes exploited.

Figure 5. West to east lithostratigraphic correlation of the Western basin at Tawargha



Source: OSS (2004).

1.3.3 Vertical structure of the NWSAS

The Saharan basin is a large, multilayered sedimentary body. Simultaneously representing all its layers enables mapping of hydraulic and chemical connections and exchanges between them, and by extension, system behaviour in the medium and long term. A 50-year study (1950–2000) of the hydrodynamic functioning of the piezometry (water level), water salinity, and its exploitation has enabled further learning about its hydrogeology. This in-depth knowledge of the basin's geology and hydrogeology has enabled mapping of the aquifers to develop a mathematical model that represents the exchanges and flows of water within the aquifer system.[6] This conceptual model is the result of successive simplifications. The NWSAS multilayer thus comprises three overlapping aquifer levels, separated or interacting through semi-permeable formations: the Intercalary Continental layer, the more localised Turonian layer and the Terminal Complex layer.

The diagram presented in figure 6 illustrates the final stage of the geological simplification of the Northern Sahara, through cross-sections for each country, followed by regional lithostratigraphic correlations.

Specifically, the last step in reading the country cross-sections was to illustrate the successive lithostratigraphic equivalents using 'aquifers' and 'aquitards'. These series, when placed side by side and compared with the stratigraphic scale, resulted in the diagram shown in figure 6, in which the most important freshwater aquifer formations are shown in blue and the saltwater aquifers are shown in pink, while the remaining formations (semi-permeable or impermeable formations, poor quality aquifers) are colourless.

[6] OSS (2004).

Figure 6. Diagram of the Saharan multilayer

Stratigraphic Unit		Aquifers & Aquitards: ALGERIA	TUNISIA	LIBYA
Plioquartenary	Mio-Pliocene	2nd sands aquifer	Impervious Top	Local aquifer
Miocene		Semi-permeable		Semi-permeable
Aquitanian		1st sands aquifer	Aquifer of the Djerid sands	Aquifer
Oligocene		Semi-permeable		Local aquifer
Middle Eocene		Semi-permeable	Semi-permeable	Poor quality aquifer
Lower Eocene		LIMESTONE aquifer	Unrecognized aquifer	
Palaeocene			Semi-permeable	Upper Cretaceous-Paleocene Mizda Aquifer
Upper Senonian	Maestrichtian		Aquifer of Nefzaoua Upper Limestone	
	Campanian			
	Santonian		Semi-permeable	
Lower Senonian		Impervious	Aquifer of Lower Limestone/Nefzaoua	Semi-permeable
			Semi-permeable	
Turonian		Turonian Aquifer	Turonian Aquifer	NALUT aquifer
Cenomanian		Impervious	Impervious	Impervious
Albian		Aquifer of the Continental Intercalaire	Aquifer of the Continental Intercalaire	Jurassic-Lower Cretaceous KIKLAH Aquifer
Aptian				
Barremian				
Neocomian		Salty water		
Malm	Kimmeridgian	Jurassic aquifer	Semi-permeable	
	Callovo-Oxfordian		JURASSIC aquifer	
Dogger	Bathonian			
Lias		Impervious top	Impervious	Impervious
Keuper				
Mushelkalk				Trias AZIZIA Aquifer
Bundstandstein		Trias salty aquifer	Trias aquifer	

Source: OSS (2004).

Excluding the Triassic, Jurassic and Neocomian saltwater aquifers in Algeria and the Triassic sandstone aquifer in Libya (which contains fresh water but is relatively well isolated from the other aquifer systems), there are, according to purely lithostratigraphic criteria, four major overlapping aquifer layers, albeit of unequal importance, whose vertical organisation and regional connections are clearly visible. From bottom to top, it is therefore possible to distinguish:

- The Intercalary Continental layer in Algeria–Tunisia, extending to Libya in the Kiklah aquifer formation (Jurassic and Lower Cretaceous).
- The Turonian layer in Algeria–Tunisia, extending to Libya in the Nalut aquifer formation.
- The limestone layer in Algeria (Senonian carbonate and Eocene carbonate), extending to Tunisia in the (lower and upper) limestone layer of Nefzaoua, and in Libya equivalent to the Mizdah aquifer.

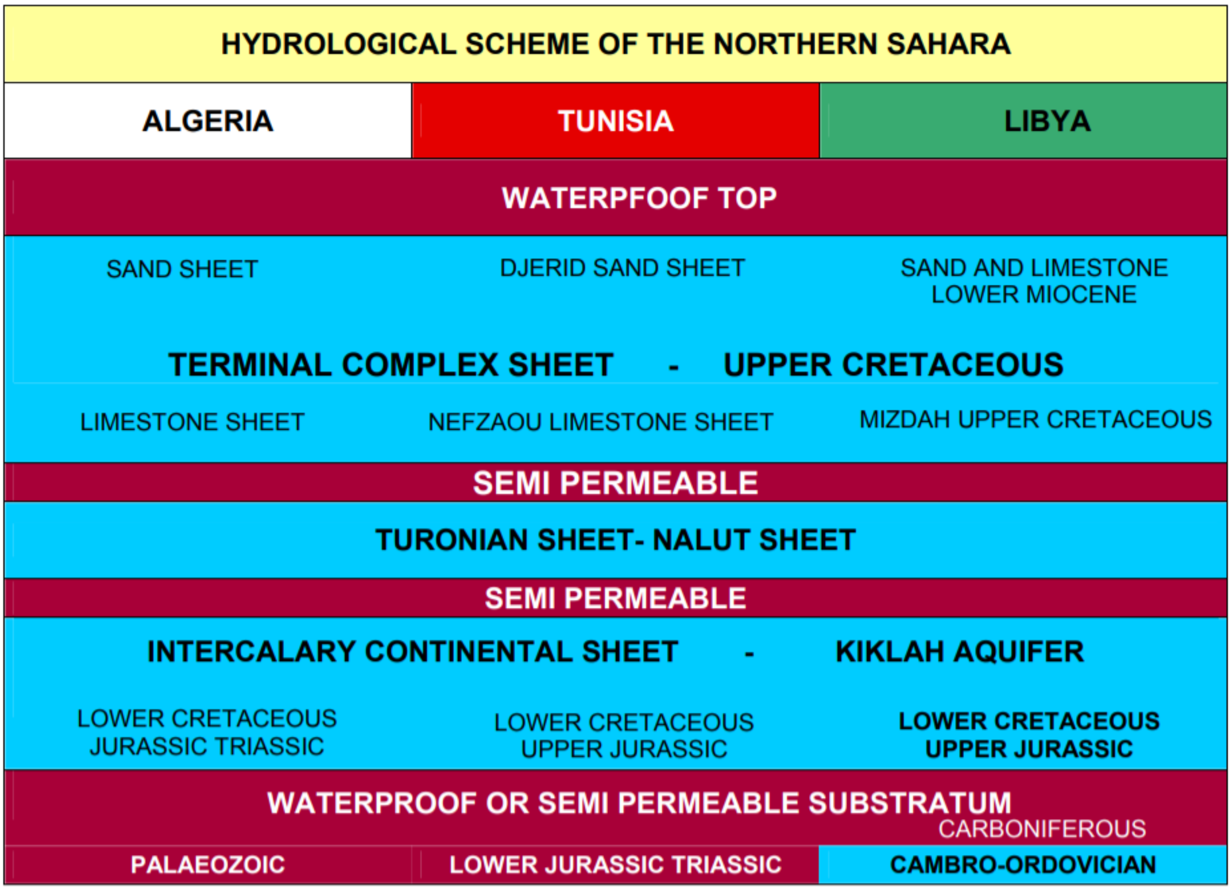
- The sand layer of the Mio-Pliocene in Algeria, extending through Tunisia to the Pontian sand layer of Djérid, equivalent[7] to the two Aquitanian and Plio-Quaternary layers in Libya.

For further simplification, the Paleozoic and Triassic sandstone layers in Libya can be excluded, and the Upper Cretaceous limestone layer, the Eocene carbonate layer, and the Mio-Pliocene sands layer (Mizdah and Plio-Quaternary) can be grouped together as is generally the practice. The NWSAS multilayer takes the form of three overlapping aquifer levels, separated by (or interacting through) semi-permeable formations, namely:

- the Intercalary Continental layer – Kiklah
- the Turonian layer – Nalut
- the Terminal Complex layer – Mizdah.

The NWSAS multilayer is shown in Figure 7.

Figure 7. Simplified diagram of the Saharan multilayer



Source: OSS (2004).

[7] This 'equivalence' is measured by stratigraphic position; however, these Libyan aquifers are limited to the eastern basin and have no physical relationship with the equivalent levels in Algeria and Tunisia.

1.4 Water resources

1.4.1 Overview of water resources in the three countries

The southern shore of the Mediterranean has scarce water resources, which are also unequally distributed over time and area. Recurrent droughts and shortages serve as a reminder that water resources in the Maghreb are limited, irregular and fragile. It is essential to ensure that water is managed in a cost-conscious way throughout the region – a challenge that has been met with varying degrees of success to date and which has required major investments (construction of large dams, long-distance transfers, etc.) to provide the water needed by the growing population and developing agriculture.

There is also some competition between rural and urban areas; in the coastal region, arable land is decreasing in favour of urban expansion. To supply urban areas, the countries in the region increasingly rely on seawater desalination – the cost of which has been reduced over the past 20 years – but not without having an impact on the environment.

In all three countries, the availability of water resources is below the water stress threshold of 500 m^3 per inhabitant. Climate change could further reduce rainfall in the region. In addition, unprecedented climatic phenomena have been observed, such as snow in the Hoggar Mountains (Sahara), but not in the Aures Mountains (in eastern Algeria).

1.4.1.1 Overview of Algeria's water resources

Algeria covers an area of 2.381 million km^2, of which 2.080 million km^2 (87 percent of its territory) is desert (Sahara), i.e. arid to semi-arid. In the northern part of the country (coastal zone and Tellian zone), rainfall fluctuates between 200 mm and 1,400 mm per year, while in the Sahara region and in the southern part of the Saharan Atlas, it hardly exceeds 50 mm.

In January 2019, the country's population was estimated at nearly 43 million,[8] with an average density of 17.6 inhabitants per km^2. More than **90 percent of the population** lives in the northern part of the country, on 13 percent of the country's total area, and has access to renewable surface and groundwater resources.

The availability of water resources is 320 m^3 per inhabitant per year (countries suffering from water stress), while the degree of dependence on external water resources is only 1 percent.

Conventional water potential

- **Surface water resources**: Surface waters, which represent two thirds of the country's water potential, could amount to 11 billion m^3 per year. The irregularity and spatial distribution of surface waters mean that no more than 5–6 billion m^3 of water can be used. Significant transfers are therefore needed to meet the water resource needs of the poorest regions.
- **Groundwater resources**: The renewable groundwater resources of the 177 aquifers in the north of the country could be nearly 2.5 billion m^3 per year. They are accessed via 92,000 water points, i.e. 9,000 springs, 23,000 boreholes and 60,000 wells.

[8] National Statistics Office (ONS) (n.d.).

In the south, there is the NWSAS, whose reserves are immense but not renewable. The potentially exploitable resources of these Saharan aquifers are estimated at nearly 6 billion m^3 per year in Algeria. The volume of water currently used from fossil reserves is 2.3 billion m^3 per year (2016).

Unconventional water potential

- **Treated wastewater**: Algeria could produce 1.2 billion m^3 of wastewater per year. With an estimated treatment capacity of 0.8 billion m^3, the country has embarked on an ambitious programme to reuse treated wastewater, particularly to irrigate agricultural land, with the sludge generated then used as fertiliser. However, despite the government's efforts, the rate of wastewater reuse remains low at around 20 percent.
- **Desalination of sea water**: Algeria has established 13 large seawater desalination plants. As of July 2018, 11 large plants were in operation with a capacity of 2.21 hm^3 per day, which amounts to a capacity of 806.6 hm^3 per year. The strategic objective of this programme is to secure the supply of drinking water to the populations in the coastal zone and to reallocate water from dams for irrigation purposes.
- **Demineralisation of brackish water**: In the south, water salinity is often higher than 2 g/l. A brackish water demineralisation programme (SDES) has been implemented in the *wilaya* (administrative division) of Ouargla (11 operational plants) and the *wilayas* of Tindouf, Adrar and Tamanrasset (one operational plant in each division). An iron removal plant was also opened in Illizi in December 2016.

Water quality

- **Surface water:** The surface water quality monitoring network, managed by the National Agency of Hydraulic Resources (ANRH) and comprising 124 stations, covers all the dams for drinking water supply and the country's main rivers. ANRH publishes a quality map every month. The country's main *wadis* (ephemeral streams) show a variably marked degradation in the physicochemical quality of their waters from upstream to downstream. In addition, pollution peaks have been recorded when crossing major cities.
- **Groundwater:** The groundwater quality monitoring network covers the main aquifers and has 510 gauging stations. This network has highlighted an increase in nitrate levels in certain localised areas (in Mitidja, for example). Seawater intrusion in some coastal aquifers has also been observed (Mitidja, Jijel, Annaba).

Mobilisation of surface water resources: dams

Algeria's hydraulic infrastructure has developed considerably over the last 50 years: there were 78 dams in operation in 2018 (compared with 14 in 1960), with a capacity of 5.8 billion m^3. The current programme to mobilise surface water resources aims to continue and complete the major transfers under way: Beni Haroun, Setif High Plains, Koudiat Acerdoun. The study programme covers nearly 50 dams, which are expected to be operational by 2030.

Drinking water supply

In 2018, Algeria produced 3.6 billion m^3 of drinking water. Network efficiency is around 70 percent. The national average connection rate is 98 percent, for an average supply of 180 litres per inhabitant per day.

Sanitation

Algeria currently has 173 wastewater treatment plants (WWTPs) with a capacity of 800 million m^3 per year, compared with only ten plants in 2000. Currently, the network's linear length is 43,000 km, with a connection rate of 90 percent.

Water resources for agricultural purposes

The country's irrigated area increased from 350,000 ha to 1,216,000 ha between 2000 and 2015. Small and medium hydraulic systems account for 92 percent of this area. The country is expected to have an additional 1 million hectares under irrigation by 2021. There are also plans to modernise and specially adapt large irrigated areas to improve water efficiency and management, expand water-saving irrigation systems and promote the use of treated wastewater for irrigation. Nearly 10,000 ha are affected: the Hennaya perimeter (912 ha), project set up; the M'léta perimeter (8,000 ha), project in progress; and the Algerian Sahel perimeter (1,300 ha), project under study.

The challenges: management of water supply and demand

To respond rapidly to the growing need for water, especially at the domestic level, the Algerian authorities favoured a supply-side policy between 2000 and 2016. This approach resulted in massive investments, following which the number of dams and transfers increased, as did the use of seawater desalination and the reuse of wastewater. The country is currently turning towards effective water management (optimisation and efficiency of infrastructure and equipment, control of wastage and leaks, etc.) to minimise this fourth resource of 'non-revenue water'. To achieve this, Algeria encourages the use of water-saving systems, reviews its pricing system and implements awareness-raising programmes.

1.4.1.2 Overview of Tunisia's water resources

Tunisia is predominately arid. Combined with the variability of the Mediterranean climate, this aridity makes water a scarce resource, unequally distributed over time and area. The country has an area of 164,000 km^2 and an estimated population of 11.722 million in 2019 (Tunisian Institute of Statistics – INS),[9] with an average density of 70 inhabitants per km^2. The majority of the Tunisian population lives in cities (64.8 percent), particularly in Grand Tunis (20 percent). Its mobilisable water potential of 4.8 billion mm^3 per year equates to an allocation of 436 m^3 per inhabitant per year, which is below the water stress threshold (500 m^3 per inhabitant per year). As Tunisia's water footprint is 2,200 m^3 per inhabitant per year, the country's water needs are mainly met by the rainwater sector (1,300 m^3 per inhabitant per year) and virtual water.

Water allocation for the irrigated sector is 2.1 billion m^3 per year on average. Agricultural water demand accounts for 80 percent of total water demand. Demand from the drinking water, industry and tourism sectors is 15 percent, 4 percent, and 1 percent respectively.

Potential of surface water resources

[9] Tunisian Institute of Statistics (INS) (n.d.).

Surface water inflows come from four natural regions, with distinct climatic and hydrological conditions and geomorphological and geological aspects[10]:

- The extreme north and Ichkeul, which represent only 3 percent of the country's total surface area, provide surface water supplies estimated at 960 million m^3 per year on average, i.e. 36 percent of the country's total potential.
- The north, which includes the Medjerda, Cap Bon and Méliane basins, provides average inflows of 1,230 million m^3 per year, i.e. 46 percent of the country's total surface water potential.
- The centre, which includes the Nebhana, Merguellil, Zéroud and Sahel watersheds, provides water resources estimated at an average of 320 million m^3 per year, i.e. 12 percent of the country's potential.
- The south, which accounts for about 62 percent of the country's total area, is the region with the lowest surface water availability. Its water resources, which are very irregular, are estimated at 190 million m^3 per year, i.e. 6 percent of the country's total potential.

In addition to this regional disparity, there is great inter-annual variability among inflows. Runoff reached a maximum rate of 11.32 billion m^3 between 1969 and 1970 and a minimum rate of 0.78 billion m^3 between 1993 and 1994.

On a transboundary scale, Tunisia shares some of its surface waters with Algeria. Thus, the Barbara and Mellila *wadis* provide Algeria with water resources of about 180 million m^3 per year. In return, Algeria provides the Medjerda, Mellègue, Safsaf and el Kebir *wadis* with 275 million m^3 of water resources per year.

Surface water quality

Tunisian waters have high levels of salinity. In fact, 53 percent of conventional water resources have a dry residue concentration greater than 1.5 g/l, and 30 percent have a dry residue concentration greater than 3 g/l. These waters are mainly used for irrigation purposes (with a dry residue concentration ranging from 4 g/l to 6 g/l in the governorates of Gabès, Mahdia and Médenine), which has adverse impacts on the soil and on the productivity, profitability and sustainability of irrigated farms.

Groundwater

- **Groundwater tables**: 226 groundwater tables (with a depth of between 0 m and 50 m) have been identified. They are largely overexploited and 60 percent have a salinity level above 3 g/l.
- **Deep aquifers** (catchment depth greater than 50 m): 347 deep aquifers provide about 1.43 billion m^3/year. Exploitation of the country's deep aquifers can be broken down as follows: 1.143 billion m^3 (77.5 percent) for irrigation; 290 million m^3 (19.6 percent) for drinking water supply; 42 million m^3 (2.9 percent) for industry.

Deep aquifer water quality

- 384.02 million m^3 per year, with a dry residue concentration of less than or equal to 1.5 g/l (i.e. 28 percent of the volume exploited).

[10] General Directorate of Water Resources (DGRE)

- 739.83 million m^3 per year, with a dry residue concentration of between 1.5 g/l and 3 g/l (i.e. 54 percent of the volume exploited).
- 197.36 million m^3 per year with a dry residue concentration of between 3 g/l and 5 g/l (i.e. 14 percent of the volume exploited).
- 48.08 million m^3 per year, with a dry residue concentration greater than 5 g/l (i.e. 4 percent of the volume exploited).

Unconventional water resources

Unconventional water resources include treated wastewater, brackish water and desalinated water, among others.

- **Treated wastewater**

The number of WWTPs of the National Office of Sanitation (ONAS) increased from 6 in 1975 to 122 in 2018. The volume of water treated increased from 6 million m^3 in 1975 to 274 million m^3 per year in 2018, for a total volume of 277.2 million m^3 of water collected per year. The treatment rate for wastewater collected by ONAS is therefore almost 99 percent. Nearly 50 percent of treated wastewater is collected in the Grand Tunis area.

- **Desalinated water**

The National Water Distribution Utility (SONEDE) and the Tunisian Chemical Group are responsible for desalination for drinking water supply purposes in Tunisia. Their desalination capacities are significant, although reduced in some tourist and industrial areas. Fifteen brackish water desalination plants (31.2 million m^3 in 2018, i.e. 4.5 percent of the volume produced) and five iron removal boreholes (8.1 million m^3 in 2018, i.e. 1.2 percent of the volume produced) have been installed in southern Tunisia to produce drinking water. The country's first seawater desalination plant was commissioned in 2018 in Jerba, with a capacity of 50,000 m^3 per day. In 2018, production for this plant reached 7.8 million m^3, or 1.1 percent of the total volume produced.

Surface water mobilisation: dams

Tunisia has 37 dams with a total usable capacity of 2.285 billion m^3, 258 hill dams, and 913 hill lakes, with respective capacities of 365 million m^3 and 58 million m^3. Water transfer takes place along an axis that runs from west to east. The large northern dams are interconnected, so that water from the extreme north and the Medjerda River travels more than 500 km to reach the coastal areas of Bizerte, Tunis, Cap Bon, Sousse and Sfax. In addition, water from Nebhana is also transported to the Sousse, Monastir and Mahdia regions. Moreover, storage of the volume transferred in surface or underground reservoirs (i.e. groundwater recharge) represents a new potential for mobilisation.

Drinking water supply

In 2018, 98.1 percent of the population had access to a source of drinking water. In urban areas, water is provided by SONEDE, and connection is universal. In rural areas, the drinking water supply is provided either by SONEDE in built-up areas (52.7 percent), or by the rural engineering services of the Ministry of Agriculture through agricultural development groups for sparsely populated areas (41.5 percent).

The current tariff system best covers the costs of operating and maintaining the networks.

Sanitation

In 2018, ONAS achieved a public sewerage system connection rate of 90.3 percent in the intervention areas, and a treatment plant connection rate of 88 percent, compared with 45.7 percent and 9.6 percent respectively in 1975. The number of communes covered by ONAS also increased from 23 in 1975 to 178 in 2018, with 122 water treatment plants and a public sewerage system that extends over 17,180 km.

Irrigated agriculture

Irrigated land, which accounts for only 8 percent of the utilised agricultural area (UAA), contributes to the country's agricultural development. These areas produce:

- 35 percent of the total value of the country's agricultural production
- 95 percent of vegetable production
- 30 percent of dairy products
- 20 percent of the value of agricultural exports, and
- 20 percent of job creation in the agriculture sector.

The irrigated area has grown proportionally to the rate of water resource mobilisation (398,000 ha in 2000 and 435,000 ha in 2018). A distinction is made between public lands developed by the state (54 percent) and private irrigated areas (46 percent).

Irrigation needs amount to about 2.4 billion m^3 of water per year, of which almost 80 percent comes from groundwater and 20 percent from dams. This situation is the root of aquifer overexploitation, which continues to intensify with the proliferation of illegal boreholes. Ninety-three percent of irrigated lands are equipped with water-saving systems, representing a total area of 405,000 ha. The average area for irrigated farms is 2.5 ha. The practice of irrigation faces several challenges, including the depletion of water resources, increasing water salinity, low crop yields, the collapse of agricultural prices, and the proximity or encroachment of urban areas on agricultural plots.[11]

The challenges: For integrated water resources management (IWRM)

Tunisia has opted for sustainable water resource management, safe water supply, and sanitation. This management must take into account the technical, economic, financial, social, cultural, institutional and environmental dimensions. The IWRM process began more than two decades ago. Decentralisation of water resource management must be accelerated to ensure new accountability of the different partners. Financial, economic, and institutional instruments must be reviewed and adapted to the new sociopolitical context, as well as to the challenges faced by societies that will affect water resources, including climate change and market liberalisation.

1.4.1.3 Overview of Libya's water resources

Libya, whose territory is 95 percent desert, has scarce water resources. Its population, which reached 6.5 million inhabitants in 2018, is mainly concentrated in large conurbations. Rainfall is minimal, with only 5 percent of the country receiving more than 100 mm of rain each year. In the northern Tripoli region, north

[11] Ministry of Agriculture, Hydraulic Resources and Fishery, 2019. National Water Sector Report 2018.

of Benghazi, and in the east of the country, rainfall can reach 250–300 mm per year, enabling rainfed agriculture.

The availability of renewable water resources is 101 m^3 of water per inhabitant per year. Libya has long relied on its groundwater reserves for its water supply, but consumption now exceeds the country's renewable resources. The volume of spring water has decreased and many underground aquifers along the coast have become brackish due to seawater intrusion. Their salinity level is too high, making them practically unusable.

There are 16 dams in the country, holding an average of 61 million m^3 of water, for a total capacity of 385 million m^3. The Qattara dam is the largest in the country, with a retention capacity of 135 million m^3.

Water resources

The total renewable water resources are estimated at almost 1,075 billion m^3, comprising 200 million m^3 of surface water and 875 million m^3 of groundwater. Aquifers with renewable resources are located in the north of Libya: the Djeffara aquifer, the Jebel Akhdar aquifer and the Hamada aquifer.

Libya shares its non-renewable water resources with its neighbouring countries, specifically the NWSAS with Algeria and Tunisia, and the Nubian Sandstone Aquifer System (NSAS) with Egypt, Sudan and Chad.

Three other aquifers (Merzouk, Sarir, Koufra) potentially hold very large non-renewable water resources (4.4 billion m^3 exploited per year). These aquifers are currently being exploited through the Great Man-Made River project, which aims to transfer 6 million m^3 of water daily from the south to the north of the country.

Water quality

Overexploitation of the aquifers in the coastal belt has led to seawater intrusion, reaching a depth of more than 15 km in some cases (the Djeffara aquifer, for example). Nearly 35 percent of aquifers have a salinity higher than 5 g/l.

Drinking water supply

Nationally, the rate of access to drinking water is estimated at 80 percent, with a current daily allocation of 220 litres per inhabitant. Given the low level of surface water resources and the overexploitation of coastal aquifers, water is supplied by the Great Man-Made River, with 12 percent of transfers reserved for domestic needs and 80 percent for agriculture.

Desalination

Despite their drop in production, desalination plants installed in the 1980s enable the supply of between 20 million and 30 million m^3 of water each year, while their installed capacity is 65 million m^3 per year. Most of the desalination plants built between 1980 and 2000 are currently idle.

Sanitation

In Libya, 48 percent of dwellings are connected to a sewerage system, but this rate varies from 9.5 percent to 91 percent depending on the district. Wastewater is treated at 55 plants, with treatment capacities ranging from 3,000 m^3 per day to 120,000 m^3 per day. However, only 40 are operational, reducing the country's total treatment capacity from 400,000–500,000 m^3 per day to almost 184,000 m^3 per day. Some of this treated water is used for irrigation.

Agriculture

The irrigated land area is estimated at between 350,000 ha and 400,000 ha. Eighty percent of the water transferred from the Great Man-Made River is used to irrigate this land, whose total area is expected to reach 650,000 ha by 2025, for an allocated water volume of 6.3 billion m^3 per year.

The challenges: sustainable water resource management

Libya, which has very limited water resources, has long been confronted with the imbalance between its resources and its water needs. To compensate for this, Libya makes use of unconventional water resources and exploits its groundwater resources, which are non-renewable.

1.4.2 NWSAS water resources

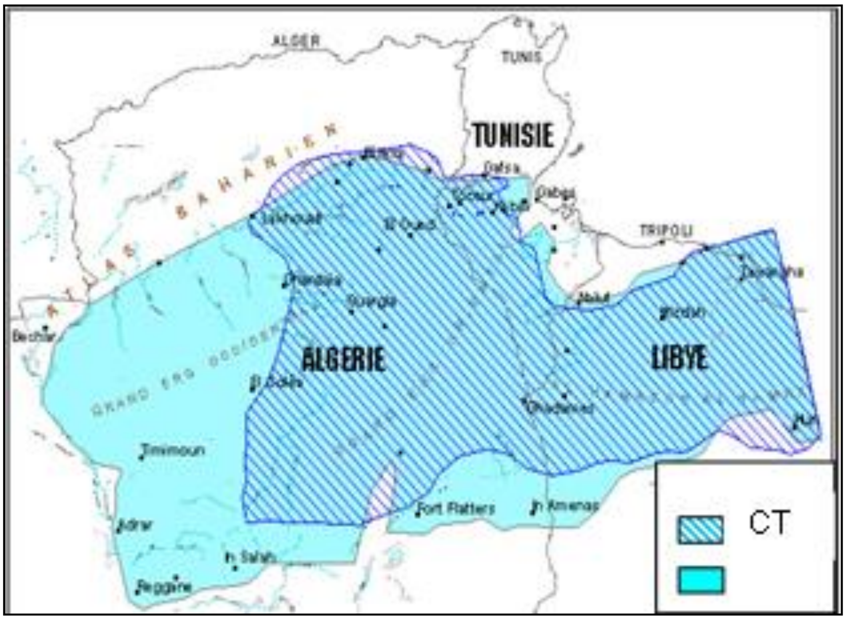
1.4.2.1 The NWSAS

As mentioned, the NWSAS, shared by Algeria, Libya and Tunisia, comprises two main overlapping deep aquifer layers (see Figure 8):

- the deeper and more extensive Intercalary Continental layer, with an area of 1 million km², and
- the Terminal Complex layer, which covers an area of 600,000 km².

The extension of the NWSAS is divided as follows: 60 percent in Algeria, 30 percent in Libya and just under 10 percent in Tunisia.

Figure 8. Delimitation of NWSAS formation



Source: OSS.

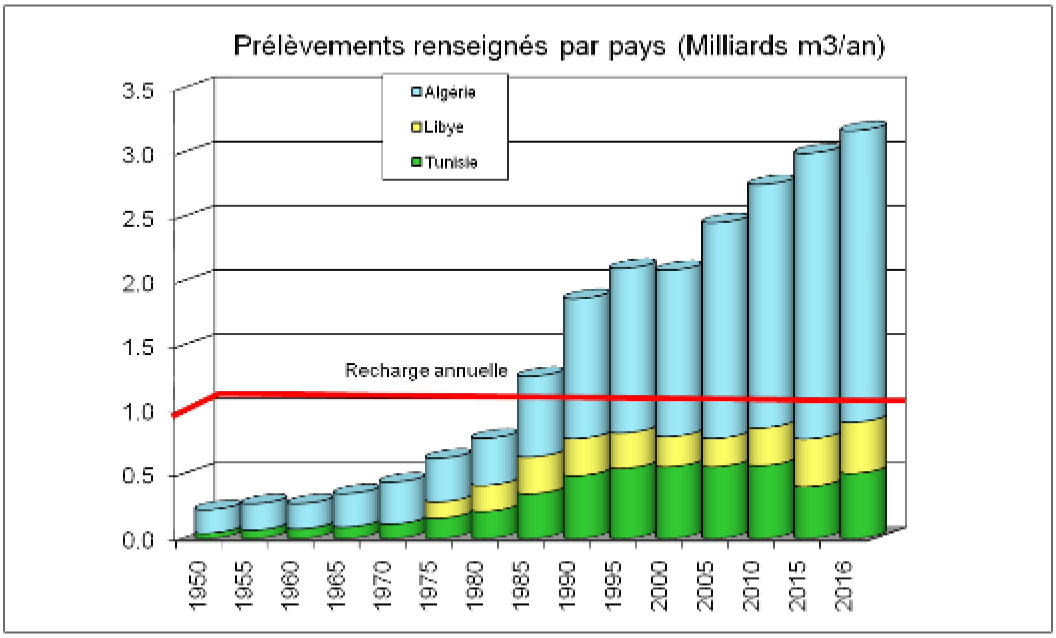
The extension of the system and the thickness of its layers have led to the accumulation of considerable water reserves, amounting to 60,000 billion m^3 of water. Given the climatic conditions of the Sahara however, these formations are poorly supplied, with only about 1 billion m^3 of water per year. Yet, the region's development requirements result in an ever-increasing demand for water.

Water abstraction has increased sharply since the 1980s and now far exceeds the NWSAS recharge capacity (see Figure 9). This abstraction, which amounted to 1 billion m^3 of water in 1980, increased to about 3.171

billion m³ in 2016, broken down as follows: 2.297 billion m³ in Algeria, 0.506 billion m³ in Tunisia and 0.398 billion m³ in Libya (see Figure 10).

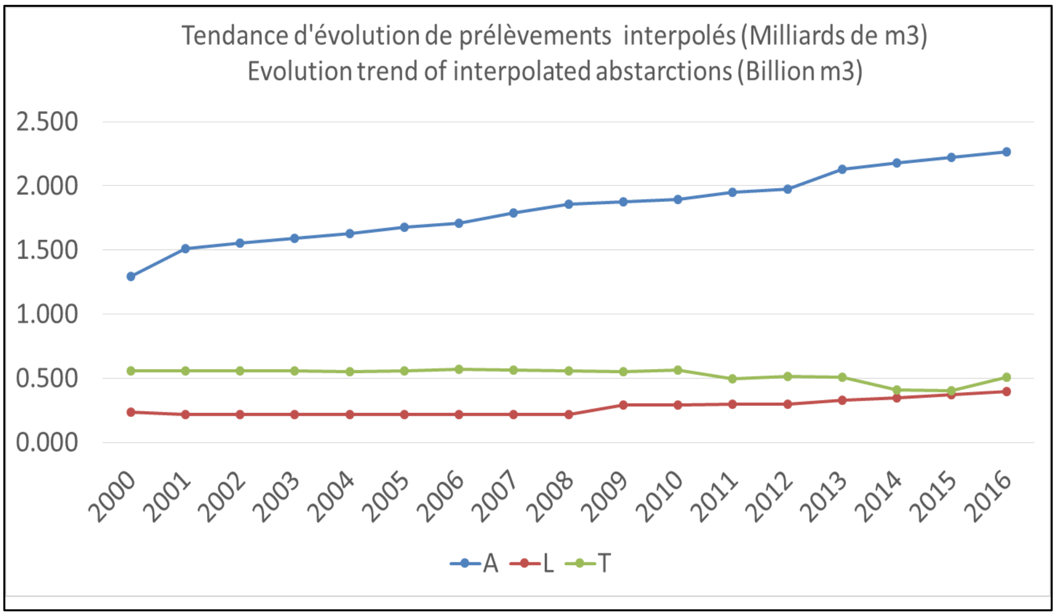
Abstraction points have multiplied: more than 1,000 water points, boreholes and springs are currently being exploited (see Figure 11).

Figure 9. Total abstraction from Saharan aquifers, in billion m³ per year



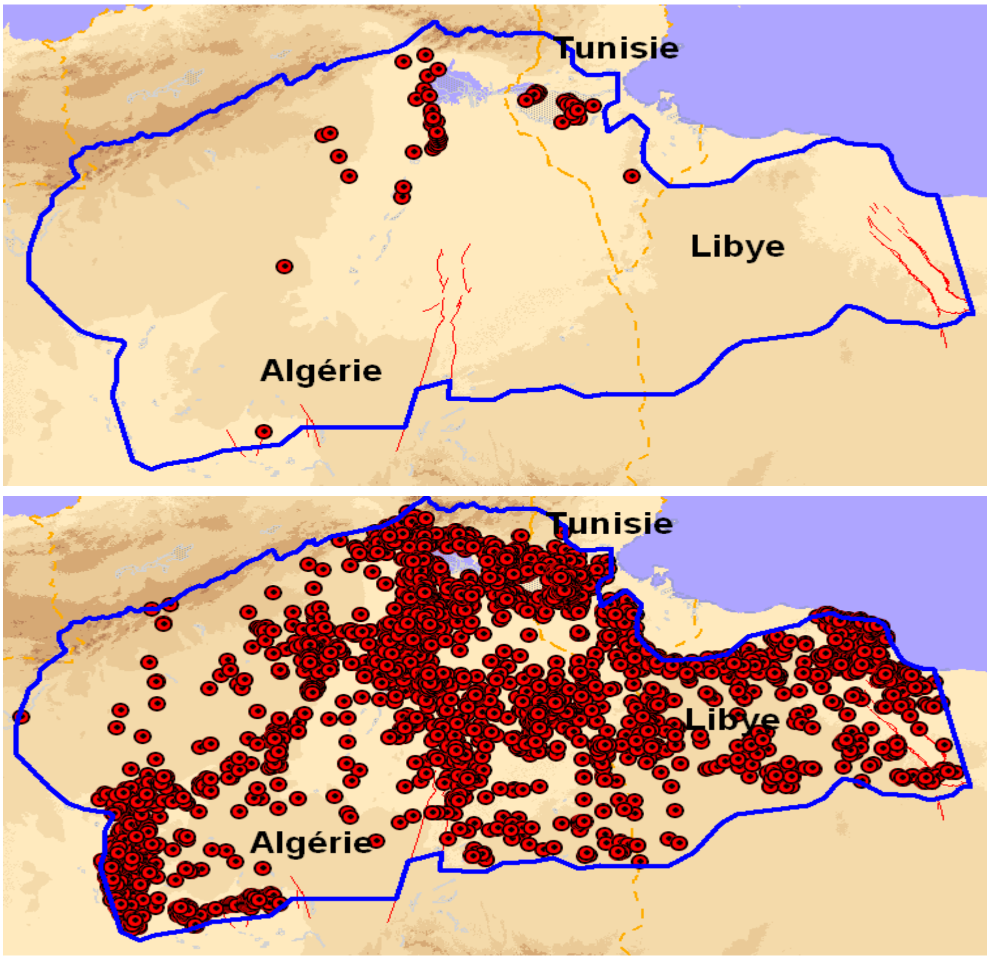
Source: OSS.

Figure 10. Evolution of abstraction by country from 2000 to 2016



Source: OSS.

Figure11. Location of water abstraction points in 1950 (top) and 2016 (bottom)



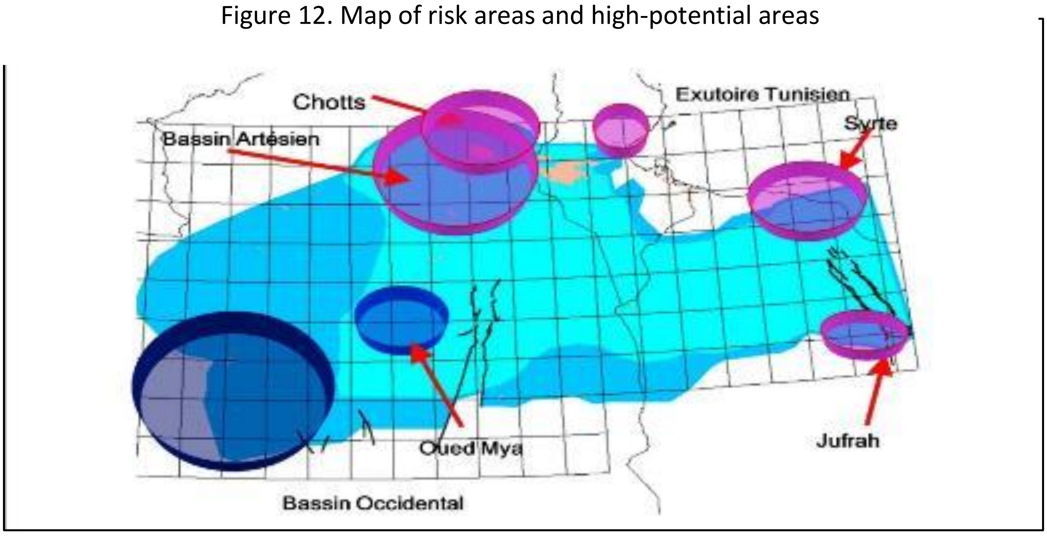
Source: OSS.

The intensification of aquifer exploitation has highlighted worrying signs of risk, including:

- significant aquifer drawdown
- an increase in water salinity
- the disappearance of artesian aquifers
- the drying up of outflows, and
- excessive pumping heights.

In 2002, the results of simulations were used to develop a map that delineates risk areas with proven overexploitation and areas with potential that remains intact (see Figure 12).

Figure 12. Map of risk areas and high-potential areas



Risk areas	High-potential areas (resource availability)

Source: OSS.

Pumping is becoming increasingly difficult and expensive, and environmental risks have increased, especially when linked to agricultural development. The following issue arises: how can water be abstracted optimally, in a way that ensures the development of the three countries in the region without risking irreversible damage to the resources?

1.4.2.2 The Djeffara coastal aquifer system, a natural outflow of the NWSAS

The Djeffara aquifer system is not intrinsically part of the NWSAS. However, they are very strongly linked, as the Djeffara aquifer is essentially fed by the Intercalary Continental, through the Tunisian outflow of the NWSAS.

Moreover, the exploitation of this resource, located in the Tunisian–Libyan coastal plain, has intensified considerably over the last 30 years.

Improved knowledge of the NWSAS therefore seems an interesting opportunity to propose a homogeneous and coordinated vision of the Djeffara aquifer system. This will fulfil the need to define water resource use policies, predict short- and long-term impacts, identify risks, contribute to their management and evaluate their consequences.

The hydrodynamic model that simulates the behaviour of the Djeffara system enabled the estimation of the total volume of the system's outflows at 594 million m^3 of water in 1950, of which 52 million m^3 were pumped. In 2000, outflows were estimated at 1,365 million m^3, of which 1,039 million m^3 were pumped. This highlights the clear imbalance to which this aquifer system is now exposed.

The assessment highlights the importance of infiltration (330 million m^3 per year) and the significance that should be attached to studying natural recharge and estimating underground lateral inflows from the NWSAS (from 260 million m^3 per year in 1950 to 200 million m^3 per year in 2000).

Exploitation of the Djeffara aquifer has intensified over the last 40 years (see Figure 13).

Figure 13. Location map of water points in the Djeffara in 1950 (left) and 2010 (right)

Source: OSS.

The Djeffara aquifer system is already characterised by a high level of risk: over 50 years, the water abstraction volume has increased from 200 million m^3 per year (in 1960) to nearly 1.4 billion m^3 per year (in 2010), for a recharge volume of about 600 million m^3 per year. The result is overexploitation equivalent to the annual recharge volume and significant drawdowns (sometimes more than 50 m) in coastal areas, where exploitation is concentrated. Saline intrusion of seawater has already been observed in both countries, particularly around Tripoli (around 34 million m^3 per year). The situation of the Djeffara plain is even more precarious, as a significant proportion of the recharge volume (330 million m^3 per year) is directly linked to rainfall.

1.4.3 Piezometry and water quality in the NWSAS

1.4.3.1 Piezometry

Piezometric maps that depict the situation of the Intercalary Continental and the Terminal Complex in 2016 have been compiled from maps showing their baseline condition in 1950, 2000 and 2012, and updated with data for 2016.[12] Comparison of these maps with those from 1950 and 2000 provides information on Intercalary Continental and Terminal Complex drawdown over the past years.

Piezometric map of the Intercalary Continental

The piezometric map of the Intercalary Continental for 2016 (Figure 14) shows:

- The division of the Saharan domain into several hydrogeological provinces, as follows:
  - ✓ the Lower Sahara with a west to east flow
  - ✓ the Tinrhert and the Grand Erg Oriental with a south to north flow
  - ✓ the Grand Erg Occidental, the Touat-Gourara and the Tidikelt with a north to south and south to west flow
  - ✓ the Dahar and Jebel Nafusah with an east to west and north to south flow

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[12] New data (from 89 water points in the Terminal Complex and 65 water points in the Intercalary Continental) was collected between 2013 and 2016 to update the piezometric and salinity maps from 2012 to 2016.

- ✓ the Jebel Hassawnah with a south to north and northeast flow.

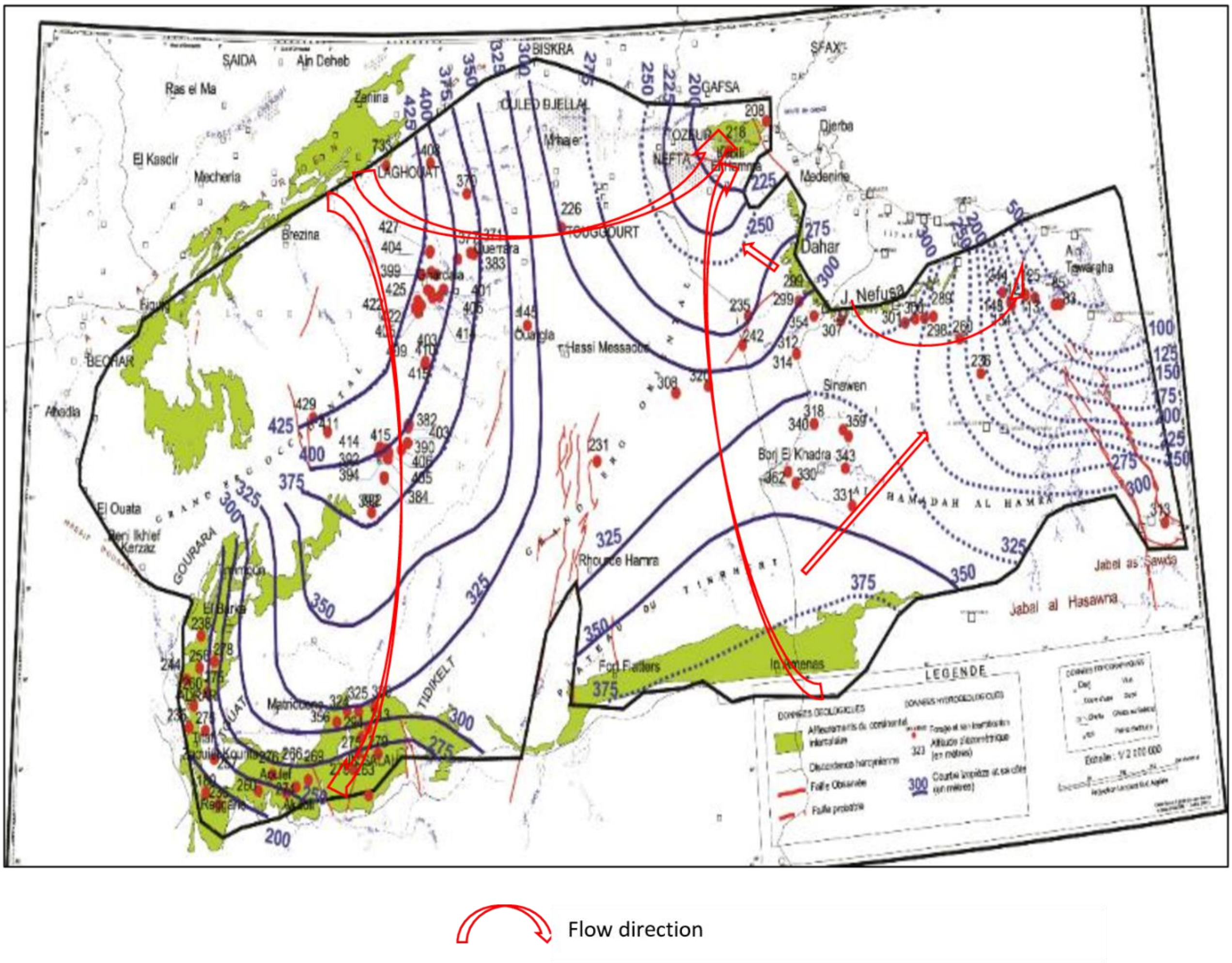
- The recharge areas, whose boundaries are suggested by the water table flow directions are:
  - ✓ the South Atlas foothills in the northwest
  - ✓ the Tinrhert, where recharge is more likely a result of the reservoir slowly emptying than true water table recharge from the extremely rare rainfall
  - ✓ the Dahar in Tunisia and the Jebel Nafusah in Libya
  - ✓ the Jebel Hassawnah, where the piezometry of the Kiklah (Intercalary Continental) connects perfectly with the piezometry of the Cambro-Ordovician layer.

- The outflow areas, suggested by the end points of the current lines drawn by the piezometric map, are:
  - ✓ the Touat-Gourara and the Tidikelt
  - ✓ the Tunisian outflow marked by the El Hamma fault
  - ✓ the Libyan outflow at Ain Tawargha.

The piezometry of the Intercalary Continental layer highlights the almost total independence of the Grand Erg Occidental sub-basin from the rest of the aquifer, with a flow from the Saharan Atlas towards the south and then the southwest, as well as a groundwater divide separating the flow towards the west from the inflow to the eastern part of the basin. Groundwater outflow firstly resulted from sources transformed by people, i.e. *foggaras*, following the drop in the piezometric surface level.

The piezometric dome centred on Dahar-Jebel Nafusah (Libya) indicates a local recharge area, in an area where the groundwater is not plentiful.

Figure 14. Piezometric map of the Intercalary Continental (2016)



Source: OSS.

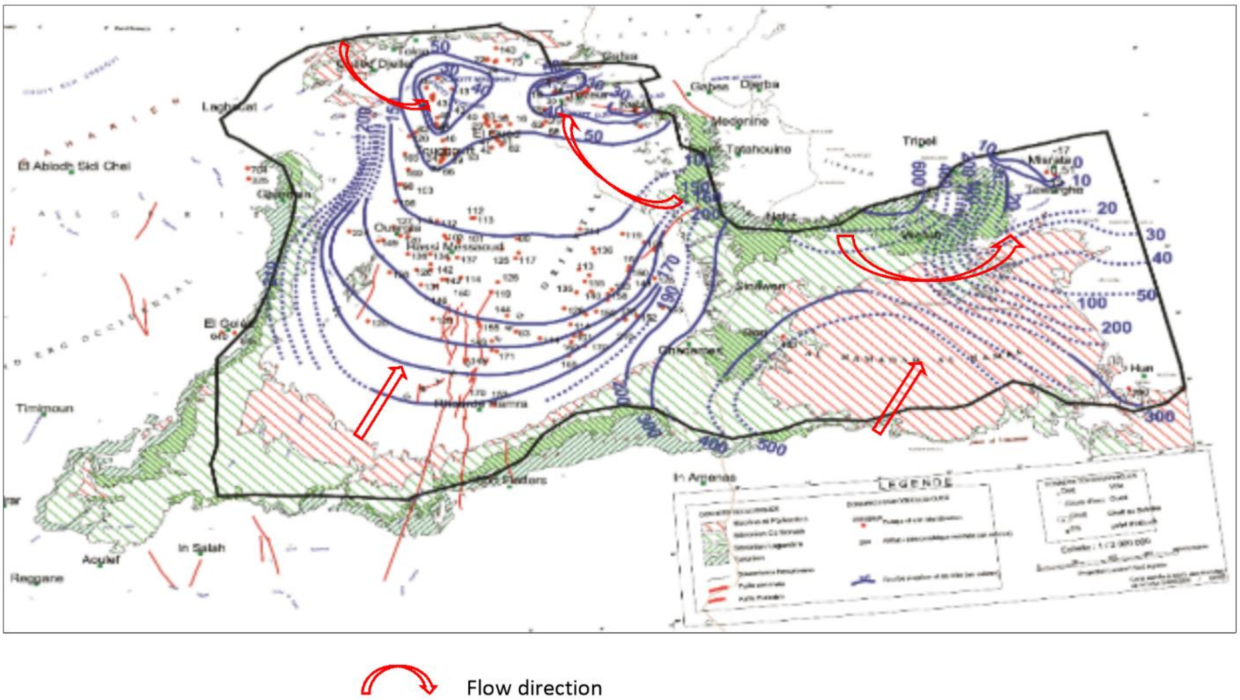
Piezometric map of the Terminal Complex

The piezometric map of the Terminal Complex (Figure 15) shows:

- the division of the Saharan domain into two main hydrogeological sub-basins, specifically the Grand Erg Oriental sub-basin and the Hamada al Hamra sub-basin
- the same main recharge areas as the Intercalary Continental–Kiklah layer (Saharan Atlas, Dahar-Jebel Nafusah, and Jebel Hassawnah), and
- the outflow areas are mainly centred on the Algerian–Tunisian chotts and the Gulf of Sirte, between Misrata and Buwayrat al Hasun.

The piezometry of the Terminal Complex layer shows, in the Grand Erg Oriental sub-basin, the role of the Algerian–Tunisian Lower Sahara in focusing the groundwater flow to form an endorheic basin. The Merouane-Melrhir chotts in Algeria and Gharsa-Djérid chotts in Tunisia are the aquifer's outflows.

Figure 15. Piezometric map of the Terminal Complex (2016)



Source: OSS.

Piezometric monitoring is more or less well ensured in the three countries; the measurements available, while discontinuous and poorly distributed over the area, nevertheless make it possible to deduce drops in piezometric level of the two main NWSAS aquifers in the main exploitation areas. The spatial and temporal distribution of observations needs to be improved. The piezometric monitoring network currently selected comprises 307 observation points.

The data on 2012 operating flows enabled simulations of the 1950–2012 period to assess the drawdowns:

- In the Intercalary Continental, significant drawdowns have been identified in areas of high exploitation. These are approximately 100 m in El Oued in Algeria. The largest drawdowns are in Algeria, in the Ouargla-Hassi Messaoud region, where they reach nearly 160 m. In Tunisia, in the Nefta-Tozeur-Kebili axis, they reach between 30 m and 100 m. A 73 m drop in the piezometric level in the Algerian–Tunisian border area of El Borma. In Libya, drawdowns are approximately 10 m in Ghadames and 60 m in the Al Djoufrah and Mardum regions (Table 2).

- In the Terminal Complex, very large drawdowns (up to 53 m) are caused by high levels of abstraction south of the Hun Graben in Libya, an area caught between two watertight boundaries. In addition, pumping in Tunisia in the Djérid and Nefzaoua, as well as in Algeria in the Rhir Wadi, caused drawdowns of between 30 m and 50 m. A maximum drawdown of 107 m was recorded in the Chott Merouane region of Algeria (Table 3).

Table 2. Intercalary Continental drawdowns (in metres)

Country	Area	1950	2000	2012	2050 (forecast)
Algeria	Ouargla-Hassi Messaoud	0	110	140	170
Libya	Mardum	0	43	46	59
Tunisia	Djérid	0	74	94	104

Source: OSS

Table 3. Terminal Complex drawdowns (in metres)

Country	Area	1950	2000	2012	2050 (forecast)
Algeria	Rhir Wadi	0	34	50	71
Libya	Hun-Djoufrah	0	49	53	80
Tunisia	Djérid, Nefzaoua	0	33	37	46

Source: OSS.

1.4.3.2 Water quality

The new data collected over the 2013–2016 period (155 water points in the Terminal Complex and 60 water points in the Intercalary Continental) have made it possible to update the previous salinity maps.

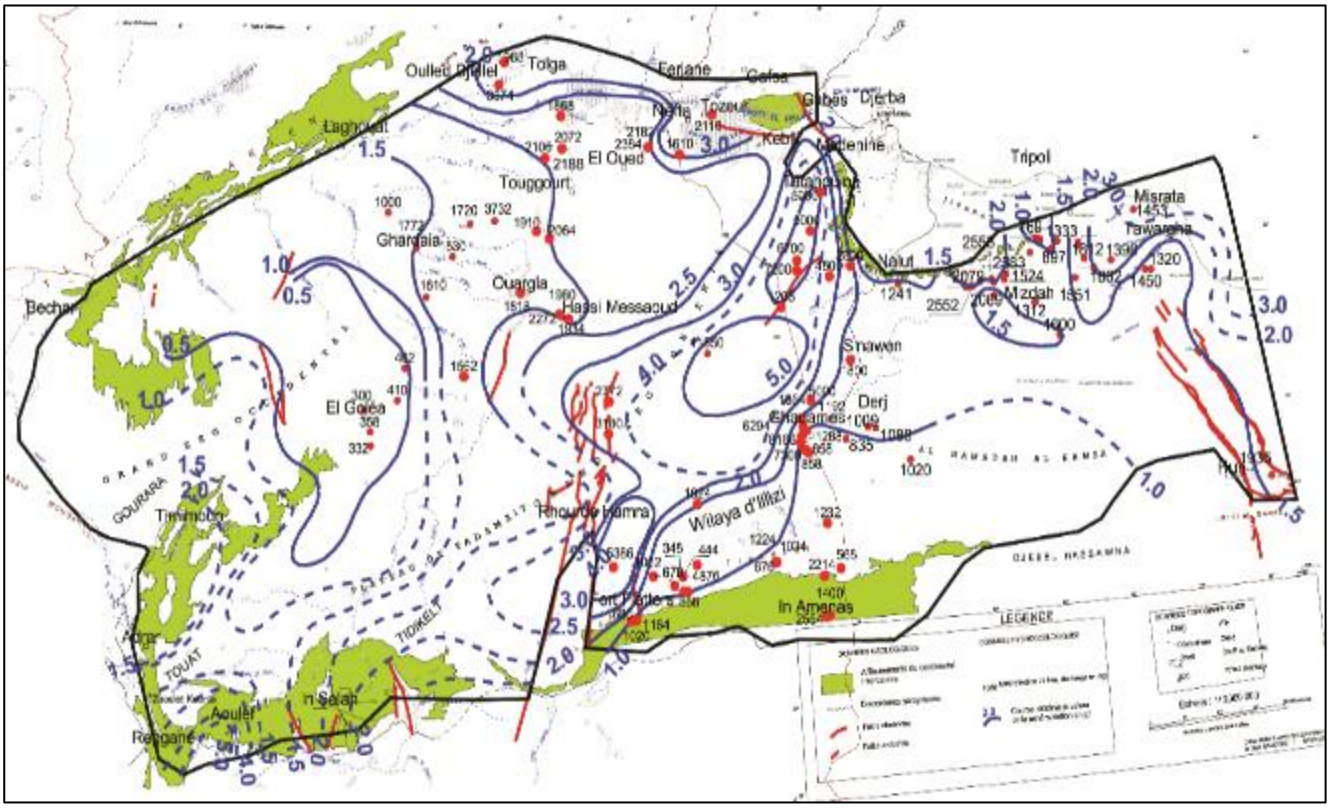
Salinity map of the Intercalary Continental (2016) and patterns of change

In Algeria, the salinity levels of the waters of the Grand Erg Occidental basin are mostly below 1 g/l in the El Goléa region. In the Tadmaït Plateau and In Salah regions, these levels are as high as 2.5 g/l. This is not the case in the Grand Erg Oriental basin, where the water table is confined at several hundred metres. Salinity levels are between 1 g/l and 3 g/l. The highest levels were recorded southeast of Hassi Messaoud, where the water table is more confined. In the *wilaya* of Illizi in the south of the country, a few high levels of mineralisation (between 4 g/l and 8 g/l) were found (see Figure 16).

In Tunisia, the dry residue concentration values of the Intercalary Continental's waters are between 2 g/l and 5 g/l, and reach 7 g/l in the *wilaya* of Tataouine. The lowest levels are found in the deepest formations (Kebar el Hajj series). The spring waters of the Chott el Fejaj have the highest levels, with 5 g/l.

In general, the waters of the Intercalary Continental in Tunisia have a relatively high salinity level (dry residue > 2 g/l) which limits their use for drinking water supply purposes. This is due to the location of these waters, which are generally located in the confined part of the water table, where they have long remained in contact with surrounding formations containing clay and gypsum impurities, due to the low speed of groundwater circulation.

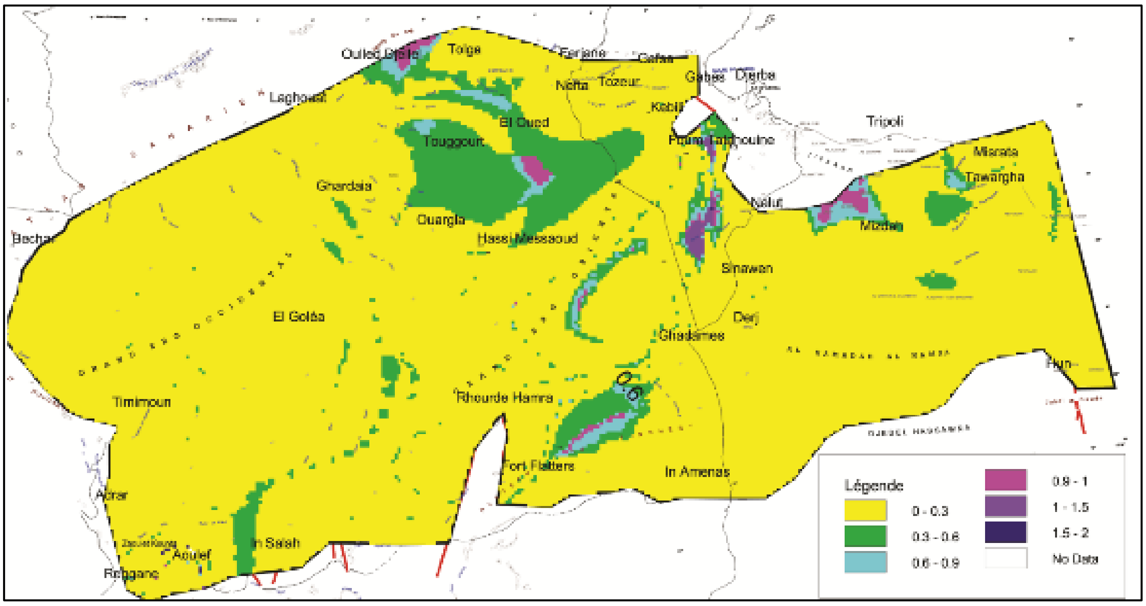
Figure 16. Salinity map of the Intercalary Continental (2016)



Source: OSS.

In Libya, the waters of the Kiklah formation of the Hamada al Hamra have dry residue concentrations that are often below 2.0 g/l. This is due to the watertightness of the aquifer formation, which ensures the cleanliness of the water by preventing any clay inclusions. Some concentrations above 2 g/l were found in the Mizdah region, El Hun and northeast of Ain Tawargha. In 2016, dry residue concentrations were generally in the same range as those measured in 1950. In all recharge areas, the total mineralisation rate of the Intercalary Continental's waters is frequently measured at less than 1 g/l. This is probably because it originates from sandstone formations with a poorly soluble matrix. The areas with the highest dry residue concentrations are found in the confined portion of the water table, where the aquifer formation is deepest. A comparison between the 1950 and 2016 Intercalary Continental salinity maps shows a more or less marked increase in salinity, especially in areas of high exploitation (Figure 17).

Figure 17. Increase in the salinity level of the Intercalary Continental (1950–2016)



Source: OSS.

In Algeria, in the El Goléa-Tadmaït Plateau and In Salah regions, salinity levels increased from 0.3 g/l to 0.6 g/l in some places (Figure 17). The largest increases were recorded in the Grand Erg Oriental basin, where the water table is confined to several hundred metres, with increased concentrations of 0.9 g/l to 1 g/l between Hassi Messaoud and El Oued. In the *wilaya* of Illizi, in the south, the increase is approximately 0.3 g/l to 0.6 g/l, or even 0.9 g/l in some places.

In Tunisia, in the Tozeur-Kebili region, the salinity rate increased by 0.5 g/l between 1950 and 2016, particularly in the Chott el Fejaj. The largest gaps were noted in the *wilaya* of Tataouine, with an increase from 1.5 g/l to 2 g/l.

In Libya, in the Derj-Ghadames region and in the Hamada al Hamra, the average salinity rate increased from 0.8 g/l to 1 g/l, an increase of 0.2 g/l. In the Tawargha-Mizda region, the average salinity rate increased from 1.5 g/l to 2 g/l in places, an increase of 0.5 g/l.

Salinity map of the Terminal Complex (2016) and patterns of change

Gauging stations are often limited to the areas of exploitation. Certain localised chemical anomalies are caused by particular phenomena, such as the consequences of concentrated intensive exploitation and the return of irrigated water.

The isohaline curves (Figure 18) highlight:

- An area, between Ouargla and the Rhir Wadi, where the groundwater is stored in sands. This area, which covers the southern half of the Grand Erg Oriental, has a salinity level of less than 2 g/l. It probably corresponds to the current recharge area of the aquifer, from water from any exceptional rainfall that falls on the erg. Another area in the western part of the aquifer shows a similar salinity level. This corresponds to the recharge areas in the M'zab reliefs.
- An area, located in Tunisia and centred on the Drâa Djérid, with a salinity level of less than 3 g/l. This corresponds to the outcrop of aquifer sands.

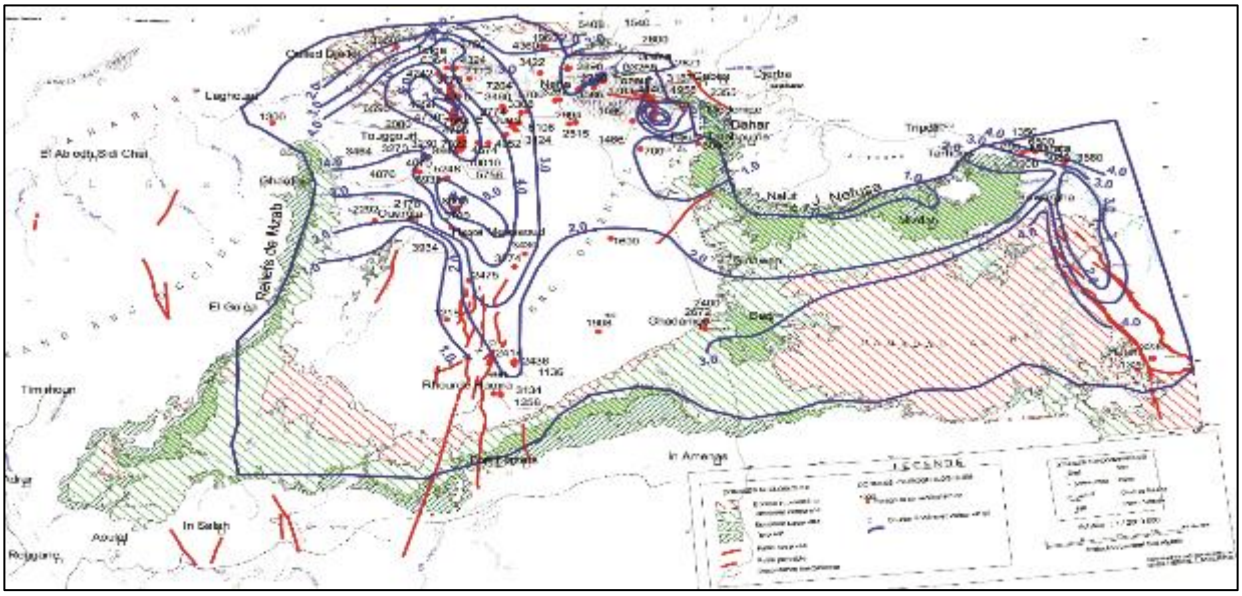
- A weakly mineralised area centred on the eastern part of the Grand Erg Oriental. This corresponds to the areas of direct infiltration of rainwater into the sand dunes. This feature is particularly visible on the western side of the Dahar.
- A moderately mineralised area on the southern side of the Jebel Nafusah. This corresponds to a recharge area of the aquifer.

Except for these specific areas, mineralisation rates are generally high. This is particularly the case:

- in the *wilaya* of Ouargla, where an area centred on the Mya Wadi has a salinity rate above 4 g/l
- along the axis linking Hassi Messaoud in the south of Algeria to the north of Chott Melrhir, where the salinity level exceeds 5 g/l and even reaches 10 g/l in places
- in the *wilaya* of El Oued, where an area of strong mineralisation (rate higher than 5 g/l) extends over the northern part of the Rhir Wadi (El Meghaïer-Djamaa)
- between Ouargla and Touggourt, where an area of strong mineralisation (rate higher than 5 g/l) extends over El Hadjira.

The area along the axis that links Hassi Messaoud to the Rhir Wadi (Chott Melrhir) has a relatively high salinity rate (above 5 g/l). This appears to illustrate the combined effects of intense groundwater exploitation and returning irrigation water to the upper levels of the water table, which is poorly drained. In these areas, where the unconfined groundwater is shallow and has even occasionally been exposed in recent years, evaporation has caused salt concentrations on the surface. As a result of the drop in the piezometric level, these areas function as saltwater recharge areas.

Figure 18. Salinity map of the Terminal Complex (2016)



Source: OSS.

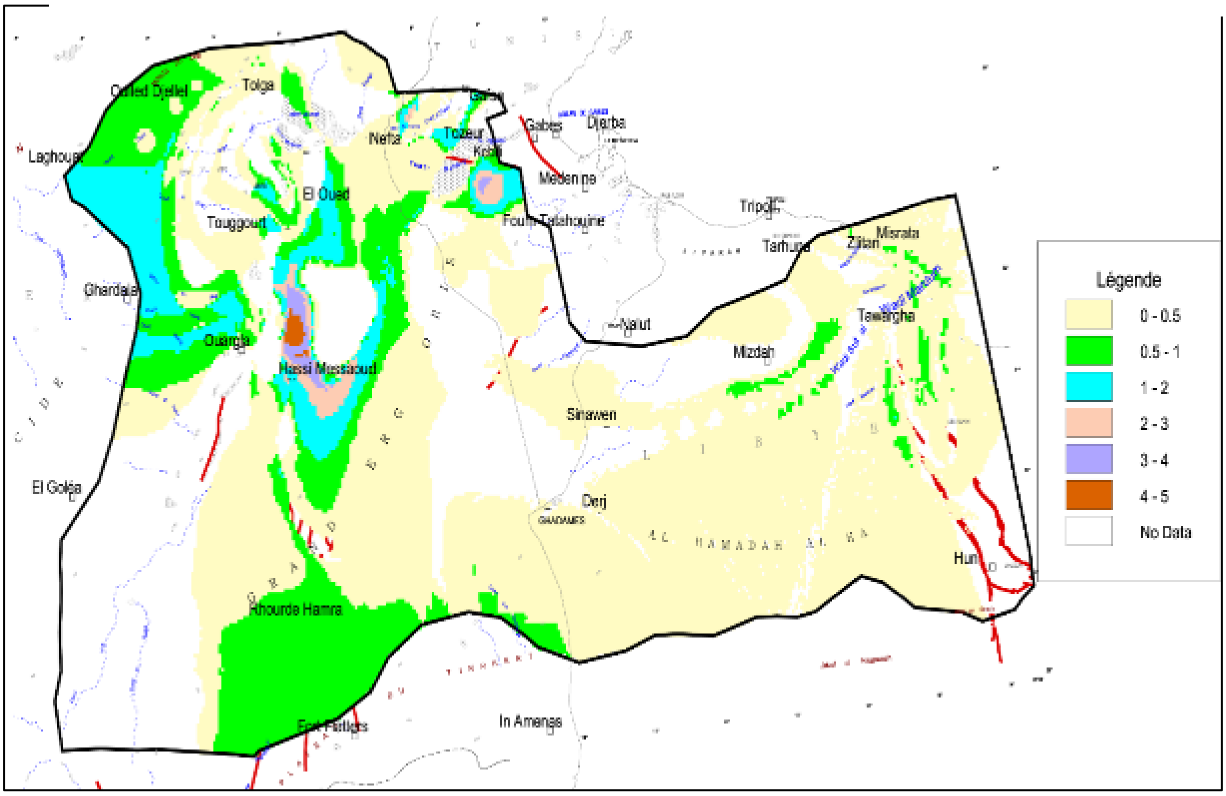
Comparison of the salinity maps of the Terminal Complex for 1950 and 2016 highlights the following gaps (Figure 19):

- Between Ouargla and the Rhir Wadi, the salinity level increased from 0.5 to 3 g/l. The highest rates were recorded in the Hassi Messaoud region. In 1950, salinity levels were mostly between 2.5 g/l and 4 g/l; in 2016, these levels were around 5 g/l and even reached 10 g/l. Salinity levels have therefore increased by 2–3 g/l, and in some places even by 5 g/l.

- In Tunisia, in the Drâa Djérid (Tozeur)-Kebili region, salinity levels, which were between 1.5 g/l and 3 g/l, are now between 2 g/l and 5 g/l. They have therefore increased by 2 g/l on average.
- Mineralisation rates in the recharge areas located in the area extending from the Grand Erg Oriental to the western side of the Dahar (Tunisia) and the Jebel Nefusah (Libya) remain low (less than 1 g/l), with gaps of between 0 g/l and 0.5 g/l.

Source: OSS.

Figure 19. Increase in salinity levels of the Terminal Complex (1950–2016)



1.4.4 Data and monitoring

1.4.4.1 The piezometric monitoring network

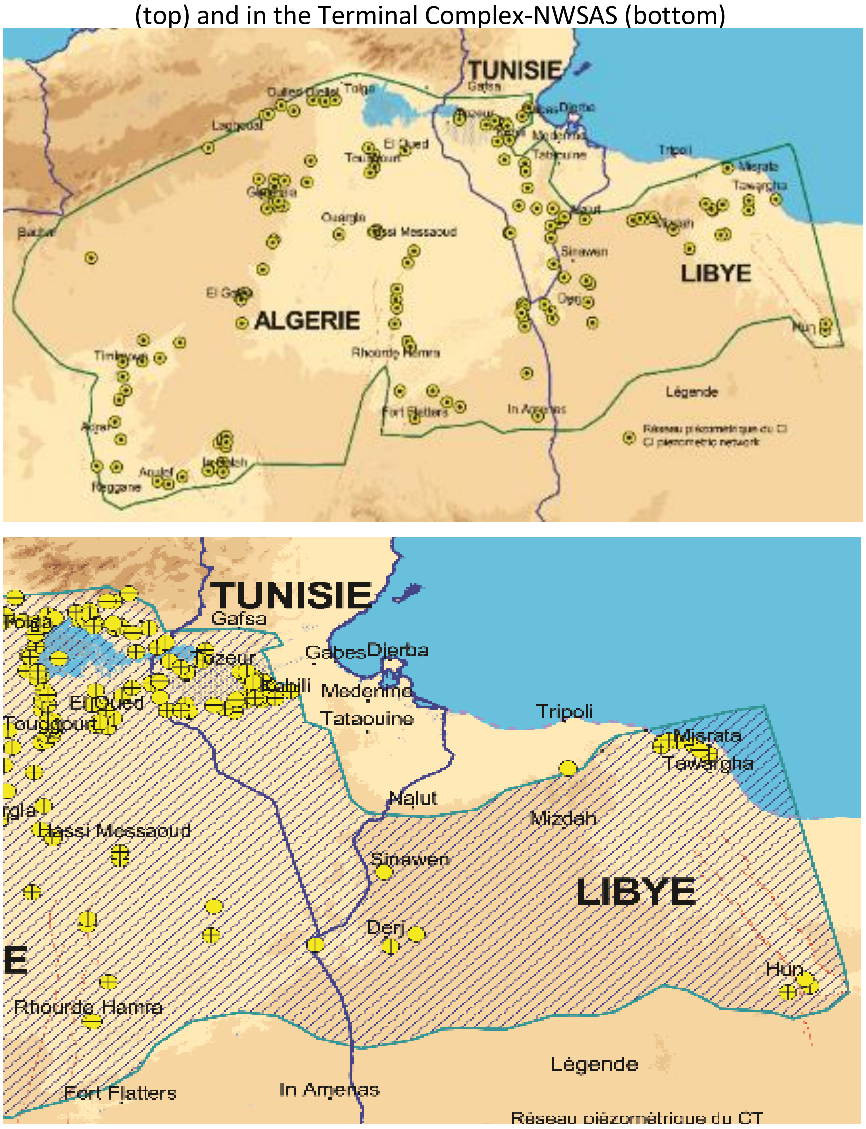
In 2005, the recognised NWSAS piezometric network had 100 monitoring points (Table 4), of which only 29 were still operational after 2000. A proposal to strengthen the network was accepted in 2017, during a consultation with the countries concerned at national workshops organised as part of the work of the NWSAS consultation mechanism. The proposal aims to establish 307 monitoring points, 142 of which would be in the Intercalary Continental and 165 in the Terminal Complex (Figure 20).

Table 4. NWSAS piezometric network

	Recognised network (in 2005)			Proposal to strengthen the network (2016)		
Country	Intercalary Continental	Terminal Complex	Total	Intercalary Continental	Terminal Complex	Total
Algeria	26	20	**46**	85	103	**188**
Tunisia	18	19	**37**	27	44	**71**
Libya	12	5	**17**	30	18	**48**
TOTAL	**56**	**44**	**100**	**142**	**165**	**307**

Source: OSS.

Figure 20. Proposal for strengthening the piezometric network (2016) in the Intercalary Continental-NWSAS (top) and in the Terminal Complex-NWSAS (bottom)



Source : OSS

1.4.4.2 Quality monitoring network

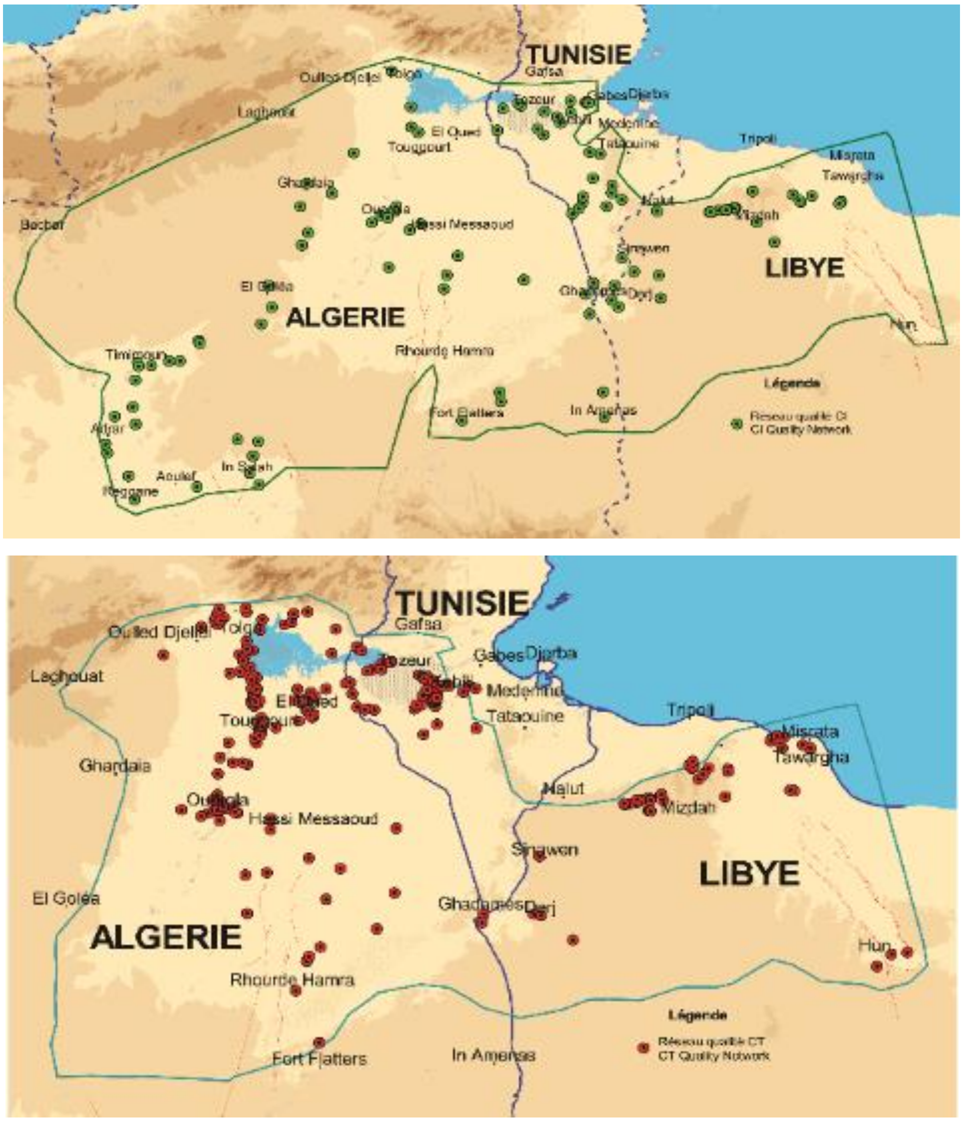
Water quality monitoring complements exploitation and piezometry monitoring. It is imperative in areas where water quality has shown significant variations (chotts areas and the coastal region in Libya). A proposal to strengthen the quality monitoring network was also accepted as part of the work of the NWSAS consultation mechanism, bringing the number of monitoring points to 384 (Table 5 and Figure 21). The monitoring network is being revised for the Libyan side.

Table 5. NWSAS quality monitoring network

	Proposal to strengthen the monitoring network (2016)		
Country	Intercalary Continental	Terminal Complex	Total
Algeria	53	130	**183**
Tunisia	31	72	**103**
Libya	45	53	**98**
TOTAL	**129**	**255**	**384**

Source: OSS.

Figure 21. Quality monitoring network in the Intercalary Continental-NWSAS (top) and in the Terminal Complex-NWSAS (bottom) (proposal 2016)



Source: OSS.

1.4.5 NWSAS water quality and quantity trends and implications

NWSAS water resources are subject to abstractions that have exceeded their renewable resources by almost threefold. The abstraction volume was estimated at 3.17 billion m^3/year in 2016, through more than 10,000 water points (for the NWSAS) and nearly 1 billion m^3/year through more than 8,000 water points (for the Djeffara).

This has led to a drop in water table levels and a degradation of water quality. There are still significant drawdowns in these exploitation areas, such as, for the Intercalary Continental layer: Ouargla and Hassi Messaoud in Algeria, where drawdowns have reached 20 m compared with 2012; Kebili in Tunisia, where drawdowns have reached 5 m compared with 2012; and Al Jufra in Libya, where drawdowns have reached 10 m compared with 2012. The average increase in drawdowns compared with 1950 is 100 m for the Terminal Complex and 50 m for the Intercalary Continental.

National development trends in the basin would double the estimated needs for 2030–2050 (i.e. more than 6 billion m^3/year). This would lead to an additional mobilisation of 3 billion m^3/year, i.e. the equivalent of the current abstraction. This situation will require:

- the creation of more than 17,000 water points
- the rehabilitation of several thousand boreholes given the depth of pumping
- the replacement of thousands of boreholes.

A drawdown of at least 20 m for the Intercalary Continental and 50 m for the Terminal Complex by 2050 is expected, without taking into account the overlaps between boreholes due to their concentration.

Water quality is directly related to the level of drawdown of the water table. Boreholes for water consumption have been closed due to increased salinity. The chotts region is still prone to a reversal of flows.

Increased water abstraction will therefore not be without risks and impacts on the NWSAS system (Djeffara), such as increased salinisation and increased competition between users. Response to development needs is therefore no longer strictly hydraulic in nature; rather, it should be pursued in terms of demand management, water savings and the use of new technologies to develop unconventional water resources.

Water quality and its future evolution are the most concerning aspects of NWSAS water resource management. Unfortunately, chemical monitoring of NWSAS aquifers is far from being adequately ensured in all areas, and in places where it is more or less ensured, monitoring only concerns water salinity. This chemical monitoring should gradually be directed towards the chemical composition of the water, in addition to its overall salinity. Through analysis of this composition, the causes of contamination and the necessary remedial measures will be better highlighted. However, the NWSAS consultation mechanism has already issued recommendations to stop drilling in the chotts region, where salinity has increased by 2.5 g/l in the Terminal Complex and 0.5 g/l in the Intercalary Continental (trends that will have to be taken into account).

1.5 Soil resources

1.5.1 Land and soil quality

Soils in the NWSAS region vary greatly as a result of the combined effect of the climate, the nature of the bedrock, and the relief. All Mediterranean and desert soil types are present. They are generally low in organic matter and have a high salt concentration.

These are skeletal soils, in which clay production is very low and the coarse fraction is dominant. The soils are sandy and very stony. Their formation is the result of wind on the bedrock and a hyper-arid water regime. The soils evolve very little and overall soil cover is extremely heterogeneous.

They are essentially mineral soils in the sense that, outside oases, the organic fraction is very low or even nil. On high landforms, the soils are rocky or sandy (hamadas, regs and ergs). In depressions, their texture can be fine, but the soils are saline (sebkhas and chotts).

Thus, very few soils have the depth, texture, structure or porosity that allow them to be irrigated without risk to the crop, the soils themselves and the environment. Of the nearly 1 million ha of the Sahara where soil mapping has been carried out, a little less than one tenth of the area has been considered irrigable land. Soil is therefore a serious constraint to developing irrigation in the NWSAS.

In these arid conditions, with soil and water constraints, crop irrigation requires a particular mastery of irrigation and drainage techniques. The soils have low water and nutrient retention capacities. The aim, therefore, is to avoid the accumulation of large quantities of salts in the soil on the one hand, and to limit water wastage on the other. As an example, a hectare of wheat consumes 6,000 m^3 of water per year; if the irrigation water contains 2 g/l of salts, the crop can then leave 12 tonnes of salts in the soil at the end of the cycle.

1.5.2 Types of land use and occupancy

The NWSAS, covering an area of 1 million km^2, is in one of the world's driest and hottest deserts; it is also an endorheic system. In this very dry and evaporating climate, life has traditionally been organised around date palm cultivation, made possible by the existence of water points: the oases. However, a new 'industrial' agriculture has been developed over the last three decades.

1.5.2.1 Oasis agriculture

This agriculture is based on general principles adopted in all the oases of the NWSAS region:

- **First principle:** Scaling up the use of three physical production factors, specifically: soil, irrigation water and sunlight. This scaling-up is achieved horizontally by a land-use rate of up to 100 percent, with the adoption of three-tier crop systems (date palm, fruit crops and various vegetable and subsistence crops). With vertical scaling-up (two successive seasonal crops on the same plot), the land cover rate can reach 120–130 percent in some cases.
- **Second principle:** Integrating family livestock farming into farm operations with a dual objective: to improve the farmer's income and to fertilise the soil through symbiotic nitrogen fixation, with the introduction of forage crops of the legume family, recovery of agricultural waste, and recycling of the manure produced on site by the livestock. In this way, oasis systems were originally all biological systems.
- **Third principle:** Using irrigation water as efficiently as possible to meet the food needs of the farmer's household and livestock first, and selling production surpluses to be able to buy other consumer goods.

- **Fourth principle:** Ensuring continued soil quality by maintaining the oasis' internal infrastructure (tracks, bridges, drainage network and irrigation water distribution works, etc.).
- **Fifth principle:** All oasis users respecting these principles, contributing to their implementation, respecting the right to water and the regulation of its distribution to users.

On the basis of these principles, various oasis crop systems have been developed in line with water constraints, water quality, market opportunities and the dynamism of oasis users. In fact, the 2004 OSS study on agricultural production systems in the NWSAS region (NWSAS 2 project) identified a large number of oasis variants that show the various ways in which farmers adapt to the multiple constraints undermining the sustainability of the traditional oasis system. These include: the extensive oasis system; the marginal oasis system (family micro-plots); the intensive oasis system, in which livestock farming is no longer integrated; the intensive integrated oasis system, in which family livestock farming is incorporated into the crop system; and the oasis system of date palm monoculture.

Each of these systems is socioeconomically in line with the farmer's financial capacities.

1.5.2.2 The open-air irrigated land system

The irrigated land system includes fruit and/or market garden crops. It covers all public land and private irrigated farms outside of oases. The majority of these are small areas irrigated with water from boreholes or surface wells with low flow and high levels of salinity.

1.5.2.3 Protected out-of-season irrigated crop systems

Protected out-of-season crop systems, irrigated with conventional or geothermal water, are for intensive and hyper-intensive crops intended for export.

1.5.2.4 Extensive rainfed fruticulture system

The extensive rainfed fruticulture system, dominated by olive tree monoculture for oil, is particularly developed in the Tunisian Djeffara (governorates of Gabès and Médenine), and in the Libyan Djeffara (west of Tripoli).

1.5.2.5 Extensive mixed family polyculture system

The extensive mixed family polyculture system largely focuses on rainfed olive trees for oil and is characterised by irrigated market gardening in the intermediate spaces. Irrigation water is obtained from traditional surface wells that produce brackish water.

1.5.2.6 Animal production systems: pastoralism and its current evolution

Pastoralism was the very first exploitation of natural plant resources developed in this area, with extensive small ruminant and camel farming. It is a transhumant breeding system originally based on:

- optimal use of the diverse and varied temporal and spatial pastoral opportunities in the area's vast steppes
- integration of the aptitudes and performance of sheep, goats, and camels: species known for their adaptation to arid environments (with different but complementary aptitudes), enabling the best possible use of the different potentials of the rangelands.

These systems currently continue to form the backdrop for development, which is constantly evolving to adapt to new circumstances brought about by socioeconomic changes. The most important of these adaptations are linked to the settlement of livestock farmers, the expansion of land areas and food security for livestock through a proactive governmental policy relating to aid for livestock farmers during periods of drought. However, livestock farming faces survival difficulties due to the overexploitation of steppic rangelands in terms of both quantity (decrease in the area of the steppe increasingly converted into cropland and lower productivity in forage units/ha) and quality (erosion of the best palatable species). Ultimately, this system faces an existential challenge in its current form, with climate change threats only amplifying the risks of decline. Awareness of this issue is constantly growing among most actors, both individuals and interest groups, who are mobilising to identify ways to preserve this important part of the economy in the areas concerned.

None of these agricultural production systems have escaped the evolution of society, technological progress and market influence. They are all in great difficulty and threatened with long-term decay. There are several causes for this regressive development, including water scarcity in the context of unprecedented growth in water demand from all economic sectors, including irrigated agriculture.

1.5.3 The regional problem of irrigation using NWSAS water

In all three countries, the NWSAS region is subject to multiple natural constraints, which are currently accentuated by new challenges and socioeconomic development issues. Analysis of the various crop and livestock systems in this area has identified and highlighted:

- their very low physical and economic productivity
- the asserted dynamics of social deconstruction that expose local populations to economic vulnerability, eventually resulting in emigration in search of other non-agricultural income
- negative impacts on natural resources.

For irrigated agriculture, these impacts can be broken down into direct and indirect impacts.

- **Direct impacts:**

These are irrigation-related impacts that affect the integrity of irrigated land, its water and saline functioning and fertility, thus reducing its agricultural production capacity and the productivity of the water used. Among these are the following:

- the salinisation of irrigated soils due to unreasonable irrigation management and the cumulative balance of salts incorporated into the soil through irrigation water
- the rise in water table levels due to several causes of poor drainage of irrigated soils
- the fertility degradation of irrigated land due to the abandonment of oasis crop systems and traditional integrated land fertility management techniques.

- **Indirect impacts:**

These result from the overexploitation of other natural resources around the irrigated lands:

- genetic erosion and loss of biodiversity in traditional oases, considered as rich habitats for species and crop varieties that are adapted to water stress and climate variability
- hydrological dysfunction of wetlands and their pollution by various industrial and domestic wastewater discharge
- desertification of steppes and landscape quality degradation around irrigated areas.

With regard to soil quality, the work carried out to date includes an inventory of saline soils, assessment of the impacts of salinisation, protection strategies to be adopted, the establishment of indicators and an attempt to quantify these impacts in economic terms. For example, the severity of the salinisation, in addition to the damage to the ecological quality of the land, can result in a considerable loss of soil resources, estimated at 4,300 ha/year over an area of 170,000 ha in Algeria and 300 ha/year over an area of 40,000 ha in Tunisia. The lack of income caused by these losses is in addition to the generally low efficiency of irrigation in terms of productivity per cubic metre of water. This productivity is reduced to:

- 0.32 kg of dates/m^3 of water for the date palm, which can normally exceed 0.5 kg/m^3
- 0.02 kg of wheat grains/m^3 of water for wheat grown under pivot irrigation systems, which can normally exceed 1.2 kg/m^3
- 2.5 kg of tomatoes/m^3 of water for field tomato cultivation, which can normally exceed 6 kg/m^3.

These adverse impacts on resources are summarised in Table 6.

Table 6. Nature of adverse impacts on resources and their changing trends

Resources threatened	**Impact**	**NWSAS area (Algeria)**	**NWSAS area (Tunisia)**	**NWSAS area (Libya)**
Soil	Salinisation	75% of the land is salinated	42% of the land is salinated	Not documented
	Poor drainage	Significant impact Not measured	Significant impact Estimated at 10,000 ha	Not documented
	Loss of fertility	Significant impact Not measured	Significant impact Not measured	Significant impact Not measured
Oasis	Dysfunction Loss of biodiversity	Strong trend Loss of local varieties	Strong trend Loss of local varieties	Strong trend Loss of local varieties
Steppic rangelands	Desertification	Severe impact, in places irreversible	Severe impact, in places irreversible	Severe impact, in places irreversible
Wetlands	Drainage pollution	Long-term risk	Long-term risk	Long-term risk
Landscapes	Silting salinisation	Severe impact	Severe impact	Severe impact

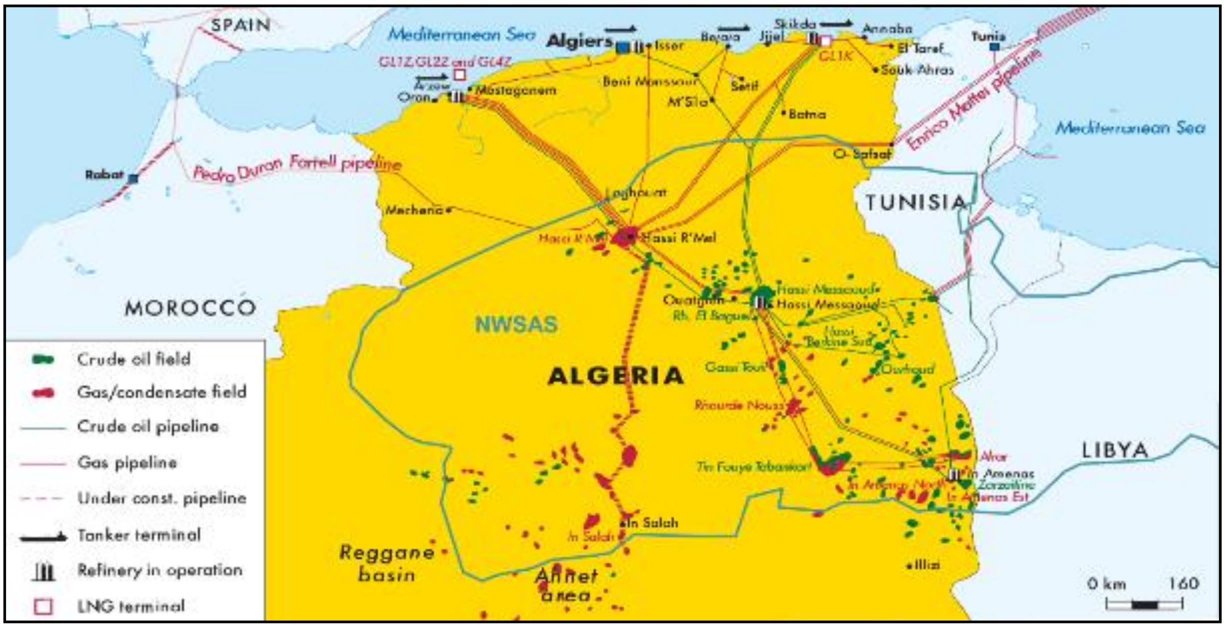
Source: Authors' elaboration.

1.6 Energy resources and electricity systems

1.6.1 Fossil fuel resources and reserves

Fossil fuels are among the most abundant natural resources within the NWSAS countries. While Tunisia is a net importer of fossil fuel products, Algeria and Libya are net exporters, ranking among the top producers of natural gas and crude oil in the world respectively. Libya has been a member of the Organization of the Petroleum Exporting Countries (OPEC) since 1963 and Algeria since 1969.[13]

Figure 1. Oil and natural gas infrastructure in Algeria



Source: IEA (2005).

According to OPEC estimates,[14] the proven crude oil reserves in Algeria were about 12.2 billion barrels (Bbbl) in 2018. The country's main oil reserves are located within the region of the NWSAS, in the eastern part near the Libyan border, as shown in Figure 22. The Hassi Messaoud – Dahar province contains more than 70 percent of the Algerian confirmed, probable and possible oil reserves combined. Hassi Messaoud, Hassi R'Mel and Ourhoud fields hold 3.9, 3.7 and 1.9 Bbbl respectively.[15] Hassi-Messoud is one of the largest oil production fields in the world, with a daily production of 296 thousand barrels per day (Mbbl/d). Ourhoud is the country's second largest oil field producing about 55 Mbbl/d and Hassi R'Mel produces additional 12.6 Mbbl/d. On top of that, the Algerian side of the NWSAS has many other oil fields, natural gas fields and pipelines.

Overall, Algeria has 1,847 wells producing about 1 million barrels per day (MMbbl/d) of crude oil, of which about 63 percent is exported (estimated in 2018). The refining capacity in Algeria is about 657 Mbbl/d, of which 54 percent is within the Skikda facility and the rest distributed between the other six refining facilities

13 OPEC (2019).

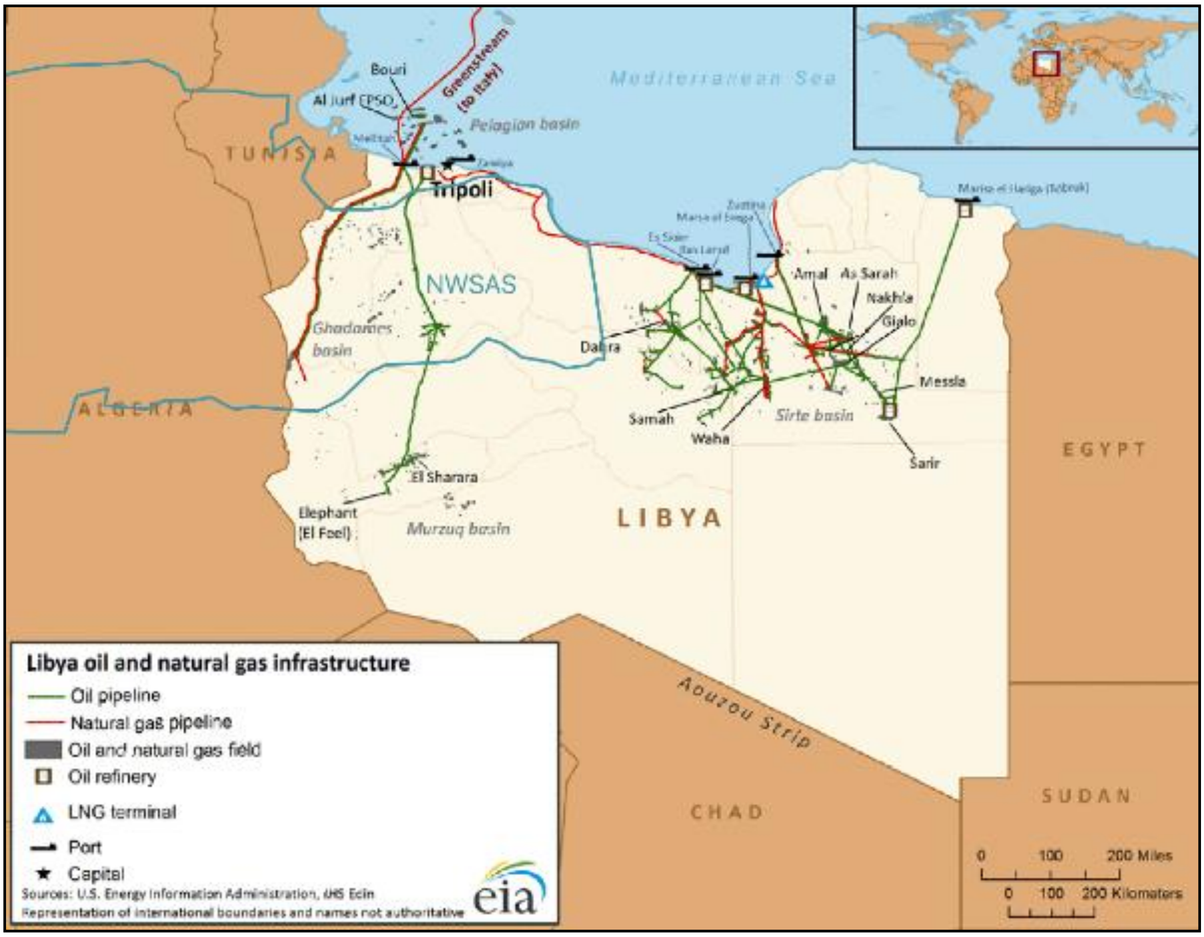
14 OPEC (2019).

15 EIA (2019a).

(Table 7). Three refining facilities are located within the boundaries of the NWSAS in Adrar, Amenas and Hassi Messaoud.

The proven crude oil reserves in Libya were estimated at 48.4 Bbbl in 2018. Out of the six main hydrocarbon basins (Sirte, Murzuk, Ghadames, Cyrenaica, Kufra, and the Pelagian offshore), the Ghadames basin (west Libya) and Pelagian offshore basins lie within the NWSAS boundaries (see Figure 23),[16] while the Sirte basin (east Libya) holds about 80 percent of Libya's recoverable reserves and produces most of the oil in the country. It is not clear how much the Ghadames and offshore basins contribute to the total Libyan oil production. In terms of refining capacity, Az Zawiyah is the second largest refinery in the country and is located close to the NWSAS border, accounting for 32 percent of the total refining capacity. The country's other refineries are in the eastern part of the country due to their proximity to the main oil reserves and production fields.

Figure 2. Oil and natural gas infrastructure in Libya



Source: EIA (2019b).

Due to the instability in Libya, oil production has been fluctuating in the last eight years. In 2010, Libya had about 2,000 production wells generating 1.48 MMbbl/d. This number dropped in the next year to only 609

[16] Depending on how the boundary of the NWSAS is defined, the offshore reserve can be considered within or outside the region.

wells and the oil production declined to 489 Mbbl/d. OPEC reports that in 2018 about 1,000 wells were operational and producing 951 Mbbl/d. Libya has a total refining capacity of 380 Mbbl/d (Table 7). The largest refinery facility is in Ras Lanuf, which is responsible for about 58 percent of the total capacity.

The situation is different in Tunisia, as it has very minor crude oil reserves, estimated at 425 MMbbl in 2017.[17] The NWSAS covers almost half of the Tunisian territory and it contains most of the Tunisian onshore oil and gas reserves, as can be seen in Figure 24. Several oil production fields are located in the south-western part of Tunisia, namely El Borma (9,100 bbl/d in 2010), which is one of the main oil production fields of Tunisia, Sanhar (95 bbl/d in 2010), Makhrouga-Laarich-Debech (MLD), Ech Chouech, Chourouq, Adam and others.

[17] EIA (2014).

Figure 3. Oil and natural gas infrastructure in Tunisia

Source: Entreprise Tunisienne d’Activités Pétrolières (ETAP) (2019).

Since the 1980s, Tunisian crude oil production has been declining mainly due to the natural depletion of most of the fields. In 2000 the demand surpassed the supply and Tunisia became a net importer. In 2018, Tunisia produced about 38.6 Mbbl/d, and had a consumption of about 109 Mbbl/d[17]. The main Tunisian oil producing fields are El Borma, Ashtart and Sidi el Kilani. El Borma is located within the NWSAS borders. Tunisia has only one refining facility located in Zarzouna in the Bizerte Governorate with total capacity of 34,000 bbl/d[17].

Table 7. Refinery capacity in NWSAS countries by company and location (1,000 bbl/d)

Country/Company	Location	In NWSAS [c]	yr 2000	yr 2018
Algeria [a]			**462**	**657**
Sonatrach	Skikda	No	323	355
	Skikda (Condensate)	No	NA	122
	Arzew	No	54	87
	Alger	No	58	58
	Hassi Messaoud	Yes	27	22
	In Amenas	Yes	NA	nap
	Adrar	Yes	NA	13
Libya [a]			**380**	**380**
National Oil Company (NOC)	Ras Lanuf	No	220	220
	Zawia	No	120	120
	Tobruk	No	20	20
	Marsa El-Brega	No	10	10
	Sarir	No	10	10
Tunisia [b]			**34**	**34**
The Tunisian Company for Refining Industries (STIR)	Bizerte Refinery	No	34	34

[a] Data from OPEC database (2019).

[b] Data from STIR (n.d.).

[c] Self-compilation using data from OPEC and geographical location using QGIS.

Looking at the natural gas reserves, OPEC statistics show that the confirmed natural gas reserves in Algeria were around 4,504 billion m^3 in 2018. However, the gas field of Hassi R'Mel remains one of the biggest in the world. It is located in the eastern part of the country, within the NWSAS borders, and holds confirmed reserves of about 2,405 billion m^3. The other fields in Algeria are combined (oil and gas) and non-combined fields in the south and southeast regions of the country, most of them within the NWSAS basin. Natural gas production in Algeria increased from 83.12 billion m^3 in 2000 to 95.9 billion m^3 in 2018, of which 51.42 billion m^3 was exported and the remaining 44.43 billion m^3 consumed locally.

In Libya, natural gas reserves were estimated at 1,505 billion m^3 in 2018. Gas fields in Libya are all combined with oil fields, and most of them are located in the Sirte basin and offshore. The production of natural gas was 5.88 billion m^3 in 2000 which had increased to 16.8 billion m3 by 2010, but suffered a severe drop to 7.8 billion m^3 in 2011. This can be explained by the conflict in the country; however, the following two years saw a large increase in production, peaking at its highest historic point in 2013 at 18.4 billion m^3. Nonetheless, mainly due to the instability in the country, the production has steadily decreased since then, getting to 13.88 billion m^3 by 2018. From the latest figures, 4.25 billion m^3 was exported and 5.04 billion m^3 consumed internally.

Tunisia produced around 77.87 billion m^3 and 65.13 billion m^3 of proven natural gas reserves in 2000 and 2018 respectively.[18] The main (non-combined) gas fields in Tunisia are Miskar and Franig.[19] The first is an offshore field, the second is onshore and lies in Chott el Djérid, which is within the NWSAS region as shown in Figure 24. Natural gas production started at 2.3 billion m^3 in 2000, peaking at 3.49 billion m^3 in 2008 and decreasing to 2.47 billion m^3 in 2015. Consumption, on the other hand, increased from around 3 billion m^3 in 2000 to 4.54 billion m^3 in 2015, therefore Tunisia does not export natural gas, and relies on imports from Algeria to meet its deficit in natural gas demand.[20,21] The natural gas fields of Borj Bourguiba and Oued Zar, Baguel, Djebel Grouz and Chouech Essaida are also located within the boundary of the NWSAS. According to ETAP, the NWSAS region contributed to about 20 percent of the total national gas production in Tunisia in 2012.[22]

Table 8 presents an overview of the fossil fuels reserves, production and exports in the three countries.

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[18] CIA (2018).

[19] ETAP (2018).

[20] Saidi and Fniech (2014).

[21] EIA (2014).

[22] ETAP (2012).

Table 8. Fossil fuel reserves in NWSAS countries

#	Parameter	Unit	Algeria[a]		Libya[a]		Tunisia[b]	
			2000	2018	2000	2018	2000	2018*
1	Proven crude oil reserves	Million Barrels (MMbbl)	11,314	12,200	36,000	48,363	300	425**
2	Active rigs	Number of rigs	17	50	8	9	1	1
3	Producing wells	Number of wells	1,235	1,847	1,436	1,091	-	-
4	Daily crude oil production	Thousand Barrels (Mbbl)	796	1,040	1,347	951	79	38.6
5	Refining capacity	Mbbl/d	462	657	380	380	34	34
6	Oil demand	Mbbl/d	192	431	203	215	85	109
7	Crude oil exports	Mbbl/d	462.2	571	1,005	998.5	-	-
8	Petroleum product exports	Mbbl/d	542.8	532.1	158.7	25.4	-	-
9	Proven natural gas reserves	Billion m^3	4,523	4,504	1,314	1,505	77.87	65.13
10	Natural gas production	Billion m^3	83.1	95.9	5.9	13.88	2.3	2.47***
11	Natural gas demand	Billion m^3	20.56	44.43	5.2	5.04	3	4.54***
12	Natural gas exports	Billion m^3	61.69	51.42	0.8	4.25	-	-

* Information presented for 2018, unless specified otherwise.

** Information for 2017.

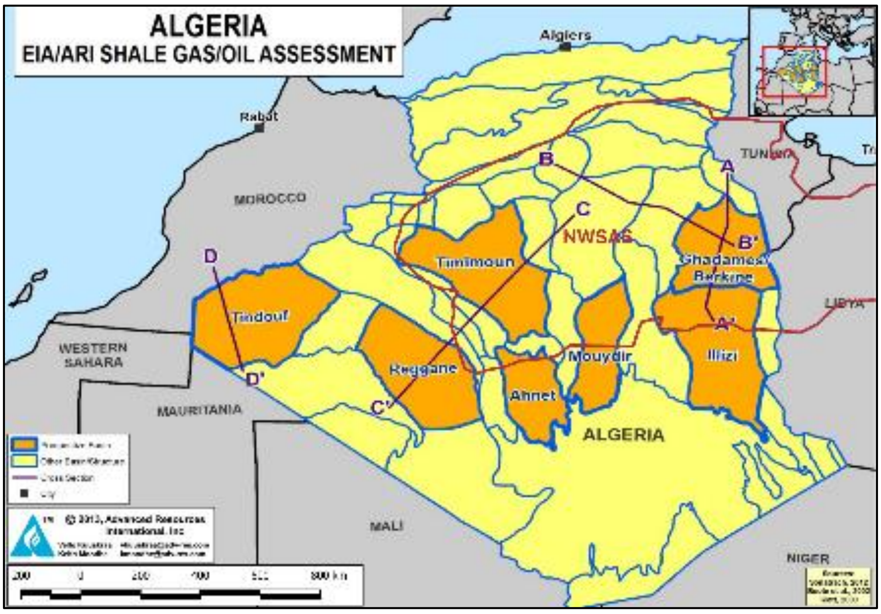
*** information for 2015.

[a] Data from OPEC database (2019).

[b] Data from ETAP (2012), CIA (2018) and EIA (2014).

Unconventional hydrocarbon reserves, including shale oil and gas, are also abundant in the NWSAS countries and in the NWSAS region. **Algeria** has the third largest shale gas reserves in the world, estimated at 20 trillion m^3 of technically recoverable shale gas. Such reserves form seven shale basins, four of which fall partially or completely within the boundaries of the NWSAS (see Figure 25): Timimoun, Ghdames, Illizi and Mouydir. Sonatrach, the national oil and gas company, has scheduled pilot wells in different basins. Statoil and Repsol have already carried out some reservoir characterisation studies, however no information on the existence of shale production wells is available.

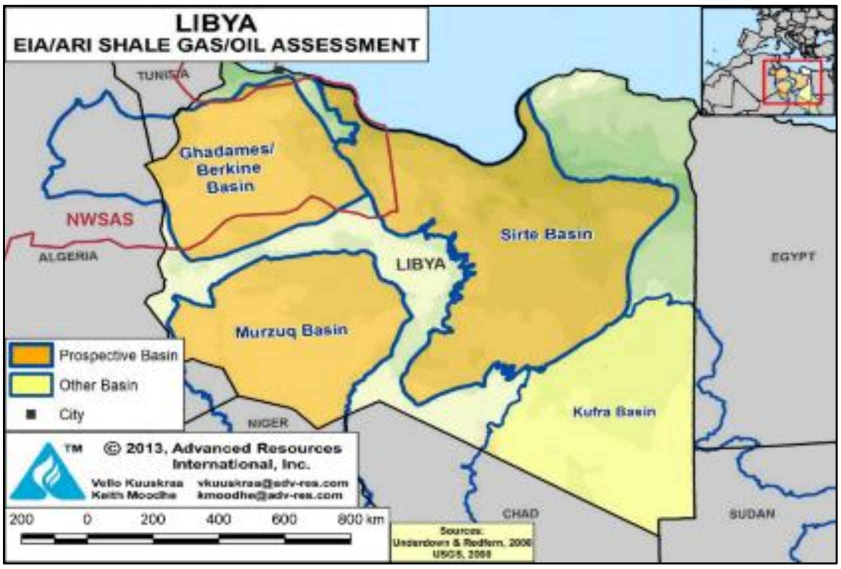
Figure 4. Algerian shale fields and the NWSAS frontier



Source: EIA (2015a).

In Libya, there are three basins with potential for shale oil and gas (Ghadames, Sirte and Murzuq), and a fourth one for which the potential has not yet been confirmed (Figure 26). The Ghadames basin is completely within the boundaries of the NWSAS, as well as a small fraction of the Sirte Basin. Due to the ongoing conflict in the country, the exploration of oil and gas resources, including alternative ones, has been stopped.[23] No information on existing shale production wells is available.

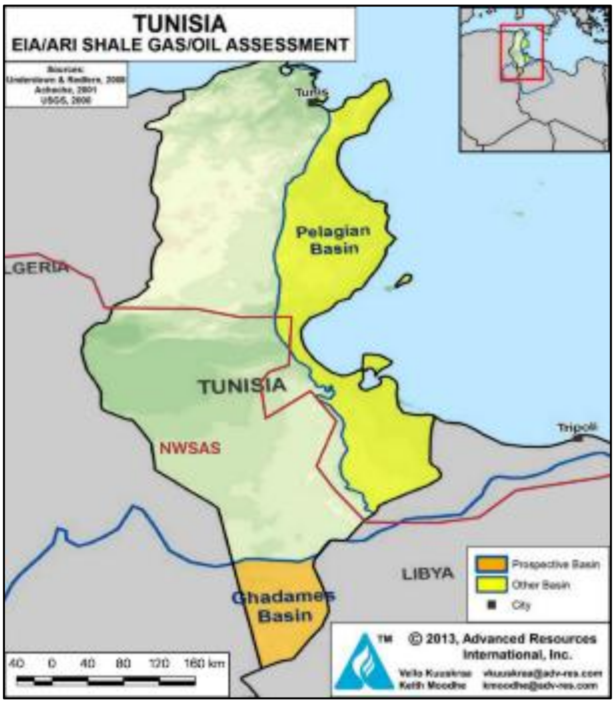
Figure 5. Libyan shale fields



Source: EIA (2015b).

[23] IEA (2015).

Figure 6. Tunisian shale fields



Source: EIA (2015c).

Tunisia contains two basins that may have potential for shale oil production, the Pelagian Basin and the Ghadames basin (Figure 27). The potential of the Pelagian Basin has not yet been confirmed. The Ghadames basin (located in the NWSAS) is under exploration, mainly targeting conventional resources. To date no company has reported production of alternative resources, although test wells are already underway.[24]

1.6.2 Oil and gas pipelines

The NWSAS supplies Europe with about 65.5 billion m^3 of natural gas annually through four main pipelines,[25] as shown in Figure 28. The first and the largest pipeline is the Trans-Mediterranean gas pipeline (also known as Transmed) that connects Algerian gas to Italy through Tunisia. This pipeline starts from the largest Algerian onshore gas field, the Hassi R'Mel, which produces 2,000 billion m^3 of natural gas annually. The Transmed pipeline extends over 2,475 km and carries about 33.5 billion m^3/year of natural gas[26] from the NWSAS region to Sicily, in Italy. The second pipeline is the Maghreb-Europe line that again starts from Hass R'Mel and travels through Algeria and Morocco to finally deliver 12 billion m^3/year to Spain. The other pipeline that connects Algeria with Spain directly is the Medgaz line delivering another 12 billion m^3/year to Spain. The fourth pipeline connecting North Africa with Europe is the Greenstream pipeline[27] which supplies 8 billion m^3/year from the Wafa field on the Algerian-Libyan border and runs through the Libyan

[24] EIA (2015).

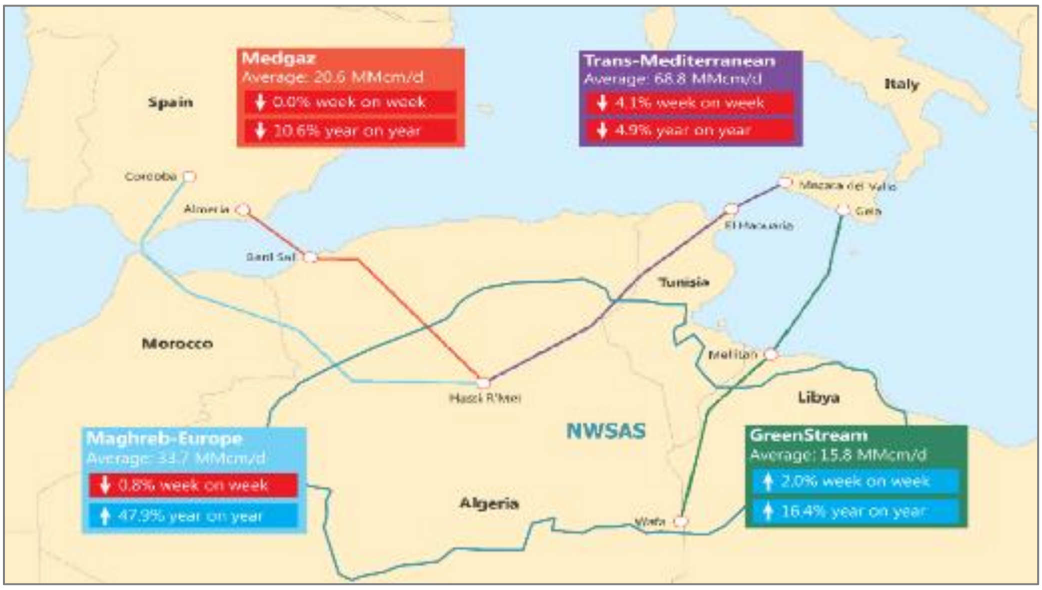
[25] SourceWatch, Center for Media and Democracy (CMD) (2018).

[26] Hydrocarbons Technology (2019).

[27] The opertation of the Greenstream pipeline was affected by the political unrest in the country and it is not clear if it is operational again.

part of the NWSAS before it passes under the Mediterranean to finally reach Italy. The aforementioned highlights the importance of the NWSAS region on the global energy map.

Figure 7. Main gas pipeline exporting natural gas from the NWSAS region to Europe



Source: Verity Ratcliffe (2018).

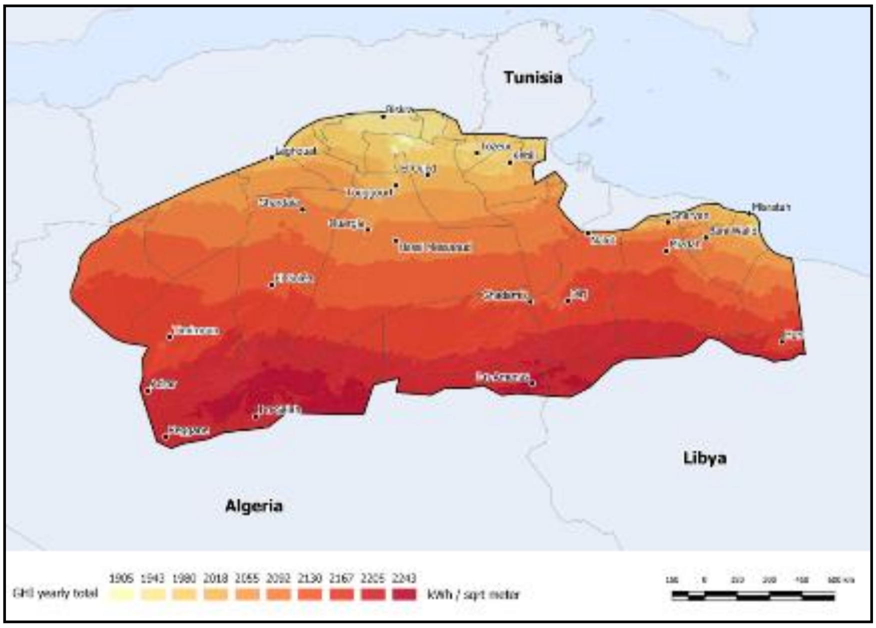
1.6.3 Renewable energy resources

The NWSAS countries are rich in solar and wind renewable energy sources (RES). The geographical location of the region makes solar energy an abundant resource that could pave the way to the transformation of the energy sector in the region. At industrial levels, electricity from solar energy can be generated through photovoltaic (PV) and concentrated solar power (CSP) technology. At a smaller scale and in households, solar energy is more commonly used for water heating and electricity generation with rooftop PV.

Wind energy has huge potential in the region due to the stable wind speeds existent throughout the year, making medium to large scale wind farms viable in the region.

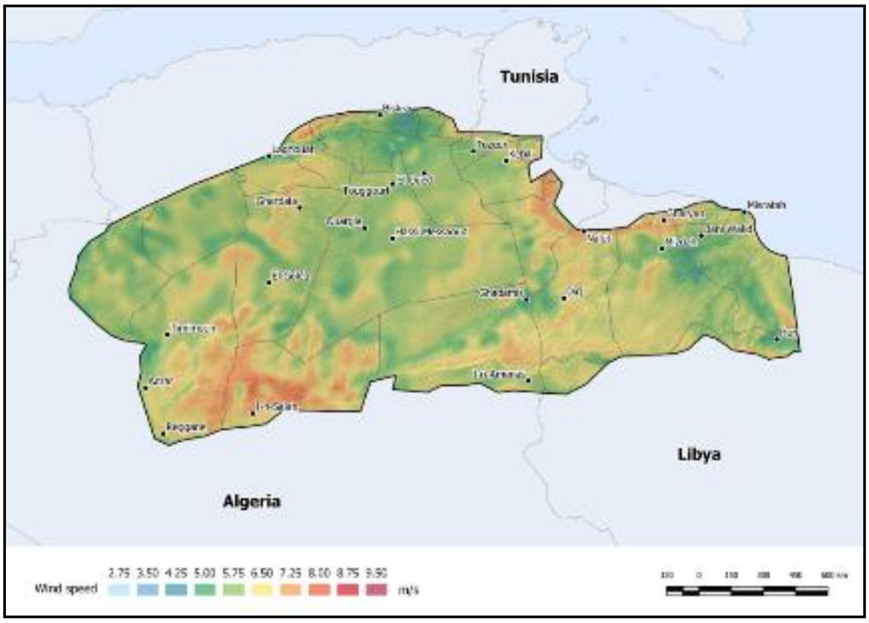
The NWSAS basin extends from 25° to 37.5° north of the Equator and from 8.7° west to 19° east of the Greenwich Meridian. As the NWSAS basin covers large parts of Algeria, Tunisia and Libya, the potential for solar and wind energy is similar within each country, having better horizontal solar irradiation to the south and higher wind speeds in the mountain areas (see Figures 29 and 30). This makes the NWSAS basin a strategic region to implement renewable energy projects. Currently, there are some renewable energy projects already operational in the countries and within the basin, but the share of RES in the countries' energy mix is insignificant. More detail about the RES share in the countries' production mix is presented in the following sections.

Figure 8. Global Horizontal Irradiation in the NWSAS basin



Source: Global Solar Atlas (n.d.).

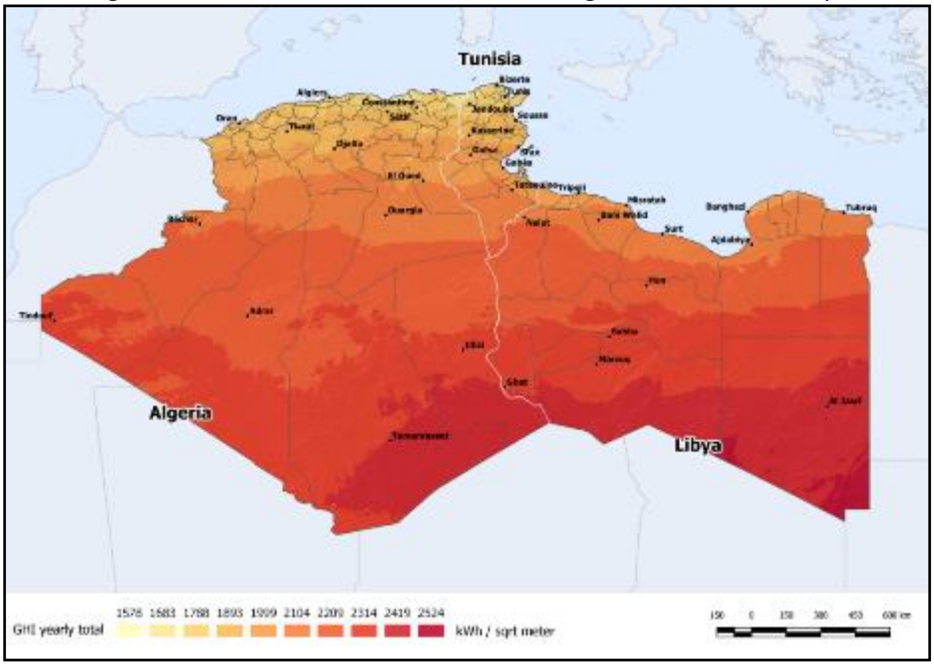
Figure 9. Average wind speed in the NWSAS basin



Source: Global Wind Atlas 2.0 (n.d.).

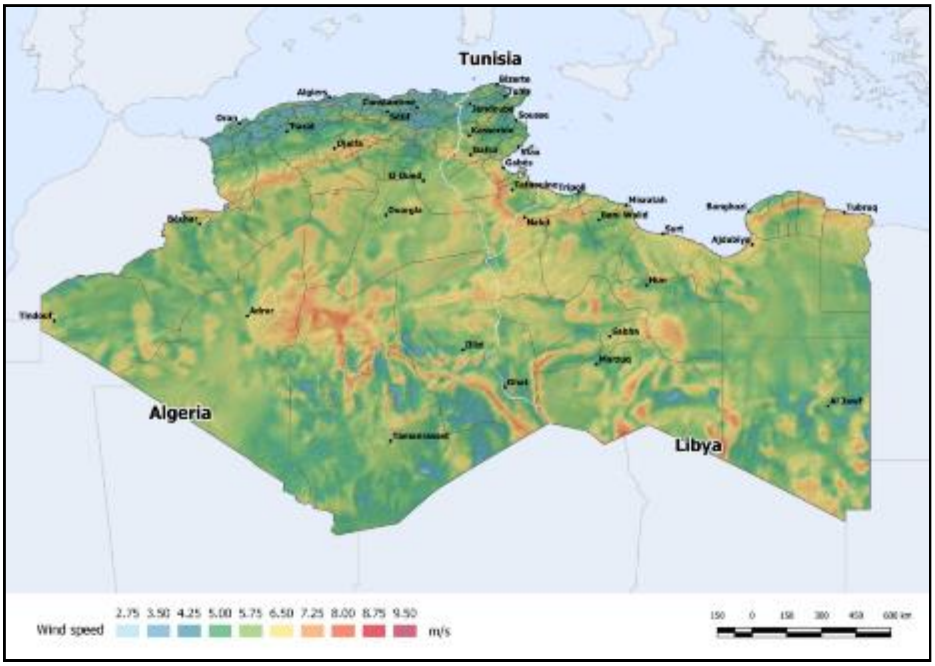
The potential for solar energy in the three countries is outstanding due to the high solar horizontal irradiation presented throughout the countries, increasing from north to south in the range of 1,500–2,500 kilowatt hours per square metre (kWh/m^2) (see Figure 31). On the other hand, wind speeds as high as 9.5 metres per second (m/s) can be found in these countries at a height of 50 metres (see Figure 32), and even faster at higher altitudes.

Figure 10. Global horizontal irradiation in Algeria, Tunisia and Libya



Source: Global Solar Atlas (n.d.).

Figure 11. Average wind speed in Algeria, Tunisia and Libya at a height of 50 metres



Source: Global Wind Atlas 2.0 (n.d.).

Table 9. Solar and wind energy potential for electricity production in Algeria, Tunisia and Libya

Country	Solar energy potential (TWh/y)			Wind energy potential (TWh/y)		
	CSP	PV	Total	CP > 20%	CP > 30%	CP > 40%
Algeria	26,530	27,904	54,434	30,155	2,536	153
Tunisia	2,045	4,645	6,690	6,842	1,244	226
Libya	11,823	13,979	25,802	21,649	5,149	1,079

CSP: Concentrated solar power
PV: Photovoltaic power
CP: Power coefficient[28]
Source: IRENA (2014).

Algeria has excellent potential for solar energy and considerable wind energy resources. According to a RES-potential study by IRENA[29] (see Table 11), a total of 54,434 TWh(terawatt-hour)/year of electrical energy could be generated with solar power in the country. The wind power potential is also substantial, ranging from 153 to 30,155 TWh of electrical energy generation per year, depending on the power coefficient (CP) considered. These figures represent a huge renewable energy possibility for the country. Even considering just the wind potential with the highest CP of 40 percent, this more than doubles the current total final electricity consumption (including losses and energy sector own use, covered in the next sections). If a lower CP is considered and the solar potential is also considered, the energy capacity from solar and wind technologies would exceed the current total electricity consumption by 1,200 times.

In Tunisia**,** the situation is not very different. Despite the very small share of RES in electricity generation, the country has large solar and wind energy potential. 6,690 TWh of electrical energy could be generated annually from solar energy, and wind power generation potential ranges from 226 to 6,852 TWh of electrical energy per year. Comparing the renewable energy potential with the total final electricity consumption, the wind potential with the highest CP (40 percent) is equal to more than 11 times the total electricity consumption, and the combined solar and wind power potential exceeds the current total final electricity consumption by almost 700 times.

Lastly**,** Libya enjoys the same conditions of high solar and wind energy potential as its neighbours**.** Solar energy would be able to generate 25,802 TWh annually and wind power could generate between 1,079 and 21,649 TWh of electrical energy per year. In the Libyan case, the wind potential at its highest CP value (40 percent) covers almost 50 times the total final electricity consumption and combined solar and wind potential exceed the total final electricity consumption by more than 2,100 times.

[28] The power coefficient (CP) is a measure on how efficient a wind turbine can convert the energy from the wind that flows into the turbine blades, into electrical energy. This coefficient varies with wind speed and turbine type. For a large-scale turbine, a 'good' CP falls in the range of 35–45 percent, however turbines with CP around 30 percent are still competitive and a CP in the order of 20 percent is acceptable for small scale applications.
[29] IRENA (2014).

1.6.4 Electricity generation system

This section presents an overview of the power generation systems, RES role and future plans in the three countries. An enhanced power generation system is a key enabler of the transition towards modern, low-carbon energy systems, and can drive the agricultural sector modernisation positively affecting rural livelihoods and quality of life. Notably, the vast RES potential of the region is not only an opportunity to modernise the energy system using domestic resources, but also a potential asset for export (this was the idea behind the DESERTEC project, which envisaged producing solar energy in the desert on large scales and transporting it in high voltage to Europe).

Despite vast RES availability, the NWSAS countries rely mostly on fossil fuels for electricity generation. The economy of Algeria and Libya is driven by fossil fuel production, and fossil fuels are heavily subsidised in all countries (see Box 1).

The three countries have ambitious plans for RES technologies deployment, but their implementation remains challenging, and progress towards decarbonisation slow. To illustrate, according to the World Electric Power Plants Database,[30] the installed capacity of the RES plants under construction in Algeria in 2015 represented only 0.7 percent of the total capacity under construction, and only 3.15 percent of the power capacity planned was from RES. Tunisia presents similar figures, as none of the power plants under construction and only 1.96 percent of the power generation capacity planned were from RES. Libya showed even lower figures, with none of the power plants under construction being of RES technologies and 0.12 percent of the power capacity planned.

Box 1. Energy subsidies in Algeria, Tunisia and Libya

There are many ways to subsidise the consumption of a certain resource, and a simple definition of subsidy would be: *"... any measure that keeps prices for consumers below the market level or keeps prices for producers above the market level, or that reduces costs for consumers and producers by giving direct or indirect support"* [31]

The subsidisation of energy products (such as electricity, natural gas, petroleum products, etc.) drives the demand for certain products over others, but most importantly it can make a difference when it comes to the viability of businesses and affordability of services. Hence, in North African countries, subsidised schemes on energy products were initially introduced to facilitate industrialisation and reduce social inequalities.[32] Today several segments of society and the economy, including the most vulnerable like small farmers, rely on the low cost of energy to carry on their activities. For this reason, the revision of energy subsidies – which would be needed today to facilitate the transition to renewable energy, increase efficiency of energy and also, indirectly, of water – is a very delicate subject. It should be noted that these challenges are not specific to North African countries, and that the revision of energy subsidies is sought with difficulty by governments all around the world, including Europe.

The existence of energy subsidisation can be difficult to capture, particularly in fossil fuel producing countries. Estimating the 'price-gap' between the consumer price and the cost of supply is the most

[30] World Electric Power Plants Database (2015).

[31] de Moor and Calamai (1997).

[32] Eibl (2017).

sensible way to measure subsidies, but it is useful to keep in mind the limitations of such an approach, particularly when the economy is already highly dependent on fossil fuels for export and/or production:

"The price-gap approach […] compares average end-user prices paid by consumers with reference prices that correspond to the full cost of supply […] For economies that export a given fossil-energy product but charge less for it in the domestic markets, the domestic subsidies are implicit; they have no direct budgetary impact so as long as the price covers the cost of production. [...] For net importers, subsidies measured via the price-gap approach may be explicit, representing budget expenditures arising from the domestic sale of imported energy at subsidised prices, or may sometimes be implicit. […] Estimates using the price-gap approach capture only interventions that result in final prices to end-users below those that would prevail in a competitive market. While such subsidies account for the majority of subsidies to fossil fuels, there are numerous others that are not captured by the price-gap approach. It does not, for example, capture subsidised research and development or subsidies for fossil fuel production." [33]

Historically, Algeria aimed at exporting its large fossil fuel reserves to subsidise its internal consumption. Between 2011 and 2012, public spending on subsidies doubled, with energy subsidies accounting for 12.1 percent of gross domestic product (GDP).[34] By 2016, the budget law raised the prices for energy products, however the increase was marginal and the price of energy products remained among the lowest worldwide. In 2018, subsidies for energy products amounted to USD 17,080 million or 9.5 percent of GDP of which 56 percent was for oil, 21 percent for electricity and 23 percent for natural gas. Such figures accounted for an average rate of subsidy of 70 percent (Table 10).

Table 10. Energy subsidy indicators from IEA (2018)

Country	Average subsidisation rate (%)	Subsidy per capita ($/person)	Total subsidy as share of GDP (%)
Algeria	70%	407	9.5%
Libya	78%	726	10.8%
Tunisia	NA	NA	NA

Source: IEA (2019).

Libya also has a long history of subsidising energy products, dating back to the 1970s. The energy products covered by the subsidies have been gasoline, diesel, liquefied petroleum gas (LPG), kerosene, and electricity.[35] Energy subsidies increased from around LYD 234 million in 1995 to LYD 404 million in year 2000, with the largest subsidies allocated to oil (around 87 percent of energy subsidies) and electricity (around 12 percent of energy subsidies)[36]. Energy prices kept increasing even after the revolution, peaking at USD 8,486 million in 2012 according to the International Energy Agency.[37] Moreover, the amount of

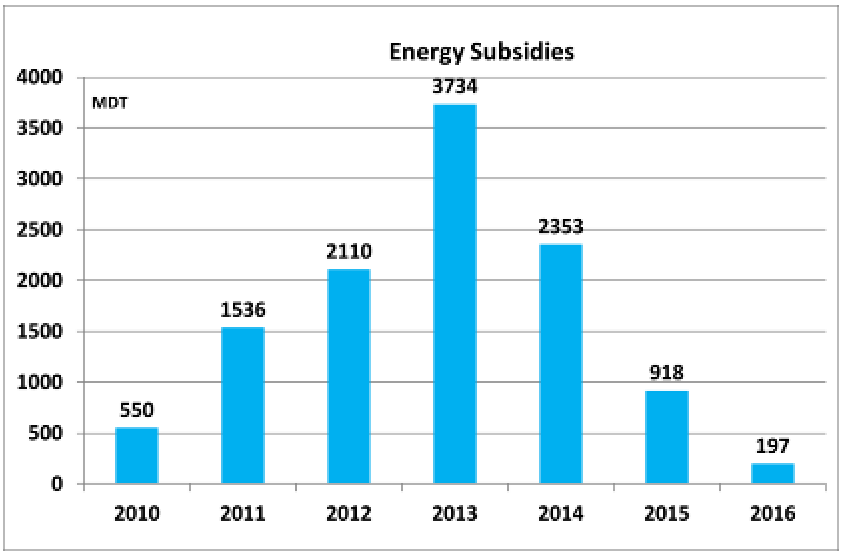
[33] IEA (2019).
[34] IMF (2014).
[35] Abdelkrim et al. (2017).
[36] Abdelkrim et al. (2017).
[37] IEA (2019).

subsidies has been reduced to USD 4,698 million by 2018, accounting for 10.8 percent of GDP and a 78 percent average subsidisation rate (Table 10).

In the case of Tunisia, the energy sector is constantly trying to cope with the rapid growth of demand for energy, which is in part driven by energy subsidies. In consequence, energy products are supplied at a price that is below that of international markets, and the government covers the deficits of the national providers with state budget. Energy subsidies have ranged from 4 percent to 7 percent of GDP in the past decades, peaking at 7.2 percent in 2013.[38] With the fall in international energy prices, especially oil, in 2015, the weight of subsidies in public finances fell sharply to 0.5 percent of GDP. Also, the Government of Tunisia started taking several measures: in 2012 and 2013 it raised the prices of oil by 7 percent, in 2014 it raised the price of gas and electricity for medium-voltage consumers by 20 percent.[39] In the same year it reintroduced a gradual phasing out of subsidies for energy-intensive industries as well as an automatic indexation mechanism for petrol, based on world market price (first attempted in 2011). This situation has considerably reduced the impact of this system on the state budget (Figure 33). However, due to the strong influence of the international energy market, and the high volatility of prices, the weight of subsidies could increase again in the coming years, representing a significant risk to the country's economic performance and its public finances.

[38] World Bank and Republic of Tunisia (2018).
[39] Eibl (2017).

Figure 12. Energy subsidies in Tunisia 2010–2016 (million Tunisian dinars)



Source: World Bank and Republic of Tunisia (2018).

1.6.5 Installed capacity and production

Algeria's electricity production in 2016 was 70,999 GWh, of which 69,693 GWh was generated from natural gas. Thus, natural gas represented 98.16 percent of the total production. The other sources used by the country were oil, hydropower, solar PV and wind, but in very small amounts, covering only 1.37 percent, 0.31 percent, 0.29 percent and 0.04 percent of the domestic electricity generation respectively[40] (see Table 11).

Table 11. Electricity production in Algeria (2016)

Source	Generation (GWh)	% of the total production
Oil	970	1.37%
Gas	69,693	98.16%
Hydro (includes pumped storage plants)	218	0.31%
Solar PV	205*	0.29%
Solar CSP	134*	0.19%
Wind	29	0.04%
Total production	**71,249**	
Imports	257	0.36%
Exports	507	0.71%
Domestic supply	**70,999**	

[40] IEA (2016a).

		* Data from IRENA

Source: Self-compilation with data from IEA (2016a) and IRENA (n.d.).

On the consumption side (see Table 12), transmission and distribution losses represented 15.1 percent of the total electricity supply. The highest amounts of final consumption come from industry (35.5 percent) and the residential sector (38.6 percent), followed by other non-specified uses 21.17 percent, then agriculture and forestry and transport sectors with very small amounts of 2.7 percent and 1.9 percent respectively.

Table 12. Electricity consumption in Algeria (2016)

Sector	**Consumption (GWh)**
Industry	18,574
Transport	1,014
Residential	20,210
Agriculture and forestry	1,419
Other non-specified	11,071
Final consumption	**52,288**
Energy industry own use	7,546
Losses	10,682
Total	**70,516**
Statistical difference	-483

Source: Self-compilation with data from IEA (2016a).

The electricity sector in **Tunisia** is highly dependent on natural gas as the main source in generating electricity. The total electricity generated in 2016 was 19,808 GWh, of which 18,961 GWh was generated from natural gas (see Table 13). This represented 95.72 percent of the total electricity production in the country. The second source, but with a much smaller contribution of only 474 GWh (2.39 percent), was wind power. Solar PV, hydropower and oil provided small contributions to overall production with 63, 45 and 41 GWh respectively.

Table 13. Electricity production in Tunisia (2016)

Source	**Generation (GWh)**	**% of the total production**
Oil	41	0.21%
Gas	18,961	95.72%
Hydro (includes pumped storage plants)	45	0.23%
Solar PV	63	0.32%
Wind	474	2.39%
Other sources	224	1.13%
Total production	**19,808**	

Imports	134	0.68%
Exports	255	1.29%
Domestic supply	**19,687**	

Source: Self-compilation with data from IEA (2016b).

The power demand in Tunisia has been steadily increasing through the decades. Between 1990 and 2000, Tunisia experienced increased living standards and economic growth, which was reflected in an electricity demand annual growth rate of 6.2 percent. Due to the introduction of energy-efficiency measures, the growth rate slowed to 4.6 percent per annum between 2000 and 2005 and fell further to 3.7 percent between 2005 and 2009.[41] According to t*he Tunisian Company of Electricity and Gas* (STEG) forecast, power demand is expected to maintain a growth rate of 4 percent between 2011 and 2031, which would require significant investment in power infrastructure.[42]

Looking into the electricity use in 2016, it can be noted that transmission and distribution losses accounted for 15.5 percent of the total electricity supplied and the remaining 79 percent and 4.7 percent used by the final consumers and the energy sector respectively. Of the final electricity consumption (Table 14), the industry sector accounted for a 34.83 percent share, the residential sector for 29.73 percent, commerce and public services for 27.32 percent, agriculture and forestry for 7.5 percent and transport for a low 0.62 percent:**Errore. Il segnalibro non è definito.**

Table 14. Electricity consumption by sector in Tunisia (2016)

Sector	Consumption (GWh)
Industry	5,423
Transport	96
Residential	4,628
Commercial and Public Services	4,254
Agriculture and forestry	1,168
Final consumption	**15,569**
Energy industry own use	924
Losses	3,052
Total	**19,545**
Statistical difference	-142

Source: Self-compilation with data from IEA (2016b).

In 2016, **Libya** produced 36,430 GWh of electricity, of which 22,802 GWh was generated from natural gas, 13,620 GWh from oil and a very small contribution of solar PV of 8 GWh (Table 15). An additional 376 GWh of electricity was imported. Natural gas represented 62.5 percent of total production, oil 37.3 percent and PV only 0.02 percent.

[41] Bridle, Kiston and Wooders (2014).
[42] Lechtenboehmer et al. (2012).

Table 15. Electricity production in Libya (2016)

Source	Generation (GWh)	% of the total production
Oil	13,620	37.39%
Gas	22,802	62.59%
Solar PV	8	0.02%
Total production	**36,430**	
Imports	376	1.03%
Exports	0	-
Domestic supply	**36,806**	

Source: Self-compilation with data from IEA (2016c).

On the consumption side, what comes as a surprise is that only 37.9 percent (13,980 GWh) of the domestic supply is available for consumption (Table 16). From this, residential (42.16 percent) and non-specified uses (29.64 percent) have the largest shares, followed by the commercial and public sector (10.77 percent), agriculture and forestry (8.74 percent) and industry (8.67 percent). The reported transmission and distribution losses are at 7,324 GWh (19.89 percent), which leaves a large negative statistical difference of minus 14,892 GWh (40.4 percent). The statistical difference refers to the difference between the calculated total consumption (i.e. energy supplied minus transmission and distribution losses) and the total consumption observed (i.e. the amount actually recorded in surveys of end-use sectors). Such a large statistical difference suggests a substantial lack of accuracy in national energy statistics.

Table 16. Electricity consumption in Libya (2016)

Sector	Consumption (GWh)
Industry	1,213
Residential	5,894
Commercial and Public Services	1,506
Agriculture/forestry	1,222
Other non-specified	4,145
Final consumption	**13,980**
Energy industry own use	610
Losses	7,324
Total	**21,914**
Statistical difference	-14,892

Source: Self-compilation with data from IEA (2016c).

1.6.6 Renewable energy power generation

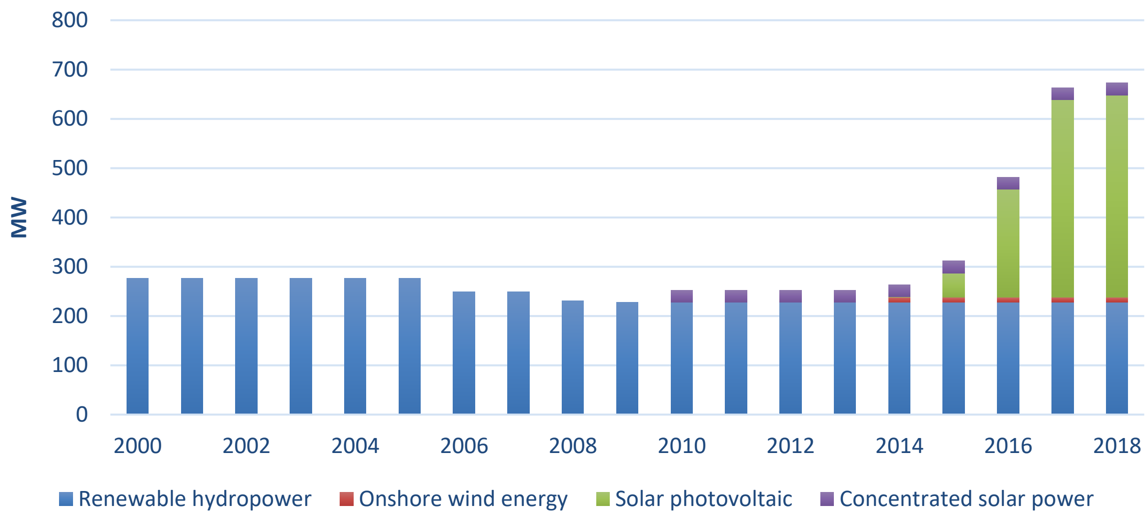
RES electricity generation is almost non-existent in **Algeria**. According to IRENA, in 2016 there was 312 MW of installed capacity and RES only represented 0.8 percent of the total electricity generation. In 2018, the total RES capacity increased to 673 MW, an increase of 39.7 percent from 2016 (Table 17). The largest RES share in 2018 (60.92 percent), is attributed to solar PV, followed by hydropower with 33.88 percent and CSP with 3.71 percent. The aggregated cumulative capacities can be seen in the table below and in Figure 34.

Table 17. Renewable sources installed capacity (2018) in Algeria

Technology	Installed capacity (MW)	% of total RES
Hydropower	228	33.88%
Concentrated solar power	25	3.71%
Onshore wind	10	1.49%
Solar photovoltaic	410	60.92%
Total	**673**	

Source: Self-compilation with data from IRENA (n.d.).

Figure 13. Installed capacity of renewable energy sources – Algeria



Source: Data from IRENA (n.d.).

Tunisia had a total renewable electricity generation capacity of 348 MW in 2016, contributing to 2.94 percent of the total electricity production in the same year. By year 2018, the capacity grew to 358 MW, with a 2.88 percent increase compared to 2016 figures.

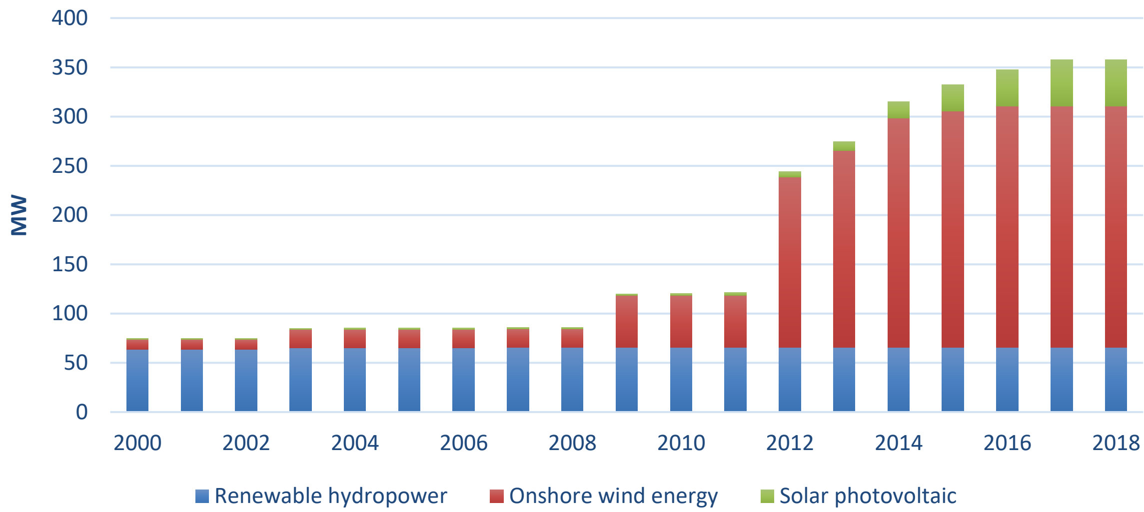
The largest RES share in 2018 (68.49 percent) was attributed to onshore wind power with 245 MW. Hydropower and solar PV were the other two RES technologies with 18.34 percent and 13.17 percent share of the RES installed capacity. The aggregated cumulative capacities can be seen in Table 18 and Figure 35.

Table 18. Renewable sources installed capacity (2018) in Tunisia

Technology	Installed capacity (MW)	% of total RES
Onshore wind	245	68.49%
Hydropower	66	18.34%
Solar photovoltaic	47	13.17%

Source: Self-compilation with data from IRENA (n.d.).

Figure 14. Installed capacity of renewable energy sources – Tunisia



Source: Data from IRENA (n.d.).

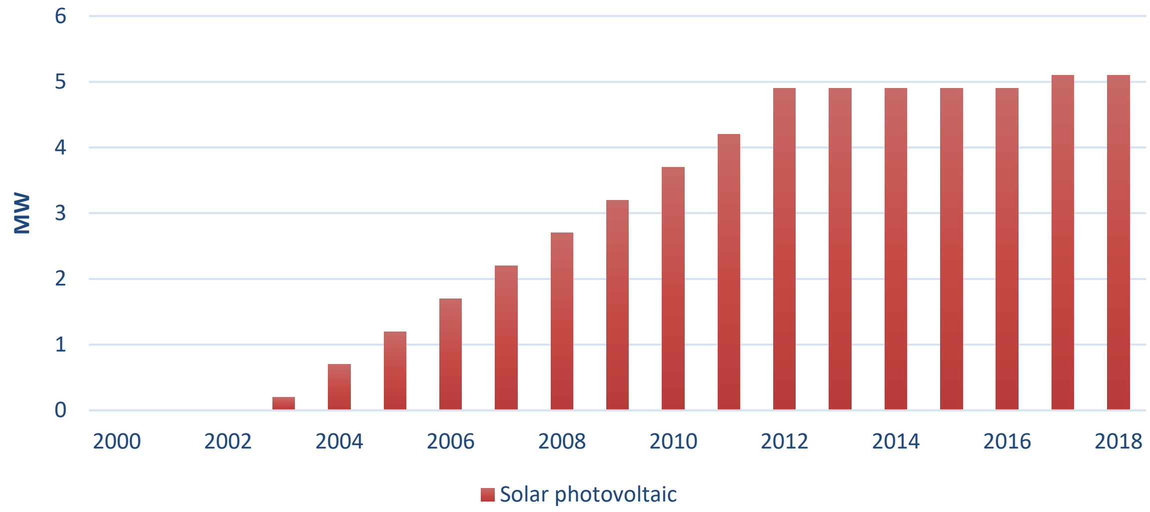
Libya has only 5 MW of renewable electricity generation capacity, all from solar PV, which has remained constant since 2012. The aggregated cumulative capacities can be seen in Table 19 and Figure 36

Table 19. Renewable sources installed capacity (2018) in Libya

Technology	Installed capacity	% of total RES
Solar photovoltaic	5 MW	100%

Source: Self-compilation with data from IRENA (n.d.).

Figure 15. Installed capacity of renewable energy sources – Libya



Source: Data from IRENA (n.d.).

1.6.7 Future electricity demand and national plans

ALGERIA

Projected electricity demand in Algeria

Sonelgaz, the **Algerian** utility company in charge of electricity and gas distribution, has prepared two electricity demand scenarios (medium and high growth) for 2025. In the medium demand scenario, electricity demand increases by 77 percent by 2025 (from 2015 levels), whereas in the high scenario demand increases by 120 percent. The maximum expected peak load is around 76 percent more in the medium scenario and more than double in the high scenario compared to 2015 levels (Table 20).

Table 20. Algerian electricity demand 2014–2025

	Medium scenario		High scenario Errore. Il segnalibro non è definito.	
Year	**Maximum peak load (MW)**	**Electricity demand (TWh)**	**Maximum peak load (MW)**	**Electricity demand (TWh)**
2015	12,355	63.047	13,060	66.619
2025	21,839	111.504	28,815	146.843

Source: Sonelgaz (2015).

To cope with the increasing demand, Algeria has plans to install new capacity, both for conventional and RES generation in the upcoming decade. According to Sonelgaz, in the period 2020–2025, new conventional generation capacity of 12,415 MW will be installed.[43] As for RES, revised targets were set in the Renewable Energy and Energy Efficiency Development Plan 2015–2030.

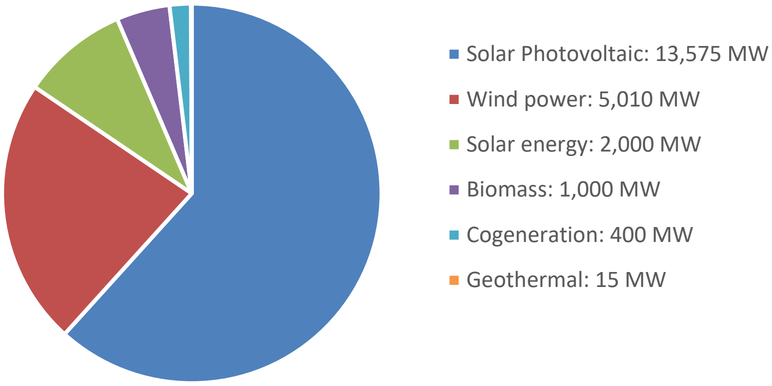
[43] Sonelgaz (2015).

Renewable Energy and Energy Efficiency Development Plan 2015–2030

This is a review and update of the Renewable Energy and Energy Efficiency Development Plan 2011–2030, with the goal of increasing the share of RES and to diversify the energy sources in the country. The plan focuses on large-scale solar PV and onshore wind installations. It also introduces some biomass, cogeneration and geothermal energy by 2020. But on the other side, the CSP plans are delayed due to the high technology costs.[44]

In total, the plan aims to install 4,500 MW of new RES capacity by 2020 and a total of 22,000 MW by 2030. By 2020, the government plans to install 800 MW of solar PV, 1,200 MW of CSP and 1,700 MW of wind power.[45]

Figure 16. New RES capacity by 2030



Source: Algerian Renewable Energy Development Centre (2015).

The revised target for 2030 contains the following capacity goals by technology (see Figure 37): 13,575 MW of solar PV, 5,010 MW of wind power, 2,000 MW of CSP, 1,000 MW of biomass, 400 MW of cogeneration, and 15 MW of geothermal energy.[46]

This update of the plan sets more ambitious targets, with larger installed capacities for different technologies and increasing the share of RES in the total power generation goal from 20 percent to 27 percent by 2030. In addition, it aims to increase energy efficiency by improving heat insulation of buildings, which could decrease the energy consumption related with home cooling by 40 percent, developing solar water heating, and promoting cogeneration and combined cycle power plants, among other actions[47].

If the suggested targets are achieved, RES would account for 27 percent of Algeria's total power generation, with savings in natural gas consumption and the consequent CO_2 emissions reduction. The National Fund for Renewable Energies and Cogeneration (FNERC) will support the implementation of the plan.

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[44] IEA and IRENA (2016b).
[45] IEA and IRENA (2011).
[46] IEA and IRENA (2016b).
[47] IEA and IRENA (2016b).

Feed-in tariff for solar PV installation

A feed-in tariff scheme for solar PV installations was introduced in April 2014 with the aim of encouraging the investment in this technology. However, this programme is only applicable for plants with a capacity of 1 MW or larger and it distinguishes between plants under or over 5 MW. The different feed-in tariff levels defined by the government can be found in the policy document.[48]

TUNISIA

Projected electricity demand

STEG expects electricity demand in 2031 to be double of that in 2011. The maximum expected peak load will be slightly lower than double (Table 21).

Table 21. Tunisian electricity demand 2011–2031

Year	Maximum peak load (MW)	Electricity demand (TWh)
2011	3,010	15.43
2013	3,144	17.064
2016	3,766	19.952
2021	4,472	23.515
2026	5,091	27.158
2031	5,687	30.862

Source: STEG (2014).

National energy targets and plans

The Government of Tunisia is planning to increase the share of RES in the electricity generation mix of the country in the upcoming decades, however thermal power is expected to remain the dominant power source. To cope with the growth of demand, more thermal power will need to be installed, and natural gas will still dominate heavily. It is expected that by 2030, thermal power will supply 70 percent of the electricity demand in the country.

On the other hand, Tunisia is already trying to increase the share of RES on the consumption side. The government set the target to generate 11 percent of the total electricity production from RES by 2016, and up to 25 percent by 2030.[49] In 2012, this target was modified as a result of the approval of the Tunisia Solar Plan (TSP), which allows for an increase in the amount of RES to 30 percent by 2030, with wind power accounting for 15 percent of the total electricity production, PV 10 percent and CSP 5 percent.[50] To accomplish this, Tunisia plans to launch tenders for about 3,500 MW of RES worth roughly USD 3.5 billion by 2030, which translates to approximately 350 MW per year over the next 10 years. One third of the capacity will be allocated to wind farms and two thirds for solar PV.[51]

Moreover, some hydro power is expected to be installed as well, as there are plans for a 400 MW pumped hydro storage (PHS) project that will be installed in 2020 in the Oued el Melah.

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[48] IEA and IRENA (2014).

[49] EIA (2014).

[50] Cherif (2016).

[51] International Trade Administration (2019).

Tunisia also aims at increasing the energy efficiency by 2020 to reduce the electricity demand by 1.4 percent per year compared to the consumption without measures or action being taken in this field.

New national transmission lines are also planned, which will aim at transmitting the power generated by RES in the south, to the bulk of energy demand in the north.[52] Some of the transmission lines planned for 2023 and associated solar PV plants are presented in Table 22.

Table 22. Transmission lines and private solar power plants to be constructed by year 2023

Location	Technology	Capacity of plant (MW)	Length of line (km)
Metbasta (Kairouan)	PV	100	8
Mezzouna 2 (Sidi Bouzid)	PV	50	1.5
Sagdoud (Gafsa)	PV	100	30
Tozeur 2 (Tozeur)	PV	50	2.5
Borj Bourguiba (Tataouine)	PV	200	100

Feed-in tariffs for selling electricity from RES to STEG

In 2009, Tunisia issued a decree setting the rules for governing the sale of renewable electricity to STEG. The rules allowed actors from the industry, agriculture and commercial sectors that self-generate electricity from RES, to sell the surplus to STEG (up to 30 percent of the annual electricity production of the country). The value of the feed-in tariff is decided by the Ministry of Energy and the renewable electricity producers cover the cost of connection to the grid.[53]

Libya

Projected electricity demand

Due to political instability in Libya, there is no clear picture of how the electricity demand will behave in the upcoming years. However, it can be argued that if a political stability is reached, the country could experience a growth in electricity demand driven by urbanisation, economic growth, population growth, industrialisation and building of new infrastructure.[54] This is backed up by an estimated electricity demand growth rate in the range of 7 percent to 13 percent.[55]

National energy targets and plans

Libya, as one of the main oil producers worldwide, will most probably keep using oil and gas as main fuel sources for electricity production. Nevertheless, the country has plans to develop its RES sector and increase the share of RES in the power generation system.

[52] World Bank (2019).

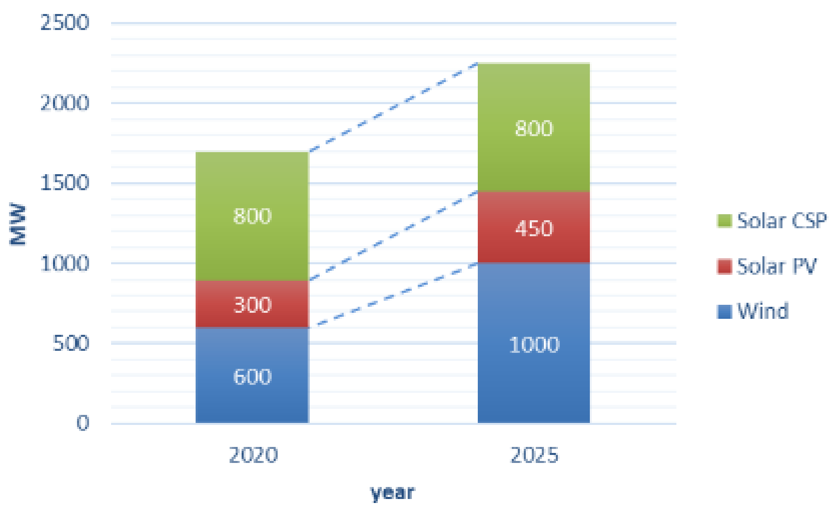
[53] IEA and IRENA (2009).

[54] Al-Hashmi et al. (2017).

[55] IEA (2016c).

The targets were set by the Libya Renewable Energy Strategic Plan 2013–2025, choosing wind and solar energy as the RES to implement, due to the high potential both resources have in the country. In brief, the targets set to the years 2020 and 2025 are 7 percent and 10 percent share of RES in the electricity energy mix, respectively.[56] The disaggregation of the capacity by technology for the goals is presented in Figure 38.

Figure 17. Libya RES capacity goals for years



Source: IEA and IRENA (2016a).

[56] IEA and IRENA (2016a).

1.7 Environment and ecosystem services

1.7.1 Biogeographic characteristics of the NWSAS

The NWSAS area of influence includes several natural ecosystems (*garâas* (marshes), sebkhas, chotts, etc.)[57] and artificial ecosystems (oases, etc.)[58] in various biogeographic areas. These areas can be divided into the following four zones:

- the coastal belt along the Mediterranean Sea, to the south of which the Djeffara plain extends
- the *jebels* (or mountains), generally rocky and stony, and frequently intercepted by several *wadis*
- the semi-desert zones, representing the transition zone between the *jebels* and the desert zone
- the desert, composed of sand dunes, barren hills and gravelly plains.

1.7.2 NWSAS ecosystems and habitats

1.7.2.1 National-level ecosystems of the three countries

The three countries that share the NWSAS are rich in biological diversity. This is due to a combination of factors: their geographical position, their immense bioclimatic diversity, their geology and their landforms. This geological and bioclimatic diversity overlaps with great bio-ecological diversity.

In Algeria, there are six different types of ecosystem:[59,60]

- Saharan ecosystems account for 85 percent of Algeria's surface area
- steppes account for 10 percent of the total area
- mountain ecosystems account for 3.66 percent of the total area
- forests account for 1.7 percent of the total area
- marine and coastal ecosystems account for 1 percent of the total area
- and lastly, wetland ecosystems account for 0.07 percent of the total area.

The most degraded ecosystems are coastal, forest, wetland and steppe ecosystems.[61] It is estimated that since 1989, the vegetation of the natural steppe has decreased by 50 percent.[62] The pressures on these ecosystems are the result of overexploitation and pollution.

In Tunisia, the most important ecosystems are:

- mountain and forest ecosystems, which account for 13 percent of the total area and are mainly concentrated in the Tell mountain ranges and the northern Dorsal mountains
- steppes, which stretch across the central and southern parts of the country[63]
- the oasis ecosystem, located in the south and covering an area of about 40,803 ha
- wetlands, accounting for 5 percent of the total area,[64] including sebkhas which are the most widespread

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[57] See definition under "Ecosystems".

[58] See definition under "Ecosystems".

[59] Ministry of Land-use Planning and the Environment (2010)

[60] Convention on Biological Diversity (n.d. a).

[61] Convention on Biological Diversity (n.d. a).

[62] Convention on Biological Diversity (n.d. a).

[63] Convention on Biological Diversity (n.d. b).

[64] Ministry of Environment of Tunisia (2015).

- and desert ecosystems, which account for about 40 percent of the total area.

Overexploitation of pastures, steppes and forests, drought, desertification, erosion and climate change pose a threat to Tunisian ecosystems. Land clearing and overgrazing have led to soil erosion, degradation of vegetation cover and increasing desertification.[65] The loss of agricultural land due to desertification is estimated at 20,000 ha per year.[66]

Libya has many ecosystems, ranging from the coastal environment to the green plains of the northeast and the highlands of the northwest, as well as desert and semi-desert ecosystems with oases and valleys. Three areas rich in biodiversity account for more than 75 percent of species diversity: Jebel Nafusah, Jebel Tibesti and Jebel Akhdhar, located in the province of Cyrenaica.[67] Most of the surface area is desert or semi-desert. Only some coastal areas have extensive vegetation, while inland vegetation is concentrated only in oases.

Essentially, there are four ecosystems in Libya:[68]

- coastal and marine ecosystems, which can extend over 120 km in the west of the country in the Djeffara plain
- the mountain ecosystems, consisting of two main mountainous areas: Jebel Nafusah in the northwest and Jebel Akhdhar in the northeast, as well as other mountains, including the Haruj, Laouinet and Akakaws
- semi-desert ecosystems, located south of the mountains and representing the main grazing area
- and lastly, desert ecosystems, which comprise most of the country, where the desert is sandy, stony or volcanic. Given the lack of rainfall, biodiversity is mainly concentrated in the oases that make up this ecosystem.

1.7.2.2 NWSAS ecosystems

The NWSAS region includes ecosystems that are very rich in flora and fauna. It includes a total of 19 ecosystems and seven wetlands classified as Ramsar sites.[69] Ecosystems are generally divided into three broad categories: agrosystems, wetlands and pastoral ecosystems.

Agrosystems: These systems include oases and dryland agriculture. They are mainly coastal and based on olive cultivation, and are irrigated by deep water from aquifers. These agrosystems differ considerably depending on the area and country in which they are located.[70]

Oases are areas with strong agricultural and pastoral activities based on rational exploitation of groundwater, equitably distributed among the indigenous people. The oasis ecosystem is crucial for the inhabitants of these environments, where rainfall is generally less than 10 mm/year. In addition to the date palm, which is the main species and resource, there are several plant species of pastoral and medicinal interest. Fauna is abundant and very varied, and includes endangered species such as the fennec fox,

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65 Food and Agriculture Organization of the United Nations (FAO) (2019).

66 Ministry of Environment of Tunisia (2012).

67 Gawhari et al. (2018).

68 Convention on Biological Diversity (n.d. c).

69 AbuZeid, Elrawady and CEDARE (2015).

70 GWP-Med (2015).

gazelle and desert monitor lizard. Oases are also considered as wetlands, and are wintering and nesting sites for a significant population of avifauna.[71]

Wetlands: Extremely vulnerable and fragile, while subject to considerable human pressure, the Sahara's wetlands comprise wetlands and natural bodies of water, divided into *garâas*, sebkhas, chotts, and bodies of water:[72]

- *Garâas*: *Garâa* is a term specific to the Saharan zone. It refers to small bodies of water (water marshes), of natural or anthropogenic origin, with relatively small surface areas, where the water is stagnant and shallow in depressions. *Garâas* are typical examples of a classic natural wetland in North Africa; they are usually temporary and often derived from freshwater sources.[73]

- Sebkhas: These are shallow depressions containing saline water, which only dry up during strong heat waves. They have a smaller surface area than chotts. Sebkhas are located above sea level. They serve as outflows that drain water from a section of the water table and from *wadi* flooding.[74]

- Chotts: These are depressions found in the shallows of endorheic basins. They are only a few metres deep during the winter period and decrease sharply in depth during the dry period. Chotts are located below sea level. The water is saline and comes from the drainage of irrigation water from palm groves, as well as from aquifers that may rise to the surface in places.[75] The chott is a suitable habitat for transcontinental avifauna, both sedentary and transhumant. It is also an important source of food for fauna and a spawning ground and nursery.

- Water bodies: located in closed basins, they are generally fed by the drainage water from palm groves, which is itself drawn from deep water tables. The water quality of these bodies is fresh to slightly saline. They contain less significant fauna and flora, but are still considered as transit points for avifauna.

Wetlands are vulnerable ecosystems. These are living environments, with a microclimate that favours biodiversity, in an arid and xeric Sahara. Wetlands are a habitat favoured by avifauna migrating from the Mediterranean to the Sahara, especially in winter.

Pastoral ecosystems: These include steppes and desert as well as ergs (a depositional environment comprising sand dunes) and regs (an erosional environment with a stony surface). They range from degraded forest formations to near-desert environments. Usually, pastoral ecosystems are located in places that are more suitable for agriculture and are therefore at risk of being converted to cropland.[76]

1.7.2.3 Habitats in the NWSAS

The habitats most equipped to support fauna and flora in the NWSAS area of influence are mainly *wadis*, dry valleys, dune habitats (ergs), stony plateaus (regs), clusters of *jebels*, rocky outcrops and mountain

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[71] OSS (2005).
[72] GWP-Med (2015).
[73] OSS (2005).
[74] OSS (2005).
[75] OSS (2005).
[76] GWP-Med (2015).

ranges, *halipedes* (green steppic areas around chotts and sebkhas) , the banks of chotts and sebkhas (or coastlines), reedbeds (common reeds, reedmace, bulrushes and rushes), wet grasslands used as grazing areas, palm groves, wetland formations with purely aquatic vegetation, islets, *seguias* (open-air channels), small irrigation channels, the water network and accumulation basins.

1.7.3 Biodiversity and important species in the NWSAS

Biological diversity in the NWSAS area of influence is marked by different plant species and the migration of several wildlife species (water birds), especially in winter.

1.7.3.1 NWSAS flora

The flora differs depending on whether the wetland area is freshwater (oasis) or saltwater (chotts, sebkhas). Wetlands adjacent to oases are rich in aquatic plants, while the flora surrounding chotts and sebkhas mainly consists of saltwort. The soils are not very evolved or halomorphic; they are most often represented by hyper-halophiles or gypsisol-psammophiles on crypto-solonchaks.

The distribution of flora is conditioned by the hydrophilicity and salinity of the soil. Nevertheless, it remains very little studied and little recorded. A list of plant species in the NWSAS region can be found in Annex 1.

1.7.3.2 NWSAS fauna

The NWSAS region is very rich in fauna, despite its arid and hostile environment. Migratory birds (ducks, coots, shorebirds, flamingos, passerines, etc.) and sedentary birds (such as the Houbara bustard, which is representative of the region) are the most important. In fact, it is a favourable environment for migratory wildlife in the autumn and winter. A list of bird species in the NWSAS region can be found in Annex 2.

The NWSAS region is the favoured site for certain endangered species (fennec foxes and gazelles). However, mammals (jackals, foxes, rodents, etc.) and reptiles also find the environment conducive to their development. Little is known about the invertebrates in these areas and the fauna in general remains largely unresearched. Similarly, little is known about the ichthyofauna (fish), herpetofauna (reptiles and amphibians) and entomofauna (insect life). A list of wildlife species in the NWSAS region (amphibians, mammals, fish and reptiles) can be found in Annex 3.

1.7.4 NWSAS protected areas

Protected areas are defined as any recognised geographical area, managed by any means and whose main purpose is the conservation of biological diversity, an ecosystem or an element of fauna, flora or landscape.[77]

Africa's protected areas contain a wide range of plant and animal biodiversity, including rare or endemic species, as well as a wide variety of ecosystems. Unfortunately, protected areas, and the associated ecosystem services they provide, are facing increasing pressures, such as illegal hunting, overexploitation and climate change, among others.[78]

Algeria has 24 protected areas, covering an area of nearly 86,593,065 ha, or 36.5 percent of the national territory. These classified areas are spread throughout the country. They are mainly national parks, biosphere reserves, nature reserves and sanctuaries. These include ten national parks, covering an area of

[77] Abid (2013).
[78] International Union for Conservation of Nature (IUCN) (n.d.).

56,565,361 ha, or 23.8 percent of the national territory; five nature reserves, covering almost 39,484 ha; four reserves with an area of 50,700 ha;[79] and 50 wetlands of international importance (Ramsar).

In Tunisia, protecting ecosystems from further degradation is of great importance. This is reflected in the country's actions to progressively implement a policy of safeguarding and conservation of its natural resources through the creation of protected areas, allowing the preservation of certain natural sites of high environmental value and fragile ecosystems. In 2018, Tunisia had[80] 17 national parks, with a total area of 541,105 ha; 27 nature reserves, with an area of 92,186 ha; four wildlife reserves and 41 wetlands of international importance (Ramsar).

Libya has the following protected areas[81,82]: 7 national parks, 5 nature reserves, 26 other protected areas and 2 wetlands of international importance (Ramsar).

1.7.4.1 National parks in the NWSAS

A national park is a relatively large area of land comprising one or more ecosystems that are generally little or unaltered by human use and occupation, where plant and animal species, geomorphological sites and habitats are of special scientific, educational and recreational interest, or where there are natural landscapes of high aesthetic value[83]. Table 23 lists the different national parks in the NWSAS region.

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[79] Argeliamanece, n.d.

[80] Ministry of Environment of Tunisia (2015).

[81] Khatabi (1993).

[82] Goodland (2013).

[83] Chapter III of the Tunisian Forestry Code, Law No. 88-20 of 13 April 1988.

Table 23. National parks in the NWSAS region (Tunisia and Libya)

National park	Year established	Area (ha)	Governorate/Wilaya
Tunisia			
Jbil	1994	150,000	Kebili
Dghoumès	2010	8,000	Tozeur
Sidi Toui	2010	6,315	Médenine
Senghar-Jabess	2010	2,870	Tataouine
Libya			
Abughilan		4,500	60 km south of Tripoli
El Kauf			Jebel Akhdhar
Karabolli			
Kouf		8,000	1,200 km east of Tripoli
Naggaza			
Rajma		1,450	
Sirman			51 km west of Tripoli

1.7.4.2 Nature reserves in the NWSAS

A nature reserve is a small site aimed at maintaining the existence of individual species or groups of natural species, animals or plants and their habitats, as well as conserving migratory wildlife species of national or global importance.[84] Table 24 gives the different nature reserves in the NWSAS region.

Table 24. Nature reserves in the NWSAS region of Tunisia and Libya

Nature reserve	Year established	Area (ha)	Governorate/Wilaya
Tunisia			
Khechem el Kelb	1993	307	Kasserine
Ettella	1993	96	Kasserine

[84] Chapter III of the Tunisian Forestry Code, Law No. 88-20 of 13 April 1988.

Dkouk Wadi	2009	5,750	Tataouine
Gabès Wadi catchment area	2010	523	Gabès
Libya			
Bir Ayad		12,000	150 km southwest of Tripoli
New Hiesha Natural Reserve		100,000	300 km east of Tripoli
Tripoli			
Zellaf			

1.7.4.3 Ramsar sites in the NWSAS

Signed in February 1971, the Ramsar Convention provides a specific framework for international cooperation on the conservation and sustainable use of wetlands and their resources.

The Ramsar Convention has adopted a broad definition of wetlands to include all lakes and rivers, underground aquifers, swamps and marshes, wet grasslands, peatlands, oases, estuaries, deltas and intertidal areas, mangroves and other coastal areas, coral reefs, and all artificial sites such as fish ponds, rice paddies, reservoirs and salt marshes.[85] Some 30 sites are classified as Ramsar sites in the NWSAS basin (8 in Algeria, 20 in Tunisia and 2 in Libya). A list of the different Ramsar sites in the NWSAS region can be found in Annex 4.

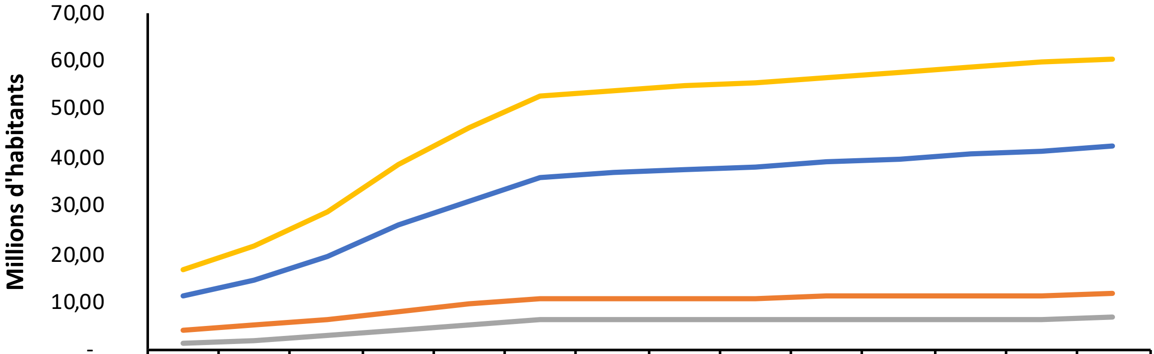
[85] https://www.ramsar.org/.

2. Socioeconomic situation and main resource uses in the NWSAS

2.1 Population

According to the World Bank database, the total population of the three NWSAS countries (Algeria, Libya and Tunisia) has almost quadrupled in 60 years. It has grown from 17 million people in 1960 to over 60 million in 2018. The distribution of the population between the three countries shows that Algeria is the most populous, with 70 percent of the total population, followed by Tunisia with 19 percent and, finally, Libya with 11 percent (see Figure 39).

Figure 39. Population trends in the three NWSAS countries



	1960	1970	1980	1990	2000	2010	2011	2012	2013	2014	2015	2016	2017	2018
Algérie	11,06	14,46	19,22	25,76	31,04	35,98	36,66	37,38	38,14	38,92	39,73	40,55	41,39	42,23
Tunisie	4,18	5,06	6,37	8,24	9,71	10,64	10,74	10,85	10,95	11,06	11,18	11,30	11,43	11,57
Libye	1,45	2,13	3,22	4,44	5,36	6,20	6,25	6,29	6,32	6,36	6,42	6,49	6,58	6,68
Total	16,68	21,66	28,82	38,44	46,11	52,81	53,65	54,52	55,41	56,35	57,33	58,35	59,40	60,47

Source: World Bank (n.d. a).

According to the data available in 2018,[86] population density per country varied between 4 inhabitants/km^2 (in Libya) and 74 inhabitants/km^2 (in Tunisia). Algeria, for its part, had 18 inhabitants/km^2. The population living in the main areas of the NWSAS accounts for 8 percent of the national population in Algeria, 12 percent in Tunisia and 19 percent in Libya (see Table 25).

[86] World Bank (n.d. b).

Table 25. Distribution of population in the NWSAS region in 2000

	Algeria	Tunisia	Libya	Total
Basin population	2,600,000	1,000,000	1,200,000	4,800,000
Total country population	39,666,519	11,107,800	6,278,438	57,852,757
Population of the NWSAS basin as a proportion of each country's total population	7%	9%	19%	8%
Population of the basin as a proportion of the total population of the three countries in the basin	54%	21%	25%	100%

Source: GWP-Med et al. (2015).

Forecast changes in population by country and within the NWSAS are given in the table below. It should be noted in this regard that the population will likely reach 88 million by 2050, an increase of more than 80 percent.

Table 26. Demographic projection of NWSAS population by country

	2000	2020	2050
Algeria	2.6	3.7	4.8
Libya	1	1.8	2.3
Tunisia	1.2	1.5	1.7
Basin total	4.8	7.0	8.8

Source: OSS (2014), p. 15.

Population density also varies greatly from one governorate/wilaya to another (see Table 27). The highest density is recorded in Gabès (Tunisia) with 51 inhabitants/km^2 and the lowest in Adrar (Algeria) with 1 inhabitant/km^2. This can be explained by the size of the Saharan zones compared with the coastal zones, and particularly in relation to coastal towns, which have high rates of concentration. In Algeria, the difference between the national density and that of its NWSAS region is also linked to the country's size.

Table 27. Population and population density in the main areas of the NWSAS region in Algeria and Tunisia

Pays	Gouvernorat/Wilaya	Population (2010-2011)	Superficie (Km²)	Densité (habitants/Km²)
Algérie	Biskra	775 797	21 671	36
	El Oued	558 563	45 163	12
	Adrar	406 318	427 368	1
	Ouargla	558 563	211 980	3
	Ghardaia	363 598	86 105	4
	Total	**2 662 839**	**792 287**	**3**
Tunisie	Tataouine	149 200	38 889	4
	Médenine	462 700	9 167	50
	Gabès	368 500	7 166	51
	Kébili	152 900	22 454	7
	Tozeur	105 500	5 593	19
	Gafsa	343 700	7 807	44
	Total	**1 582 500**	**91 076**	**17**

Source: GWP-Med et al. (2015). Data not available for Libya.

2.2 Institutions and households

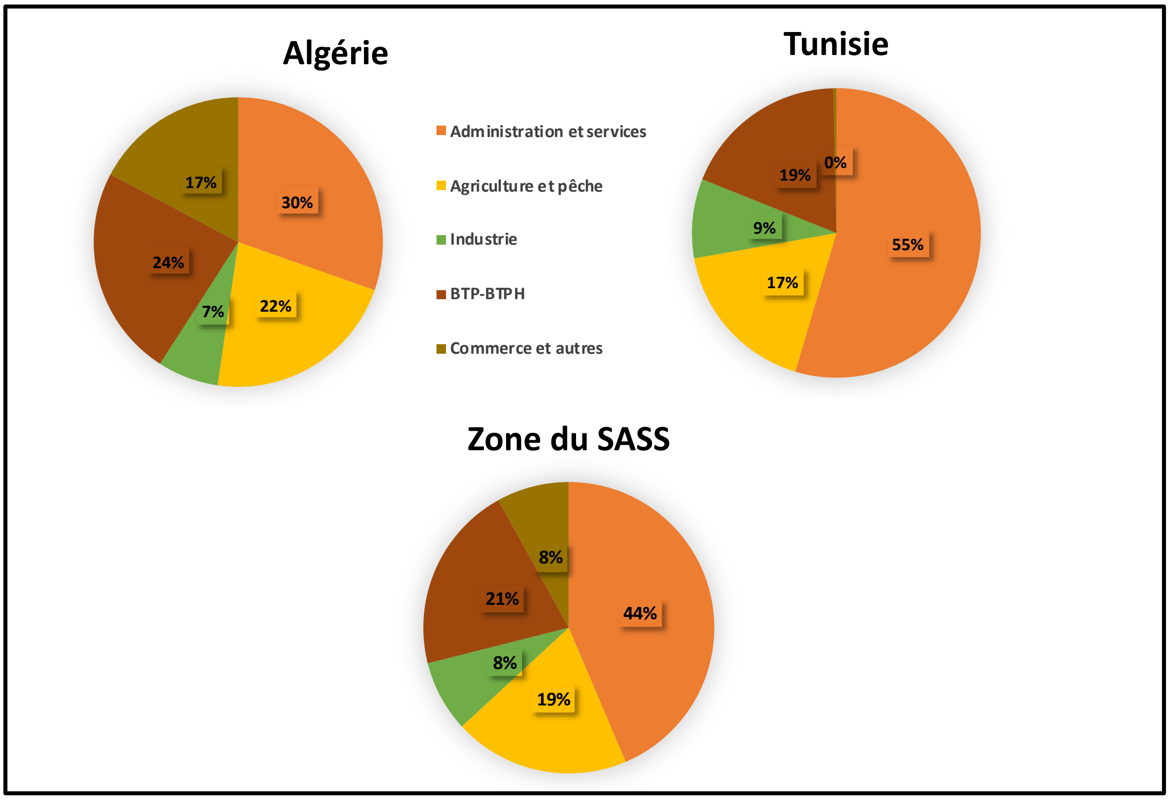
Population growth in the NWSAS region is being accompanied by considerable urbanisation. In Tunisia, for example, the average urbanisation rate in the five governorates of the NWSAS region is around 68 percent.[87] This is comparable in the main NWSAS regions of Algeria (Biskra, El Oued, Adrar, Ouargla, Ghardaïa). This strong urbanisation can best be seen in the wilaya of Ghardaïa in the number and size of urban communes, i.e. eight (64,426 km^2) out of a total of 13 (85,560 km^2) communes, meaning 75 percent of the wilaya's area is therefore urban (DSA, 2018a). According to the OSS (2008), 73 percent of the population of these regions will be living in urban areas by 2030. This projected population will result in increasing demand for domestic water.

The working population of Tunisia and Algeria, countries that account for 89 percent of activity in the NWSAS region (see Figure 40), is largely concentrated in the service sectors (public and private), in construction, public works and hydraulics, and in agriculture. In these two countries, 84 percent of the working population in the NWSAS region is employed in one of these three sectors.

The agricultural sector ranks second in Algeria, employing 22 percent of the working population, and third in Tunisia, with 17 percent of the working population. With 21 percent of the working population, the construction, public works and hydraulics sector is the second largest employer in the NWSAS region (mainly in Algeria).

[87] ODS (2018).

Figure 40. Breakdown of the working population by sector in the NWSAS regions of Algeria and Tunisia



Sources: Agence Nationale d'Intermédiation et de Régulation Foncière [National Agency for Land Regulation and Intermediation – ANIREF] (2013); Directorate of Agriculture Services (DSA) (2018); ODS (2018). Data not available for Libya.

2.3 Sectoral water use in the NWSAS

Overall demand for water has been steadily increasing over the last few decades in all three countries of the NWSAS region. This growing demand for water is resulting in increased groundwater abstraction. Abstraction therefore increased from 0.3 billion m^3/year in 1950 to 3 billion m^3/year in 2019, and has resulted in resource overexploitation since the 1980s, with an estimated 1 billion m^3 more water being withdrawn every year than is being recharged.

The sectoral allocation of water in 2010 in the NWSAS[88] region shows that agriculture is the sector most dependent on groundwater in the three countries, accounting for 67 percent in Algeria, 82.8 percent in Libya and 95 percent in Tunisia. Domestic water (drinking water and water for the tourism sector) comes second with 21 percent in Algeria, 11 percent in Libya and 3 percent in Tunisia, while water used by the industrial sector represents only around 11.5 percent, 1 percent and 2 percent in the three countries respectively.

According to the projected trends emerging from the Water, Climate and Development Programme for Africa (WACDEP) study, this allocation of NWSAS water use by sector is likely to remain the same for the next ten years, with slightly different percentages reflecting the level of sectoral development by country. Table 28 shows these changes in sectoral needs to 2030.

[88] GWP-Med et al. (2015).

Table 28. Trend in the sectoral distribution of water needs by country and for the NWSAS region in m³/year

Besoins domestiques				
Années	**Algérie**	**Libye**	**Tunisie**	**Total SASS**
2000	483	57	9	549
2010	610	96	12	718
2020	756	128	15	899
2030	967	170	18	1154
Besoins industriels				
Années	**Algérie**	**Libye**	**Tunisie**	**Total SASS**
2000	280	5	10	295
2010	333	7	10	350
2020	387	9	10	406
2030	440	11	10	461
Besoins en eau d'irrigation				
Années	**Algérie**	**Libye**	**Tunisie**	**Total SASS**
2000	698	540	448	1686
2010	1943	716	448	3170
2020	2746	1087	406	4239
2030	3702	1261	487	5450
Besoins totaux en eau				
Années	**Algérie**	**Libye**	**Tunisie**	**Total SASS**
2000	2207	602	469	2676
2010	2886		470	4175
2020	3942	1087	406	5435
2030	5109	1442	515	7066

Source: GWP-Med et al. (2015).

2.4 Agriculture

The irrigated area of the NWSAS region in the three countries is estimated at some 170,000 ha in Algeria and 40,000 ha in both Libya and Tunisia. The average irrigated area per farmer in the NWSAS region is around 4.2 ha. This is largest in Libya, with an average of 6 ha, followed by Algeria with 5.1 ha. Landholding is more fragmented in Tunisia, with an average of 1.8 ha per farmer, which is much lower than the average for the NWSAS region. There is more significant livestock integration in Libya, with the activity representing 27.9 percent of the farmers' total agricultural income. Revenue from livestock farming in Tunisia is less than 10 percent, well below the average of 17.72 percent for the region (see following table).

Table 29. Average irrigated area per farm in the NWSAS region and significance of livestock as a percentage of agricultural income

	NWSAS average	Access to water			Algeria	Libya	Tunisia
		Private	Collective	Free			
Average irrigated area (ha)	4.2	6	2.6	0.85	5.1	6	1.8
Significance of livestock (% of agricultural income)	17.72	19.7	12.94	30.85	14.9	27.9	9.4

Source: OSS (2015).

Irrigation methods vary but the traditional gravity-fed technique is mostly found in the oases. Submersion irrigation is also used, as well as sprinkler or pivot irrigation for cereal crops. More recently, localised irrigation and drip systems, particularly in greenhouses, have been introduced.

2.4.1 Main agrarian systems, methods of access and patterns of water use

2.4.1.1 Algerian agrosystems

In the Saharan regions, two different agrarian systems are mainly used for agriculture:[89]

- ***Traditional oases,*** focused mainly on subsistence agriculture with a three-tier agricultural system (palm trees, fruit trees and annual crops). Family livestock farming is also widespread with herds of small animals. The palm groves have local varieties of palm, high tree density, an asymmetrical arrangement and trees with a highly heterogeneous age structure. The private gardens are divided into extremely small plots (less than 1 ha), reflecting social practices associated with heritage. These oases are irrigated using traditional *seguia* methods (open-air irrigation channels). Different forms of traditional water mobilisation in the Sahara and their spatial distribution have, however, shaped different agrarian structures in the oases. There are four types of oasis agrosystem in Algeria, depending on the water resource mobilised:[90]

- oases located in the erg depressions, where irrigation water is abstracted from the water table by means of wells and boreholes (Ouargla Oasis)

- oases located in Ghouts, where irrigation water is drawn by capillary action (El Oued Oasis)

- river oases, supplied with water from the wadis (Sidi Okba Oasis in Biksra, M'zab in Ghardaïa)

- depression oases, supplied with water by the *foggaras* (Taouat, Gourara and Tidikelt Oasis in Adrar).

Oases are experiencing strong urbanisation, with several negative impacts such as the fragmentation of garden plots, loss of agricultural land, pollution and rising water tables caused by a lack of and/or failure in the drainage network, etc.

- Created largely within the context of agricultural land reclamation and various development programmes***, the new agricultural plots*** are based solely on an individual use of groundwater resources. A recent study conducted in the Biskra region showed that 95 percent of the agricultural boreholes in El Ghrouss

[89] Amichi (2019); Bisson (1991); Hamamouche (2017); Hamamouche et al. (2015); Hamamouche et al. (2018); Khene (2013).

[90] Kouzmine (2012).

commune and part of El Doucen (1,320 boreholes) are connected to the power grid.[91] These boreholes have thus made it possible to irrigate 470 ha of greenhouses and 4,800 ha of palm groves.[92]

Two agricultural models can be distinguished within these new developments:

- Considered an extension of the agricultural oases, the first 'pre-urban agriculture' model is found mainly around the edges of former oases. This form of agriculture is largely practised by small-scale farmers. These new lands were, for the most part, informally taken by oasis dwellers from the 1960s onwards. This land was subsequently formally recognised under the Accessing Agricultural Land Ownership (APFA) programme. At the same time, agrarian programmes (APFA and concessions) have encouraged the expansion of the agricultural area towards *ksours* (fortified village) and former palm groves. Farms are small (1–3 ha) but now more structured. This form of agriculture is diversified, relatively semi-intensive and therefore more profitable. The basic crop grown is the date palm.
- The second 'intensive agriculture' model is found largely in reclaimed agricultural plots. These plots were created in locations far removed from urban areas within the APFA framework in the 1980s and, later, as part of the concession programmes of the 1990s and 2000s. This agrarian system is the most widespread in the main areas of the NWSAS region. Its development has been made possible by the enormous land and water (deep groundwater) potential of the five wilayas in the NWSAS region. By way of illustration, data specific to the wilayas of El Oued and Adrar is given in Figure 41.

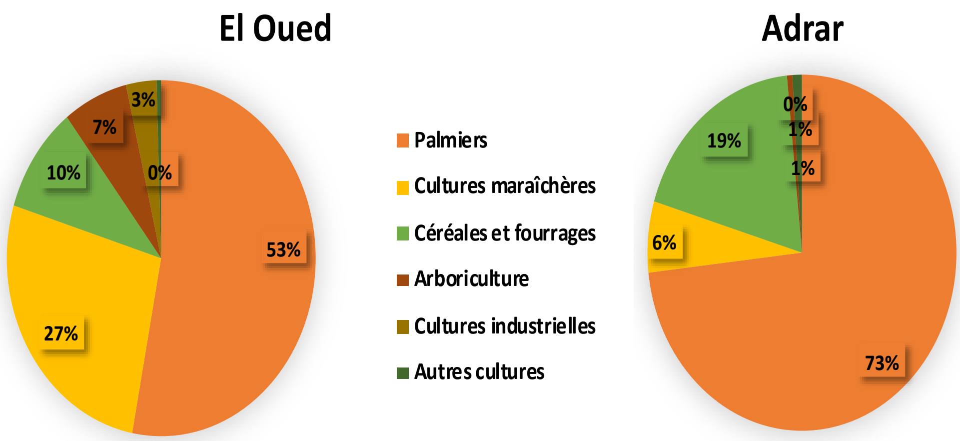
The development of new oasis agricultural areas has made it possible to extend the cultivated area of the Saharan regions by some 44,000 ha in the space of little more than a decade (1988–2002), a growth rate of 84 percent.[93]

[91] Amichi (2019); Amichi et al. (2019).

[92] Massuel et al. (2017).

[93] GWP-Med et al. (2015).

Figure 41. Main crops in the wilayas of El Oued and Adrar



El Oued	
Cultures	Superficie irriguée (ha)
Palmiers	25 962
Cultures maraîchères	13 120
Céréales et fourrages	4 783
Arboriculture	3 326
Cultures industrielles	1 560
Autres cultures	233
Total	48 984

Adrar	
Cultures	Superficie irriguée (ha)
Palmiers	29767
Cultures maraîchères	2622
Céréales et fourrages	7639
Arboriculture	230
Cultures industrielles	0
Autres cultures	401
Total	40 659

Source: Ministry of Water Resources (MRE) (2008).

Modern irrigation techniques are used in these areas. Irrigation pivots, fed by wells dug into the water table, currently represent the most typical form of land use in the Oued region. The pivots used on these 'circular' plots are modest in size (diameter ranging from 40 m to 100 m), manufactured locally using artisanal processes.[94] This form of pivot is widespread across almost all of the region's lands; there are estimated to be more than 12,000 irrigation pivots in total. Sprinkling is also used for cereal and fodder crops grown over small areas.

In the wilayas of Adrar and Biskra, irrigation is largely individual, based on private access to groundwater and land. This accounts for 66 percent of the UAA of the Adrar wilaya (30,882 ha)[95] and 70 percent of the UAA of the Biskra wilaya (84,285 ha).[96] The remaining irrigated land is managed collectively by irrigation communities in former oases (21 percent of the collectively irrigated area) or directly by beneficiaries in areas cultivated as part of agricultural development programmes (9 percent of the area).
The assessment carried out by OSS in 2015 for better use of irrigation water in the NWSAS basin also made the following observations:[97]

- *When the cost of water is not borne by the farmer,* the price elasticity of demand for irrigation water is around 0.06, which shows that when the price of water increases by 100 percent, the

[94] GWP-Med et al. (2015); Rebai et al. (2017).
[95] MRE (2008b).
[96] Hamamouche et al. (2017).
[97] OSS (2015).

corresponding demand only shows an insignificant decrease of 6 percent. On the other hand, when the cost is directly borne by the irrigator and the price of water increases, their demand for water falls substantially (between 20 and 90 percent).

- *Water salinity*: the results obtained demonstrate the highly negative impact of water salinisation on the production of irrigated agriculture as well as on water productivity. Production would decrease by 150 percent with a 100 percent increase in the salinity of the water used.
- *Elasticity of the irrigated area*: if the irrigated area of a farm doubled, its production would fall by 15 percent. As the size of the farm increases, water productivity therefore decreases. This crucial point justifies an agrarian reform in favour of small farms.
- *Elasticity of agriculture without livestock farming.* The results obtained indicate that when the irrigator excludes livestock from their farm, the productivity of the allocated water drops by around 33 percent. This result perfectly illustrates the need to take into account livestock in these regions.
- *Impact of the farmer's availability*: when the farmer is involved in no activity other than agriculture, the productivity of the water resource increases by 22 percent.
- *The main determinants of irrigated agricultural production* in the Algerian NWSAS region are:
    - water input with an elasticity of around 0.54 (a 100 percent increase in water expenditure per hectare leads to a 54 percent increase in production) is a key variable in managing the resource in these poor regions
    - salinity with an elasticity of around -0.65 (a 100 percent increase in the salinity rate of the water resource would cause an overall 65 percent decrease in output).
- *Type of irrigation network* (free, collective, individual): in Algeria, when moving from free water to highly subsidised water (collective network) and then to a slightly subsidised water source (private sector), water productivity increases substantially.
- *In conclusion*: the parameters that have a significant and non-negligible impact on the economic productivity of water are:
    - the price of water
    - salinity
    - the size of the farm
    - family labour
    - the availability of the farmer for agricultural work
    - the importance of livestock farming in the farm's income.

Any economic policy that aims to improve the quality of current management of this precious resource in a highly unstable context with a view to ensuring its sustainability must explicitly incorporate all these key variables.

2.4.1.2 Tunisian agrosystems

The integrated agricultural area in the NWSAS region can be subdivided into four large and fairly homogeneous regions:[98]

- ***The Djeffara region,*** incorporating, in this context, the two governorates of Médenine and Tataouine. This region is steppe by nature, predominantly rangeland. The dominant form of agriculture is rather extensive and focused on arboriculture in *bour* areas (drylands), mainly olive trees. Irrigated agriculture is

[98] Ferchichi (2013); GIZ (2009); GWP-Med et al. (2015); OSS and Matoussi (2013).

a recent activity in this region, covering as yet modest areas of less than 10,000 ha in the two governorates. However, livestock farming is an age-old activity that remains important.

- ***The coastal oasis region*** largely relates to the Gabès Governorate. This highly dynamic region is undergoing significant structural changes. Agriculture, which used to be essentially based on arboriculture (palm and pomegranate) and practised on terraces in the former oases, is currently going through deep changes with the growth of intensive and semi-intensive agriculture outside the traditional oases. In this region, as in much of the Sahara, traditional oases, which used to be the main pillar of agricultural activity, are now declining in favour of modern agriculture outside oases. Coastal oases tend to have a relatively mild climate and high humidity. The date palm is a secondary crop (representing around 10 percent of the total), but it offers important protection from the sun's rays and heat, enabling a wide range of fruit and annual species to be grown. Sheep and goat rearing occurs on these oasis farms.

- ***The continental oasis region*** (governorates of Kebili and Tozeur). This region is primarily focused on oasis agriculture, with palm trees being the predominant crop. This region owes its existence to intensive irrigation based exclusively on the poorly renewable groundwater of the NWSAS. This is currently the region most threatened by overexploitation and therefore the most vulnerable to continued degradation of this vital aquifer. The palm trees in the continental oases represent 88.4 percent of the national total, with the Deglet Nour date variety dominating. This variety accounts for nearly 97 percent of total palm tree numbers and 94.4 percent of total date production. Nefzaoua is home to a large number of oases and more recent plantations than Jérid. The traditional date palm gardens can be found in the former continental oases, grown alongside other fruit species, as well as annual market gardening and fodder crops (three tiers of planting). Sheep and goat farming is often present on the farms, unless fodder production has been abandoned or the farmer (or *khammès*) has left the oasis to move to the city.

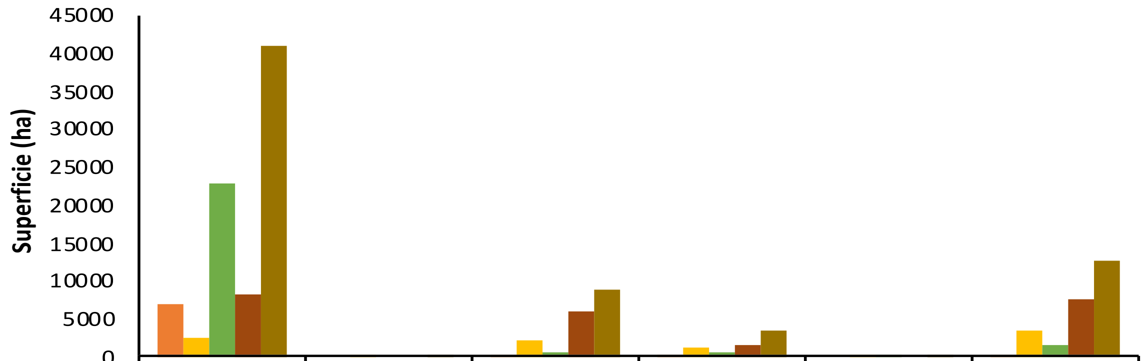
- ***The mountain oases*** are located in Gafsa and also in Jérid: Tameghza, Chebika and Midès. They are characterised by a cool winter and a cumulative temperature during the date fruiting period that does not always enable the Deglet Nour variety to reach maturity. The date palm is therefore relatively secondary and represented by varieties of less commercial value than the Deglet Nour. Arboriculture and market gardening are the most popular activities in these oases. The main crops are olive, apricot, pistachio, fig and pomegranate, with secondary varieties including palm and, sometimes, Deglet Nour. This system also includes market gardening, herbs, cereals, fodder crops (alfalfa, in particular) and industrial crops (henna and tobacco), as well as sheep, goat and cattle farming.

Tunisian oases can be classified into two different types by method of cultivation:

- ***Traditional oases***, which have a mixture of many different cultivars, with a slight predominance of secondary varieties (53 percent traditional varieties). Different fruit and annual species are cultivated under the palm trees in these oases. These traditional oases account for an area of 15,051 ha, or 37 percent of the total land mass. They contain 46 percent of the palm trees, most of which are common varieties, with a relatively high planting density of 166 plants per hectare (approximately 300 plants per hectare in Kebili). The middle and herbaceous tiers contain a great diversity of species. These oases have a high degree of fragmentation and a small farm size resulting from a sharing of inheritances.

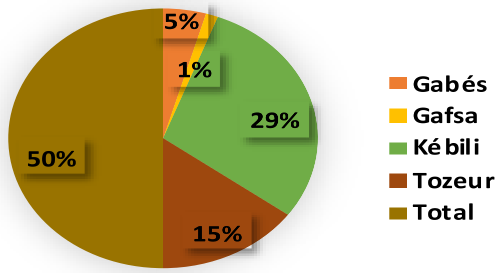
- ***Modern oases*** cover 25,752 ha (63 percent) of the total oasis area. They are characterised by a larger size of farm. The main means of production here is salaried workers and owner-operated farms. Modern oases are more open to the socioeconomic environment than traditional oases. These oases contain nearly 3 million palm trees (55 percent of the total number) and produce 88,600 tonnes of dates (55 percent of total production). Deglet Nour dates are predominant in modern oases, with 84.2 percent of the total number of palm trees in this type of oasis, compared with 15.8 percent of secondary varieties. The average planting density is around 120 plants per hectare, excluding fruit trees.

Figure 42. Main crops in the four governorates of the NWSAS region in Tunisia



	Palmier + arbo (ha)	Céréales (ha)	Fourrages (ha)	Cultures maraîchères (ha)	Autres (ha)	Total (ha)
Gabés	7080	0	124	124	0	248
Gafsa	2380	41	2170	1100	123	3434
Kébili	22980	0	650	728	35	1413
Tozeur	8363	0	6027	1440	0	7467
Total	40803	41	8971	3392	158	12562

Répartition des palmiers



Gouvernorat	Palmier (nbre de pieds)
Gabés	491 000
Gafsa	141 000
Kébili	3 198 000
Tozeur	1 636 000
Total	5 466 000

Source: GWP-Med et al. (2015).

Tunisia also exploits the geothermal potential available in the NWSAS region, with 115 hectares of geothermal agriculture.[99] It is now ranked third in the world after the United States (180 ha) and Hungary (160 ha). The main crops grown in greenhouses are watermelon, melon, courgette, cucumber, tomato,

[99] OSS and Matoussi (2013).

chilli pepper and aubergine. Other species such as green beans and lettuce are grown in the ground for just 3–4 months. These crops are grown before or after solanaceous or cucurbit crops.

Water resource management method

There are two types of water management in the oases of the Tunisian NWSAS region:[100]

- **Public irrigated areas**, which are fed by collective boreholes with the government covering the cost of all development and renovation of irrigation and drainage infrastructure. Management is entrusted to agricultural development groups, which are responsible in principle for all the running and maintenance of the irrigation and drainage network equipment. The total area covered by these irrigation systems is estimated at 24,800 ha, run by 230 agricultural development groups.
- **Private areas:** Based on the available data, private oases account for more than one third of the total irrigated area in the oasis regions. These developments are implemented by private investors with the cost of the water services borne entirely by themselves. The areas are estimated at nearly 15,200 ha, including 14,300 ha in Kebili, irrigated individually from groundwater. Since most of these areas are illegal and therefore have no access to electricity, investors are increasingly turning to solar energy.

In addition, the assessment carried out by OSS in 2015 for a better use of irrigation water in the NWSAS basin made the following observations:[101]

- The *cost of water is usually borne by the farmer* and demand is largely dependent on the price. In fact, the price elasticity of demand for water varies, by category of operator (public, private), the geographical area in question (Jeffara, maritime oases, continental oases) and the specification chosen, between 0.16 and 0.75 (when the price of water increases by 100 percent, its demand falls between 16 percent and 75 percent).
- *The production of an irrigated hectare would fall by 150 percent for a 100 percent increase in the salinity of the water used.* All the results show very clearly that the salinisation of water caused by its overexploitation is a major problem that must be overcome by all possible means.
- *As the area of irrigated land increases, the profitability of the irrigated farm improves* and, more importantly, water productivity increases significantly.
- *Origin of the water (private or public).* When moving from free water to highly subsidised water (public sector) and then to slightly subsidised water (private sector), water productivity increases by 30 percent.
- *Length of time irrigation has been in operation*: estimates suggest that the older the irrigation practice, the better the profitability and productivity of the water used.
- *Level of education*: the higher the farmer’s level of education, the more water is valued.
- *Role of animal husbandry:* in the Jeffara and Gabès regions, livestock farming plays a positive role in improving the use of water on irrigated farms.

[100] Ferchichi (2013) and GIZ (2009).
[101] OSS (2015).

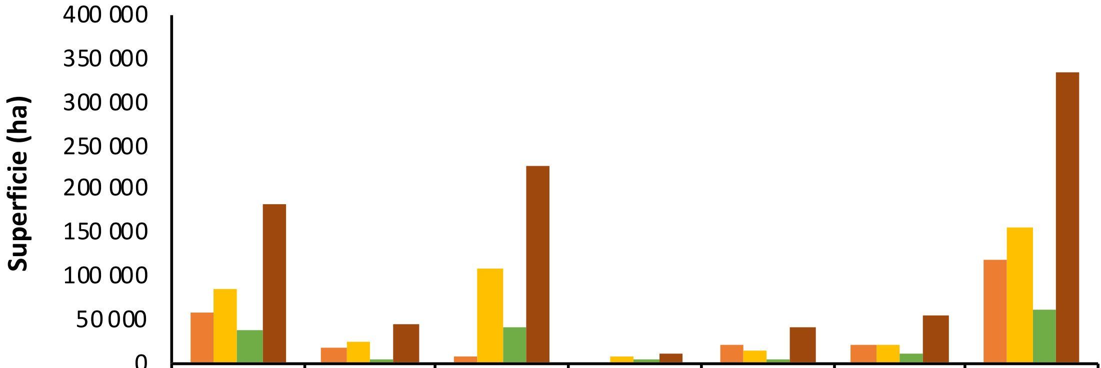
- *Encouragement of farmers to devote more time to their farms*: all estimates point to the fact that when the farmer devotes their time entirely to agricultural activity, water productivity increases significantly.

2.4.1.3 Libyan agrosystems

Main agrarian systems and crops

This relates mainly to irrigated areas along the Jeffara River and oases elsewhere. Cultural practices in the Jeffara River region are dominated by arboriculture, cereal crops and market gardening (see Figure 43).

Figure 43. Main crops in the NWSAS region in Libya



	Jeffara	Hamada Hamra	Bassin SASS	Jebel Lakhdar	Kufra & Sarir	Murzouk	Total
Céréales	59 200	18 315	7 515		20 400	20 926	118 841
Arboriculture	85 780	23 606	109 386	7 123	16 014	22 686	155 209
Maraîchage	38 044	2 020	40 064	4 490	3 786	12 730	61 070
Total	183 024	43 941	226 965	11 613	40 200	56 342	335 120

Source: GWP-Med et al. (2015).

Irrigation is based almost exclusively on groundwater. Water is primarily drawn from private wells (92 percent of irrigation sources), while only 8 percent of irrigation in Libya is public.[102]

The assessment carried out by the OSS in 2015 for a better use of irrigation water in the NWSAS basin made the following observations:[103]

- *Cost of water borne by the operator*: the estimated price elasticity of water based on the Libyan sample gave a very interesting result justifying the approach adopted. This demonstrated the crucial importance of the 'price' dimension of water in controlling its demand.

[102] GWP-Med et al. (2015).
[103] OSS (2015).

- *Water salinity*: the production of an irrigated hectare would drop by 62 percent for a 100 percent increase in the salinity of the water used.
- *Importance of livestock in irrigated agriculture*: the results obtained indicate that when the farmer excludes livestock from their farm, the productivity of the allocated water drops quite significantly. The average income from each farmer's livestock is around 44.5 percent of total income.
- *The crop system has a significant impact on production*. When the farmer switches from arboriculture to market gardening and glasshouse cultivation as their main activity, their total production increases significantly by around 24 percent.
- *Irrigated agriculture is experiencing a certain decline*: the average area actually irrigated per farmer is currently around 6.1 ha, compared with 7.2 ha at the start of the activity, or a drop of around 18 percent.

The aspects that therefore have a significant impact on the economic productivity of water in Libya are:

- the price of water
- salinity
- the crop system
- the importance of livestock farming in the farm's income.

Any economic policy that aims to improve the quality of current management of this precious resource in a highly unstable context with a view to ensuring its sustainability must explicitly incorporate all these key variables.

2.4.2 Performance of irrigation water in NWSAS agrosystems

Agriculture in the NWSAS region is blamed not only for being the largest consumer of water (85 percent of total consumption) but also for being a source of water wastage. This is for good reason, as water consumption per hectare remains high, particularly in the continental oases, where it is as much as 16,831 m^3/ha. The average in the NWSAS region is around 11,000 m^3/ha.[104] The area of irrigated crops (per pivot) is also a threat to the resource, given the high demand for water for this type of market gardening. It should be noted that efficiency of use of water for irrigation is at best only 60 percent, with an average of 42.4 percent across the region. This efficiency remains low and results in substantial water wastage. Losses are estimated at more than 2,500 m^3/ha. This low irrigation efficiency is mainly due to the irrigation techniques used. Accounting for 72 percent of irrigated land in the NWSAS region, gravity-fed irrigation systems remain predominant. This is followed by sprinkler systems, which are used on 26.18 percent of irrigated areas in the NWSAS region and, finally, by localised irrigation systems, which are used in less than 2 percent of irrigated areas.

With the rapid development of intensive and diversified irrigated agriculture in this region to support these countries' food security policies, the water deficit is becoming greater over time, making resource management increasingly difficult. The rate of intensification varies from 83 percent to more than 124 percent depending on the agrosystem. It is 96.3 percent for the NWSAS region as a whole.

One of the consequences of intensive agriculture based on poorly renewable groundwater is the widespread salinisation of irrigation water (see above: *The regional problem of irrigation using NWSAS water*).

[104] GWP-Med et al. (2015).

Water productivity in agriculture, which is expressed in United States dollars at constant 2005 prices, is estimated at an average of USD 0.413/m^3 in the NWSAS basin. It has seen continuous progression over the 2002–2011 period in the three countries, with slightly higher figures for Algeria. It is now USD 0.405, USD 0.341 and USD 0.458 in Algeria, Libya and Tunisia respectively (Table 30). A difference can be seen in favour of the private management system, which has the highest productivity: USD 0.484/m^3 compared with USD 0.35/m^3 and USD 0.274/m^3 respectively in collective or free systems. As for gross margin, this is estimated at USD 3,909/ha, being lower in collective systems (USD 3,176/ha) compared with the higher gross margins in private systems (USD 4,270/ha) or when water is free (USD 4,683/ha).

Table 30. Summary of results by type of access to water and by country

	NWSAS average	Access to water			Algeria	Libya	Tunisia
		Private	Collective	Free			
Water consumption in m^3/ha	12,686	10,516	14,746	21,735	13,520	9,134	13,266
Cost of water (USD/m^3)	0.036	0.045	0.028	0.004	0.036	0.028	0.04
Water productivity (USD/m^3)	0.413	0.484	0.350	0.274	0.405	0.341	0.458
Gross margin per ha	3,909	4,270	3,176	4,683	4,632	2,861	3,478
Price elasticity of demand	-12	-27	-8		-45	-25	-33

Source: OSS (2015).[105]

Average water consumption per hectare and per farmer for agriculture in the NWSAS region is 2,686 m^3/ha/year. A difference can, however, be seen by type of water management – collective, private or free (freely accessible for use as required) – revealing a significant impact on user behaviour. In fact, private users seem to be the most economical, with an average consumption estimated at 10,516 m^3/ha/year as opposed to a consumption of 13,520 m^3/ha/year and 21,735 m^3/ha/year for users of collective networks or those benefiting from free water respectively. This shows that users who bear all or part of the cost of the water are more inclined to behave responsibly with regard to their water consumption.[106]

The average cost per cubic metre of water paid directly by users is USD 0.036/m^3. There is, however, a clear difference between the three methods of water management. In fact, the cost is USD 0.028/m^3 and USD 0.045/m^3 respectively for collective and private systems compared with USD 0.004/m^3 in the free and open access system. Across the three countries of the NWSAS region as a whole, the unit cost of water is highest in Tunisia at USD 0.04/m^3. Unit costs are lower in Algeria and Libya, at around USD 0.036/m^3 and USD 0.028/m^3 respectively. The significant subsidies applicable to operating costs, particularly energy costs, in Algeria and Libya (hydrocarbon-producing countries), partly explains this tariff difference.

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[105] The results given in the table are taken from a study conducted on a sample of 3,000 farms in the NWSAS region selected based on several criteria that ensured their representativeness, including, in particular, the proportion of area irrigated, the size of the farms and the type of access to water. Two surveys were conducted on this sample.

[106] OSS (2015).

2.5 Socioeconomic trends

2.5.1 Demographics and population

According to forecasts produced by the OSS (2014), the population of the three NWSAS countries is going to continue to grow. The following distribution of demographic weight in the NWSAS region is expected: Algeria (55 percent), Libya (26 percent) and Tunisia (18 percent) (see Table 31). It should be noted that these projections are indicative only and the figures given are estimated based on the information from the countries over the last 15 years. Current social and political conditions in the three countries were also taken into consideration.

Table 31. Projected population in the NWSAS region by country

Year	2020		2050	
Country	Inhabitants	%	Inhabitants	%
Algeria	3.7	55%	4.8	55%
Libya	1.8	27%	2.3	26%
Tunisia	1.3	18%	1.6	18%
Total	6.8	100%	8.7	100%

Source: OSS (2014), p. 15.

2.5.2 General economic development

Other socioeconomic indicators for the three countries of the NWSAS region show that average annual population growth is less than 2 percent, the lowest rate being in Tunisia (1 percent). The rates for each country in the main NWSAS areas are generally higher than the national average given the traditional and rural nature of Saharan societies in the Maghreb.[107] Other socioeconomic indicators differ from one country to another. For example, unemployment is higher in Libya, affecting 30 percent of the population. The migration rate is low in Algeria and Tunisia (0.6 percent and 0.5 percent respectively in 2015), while it is significant in Libya (12 percent in 2015). This can be explained, among other things, by the use of foreign labour and the instability of the Sahel region. Migrants are trying to reach Europe using Libyan smugglers. It should be noted that the 2018 Human Development Index (HDI) for African countries (United Nations Development Programme – UNDP)[108] puts Libya ahead with an HDI of 108, followed by Tunisia with 95 and Algeria with 85. Another highly contrasting indicator is the proportion of the workforce involved in the agricultural sector: 23 percent in Algeria, 18 percent in Tunisia and less than 5 percent in Libya.

[107] GWP-Med et al. (2015).

[108] Agence Ecofin (2018).

Table 32. Socioeconomic indicators in the three countries of the NWSAS region

Indicateurs socio-économiques	Algérie	Libye	Tunisie
Population (2018 ; Millions d'habitants)	42 228 429	6 678 567	11 565 204
Croissance démographique annuelle moyenne (2018; %)	1.7	1.2	1.0
Population de moins de 15 ans (2018 ; %)	29	24	28
Population active (2018 ; habitants)	12 302 396	2 523 550	4081392
Population active (2018 ; %)	29	38	35
Population féminine active (2018; % de la population active)	18	25	27
Population active agricole (%)	23	4,65	18,3
Stock international de migrants (2015; nombre)	242 391	771 146	56 701
Stock international de migrants (2015; % de la population active)	0.6	12	0.5
Ratio de la population pauvre en fonction du seuil de pauvreté national (% de la population)	5.5 (2011)	/	1.2 (2015)
Espérence de vie (ans)	76.18	75.83	75.46
Taux de chômage (%)	10,3	30	18,8
IDH (2011)	0.698	0.76	0.698

Sources: World Bank data; Statistiques Mondiales (n.d.); GWP-Med et al. (2015).

In addition, the main economic indicators for the three NWSAS countries show that the GDPs of Algeria, Libya and Tunisia were USD 180.69 billion, USD 48.32 billion and USD 39.86 billion respectively in 2018 (see Table 33). The fall in the price of oil in recent years in Algeria and Libya has contributed to a decline in their respective GDPs. In Algeria it fell from USD 209 billion in 2012 to less than USD 181 billion in 2018 (a 14 percent decline in GDP), and from USD 81.87 billion in 2012 to USD 48 billion in Libya (a 41 percent decline in GDP). Tunisia's GDP also fell by 13 percent between 2012 and 2018.

Libya had the highest growth rate in 2018, at around 7.8 percent. Algeria and Tunisia have economic growth rates of 2.5 percent or less. In terms of per capita GDP, in 2018, this was USD 3,447 in Tunisia, compared with higher levels in Algeria and Libya at USD 4,279 and USD 7,447 respectively.

The importance of the agricultural sector in the three NWSAS countries can be seen in the indicator 'Share of agricultural GDP/total GDP'. In 2011, the lowest agricultural GDP was recorded in Libya with 3.3 percent, and the highest in Tunisia with 12 percent. In Algeria, it was 8.9 percent. The importance of the agricultural sector can thus be seen for the Tunisian economy compared with the two other hydrocarbon-producing countries.[109]

[109] GWP-Med et al. (2015).

Table 33. Economic indicators in the three countries of the NWSAS region

Indicateurs économiques	Algérie	Libye	Tunisie
PIB (2018 ; Milliards $ US courants)	180.69	48.32	39.86
PIB/habitant (2018 ; $ US courants)	4 279	7 235	3 447
Taux de croissance économique (2018 ; %)	2.1	7.8	2.5
Part du PIB agricole/PIB total (2011 ; %)	8.9	3.3	12

Sources: World Bank (2018); Statistiques Mondiales (n.d.); GWP-Med et al. (2015).

2.5.3 Climate change impacts and adaptation measures

2.5.3.1 Climate change impacts

The impacts of climate change in the NWSAS basin can largely be seen in the increased demand for water for both domestic and agricultural needs, resulting in additional pressure on water resources and risk of degradation. More significant in terms of greater abstraction of volumes and reduced recharge in the Djeffara area are the risks caused by salinisation and the flow reversal of chotts towards the water table as a result of decreasing piezometric levels. Farmers will not be able to avoid costly interventions to improve water quality, such as the installation of desalination plants, if they are to avoid suffering yield losses and thus income losses.

The first quantitative assessment of the direct and indirect impacts of climate change on the NWSAS basin was carried out by the Global Water Partnership Mediterranean (GWP-Med) as part of the WACDEP programme.[110] The 'strong' simulated scenario takes into account the following assumptions up to 2050:

- A decline in average rainfall of -18 percent. For recharge areas, the maximum decline in rainfall is -29 percent (worst case) in the recharge area on the Tunisian side and -22 percent in the recharge area on the Algerian side. In terms of temperature, an increase of +2.1 percent is expected in the recharge area and +2.7°C in the rest of the area.
- Socioeconomic developments are exacerbating recent trends and there is therefore some continuity in the corresponding water needs (domestic, industrial and agricultural). The increase in irrigated area is considered likely to continue its current trend until 2030 and then, from 2030 to 2050, to continue at a rate 50 percent lower than observed from 2010 onwards to take into account the non-availability of land and water resources. This scenario anticipates an increase in irrigated land area in the NWSAS from 141,840 ha in 2012 to 178,920 ha in 2050.

Based on these assumptions, there will be an estimated 25 percent decline in infiltration in recharge areas by 2050. Increased abstractions to compensate for evaporation losses due to the temperature increase will increase water drawdown from 82.07 m^3/s in 2012 to 142 m^3/s by 2050 under the effect of socioeconomic development without climate change, and to 179 m^3/s with climate change (a 26 percent difference attributable to climate change).

[110] WACDEP stands for Water, Climate and Development Programme. It is a programme of the African Ministers' Council on Water (AMCOW) implemented at the pan-African level by the Global Water Partnership (GWP) and in North Africa by the GWP-Med.

Simulations of the behaviour of aquifers with these abstractions, using the NWSAS hydrogeological model, give the following results:

- some areas (Rhir Wadi, Tozeur, Ghadames) are directly subject to strong interference between countries
- the Tunisian outflow is likely to dry up from the 2020s on; there will be an inversion of the hydraulic gradient leading to an irreversible degradation of the Djeffara basin (piezometry reaching 30 m below sea level)
- considerable drawdowns at the Intercalary Continental level bringing the piezometric level up to 1,500 m below sea level on the Hassi Messaoud side
- significant drawdowns also at the Terminal Complex level with a 40 m layer below the surface of Chott Djérid and 130 m below the surface of Chott Melhir.

This alarming assessment of changes in drawdowns would probably not occur in reality. In fact, stakeholders, both farmers and governments, are expected to adopt reactive strategies as the situation in the basin worsens (demand management, use of solar energy for the demineralisation of brackish water and recovery of drainage water, irrigation efficiency, adapted pricing, etc.).

Crop yields may also decline as a result of the combined effect of excessive temperatures and drought, as water stress disrupts phenology (flowering and leafing), growth and thus yields. Thermal factors also act on crops' phenology (cycle length and yields, number of flowers or fertile ears, size of the fruits or grains, quality, etc.). This risk increases for species sensitive to higher winter temperatures (e.g. alfalfa or palm). By 2050, crop yields are expected to be down by 25 percent (32 percent for pomegranate and 15 percent for date palm) compared with 2010, the baseline year considered in the WACDEP project. For pastoral production, above-ground biomass and fodder units will therefore decline by between 60 percent and 70 percent, depending on the vulnerability of the environment and ecosystem. The most vulnerable pastoral ecosystems are *Stipa tenacissima*-based areas, with those moderately vulnerable being *Rhanterium suaveolens*-based rangelands, and those with low vulnerability being primarily *Haloxylon schmittianum* and *halophyte*-based areas. These latter include xerophilic perennial species known for their adaptation to drought and rising temperatures.

2.5.3.2 Adaptation measures planned by the countries

Surveys conducted by the WACDEP have shown that farmers are aware of the impact of climate change, which is exacerbating the sustainability challenges they already face. To ensure their survival and profitability, farmers are implementing their own adaptation measures, some of which have adverse effects. For example, the digging or deepening of surface wells, including the use of solar energy to meet the growing needs of crops, is exacerbating the decline in the piezometric level and the deterioration in water quality.

Nationally, the countries have included a set of actions in their climate change adaptation policies and strategies which, while not specifically targeting the NWSAS oasis ecosystem, would help enhance the resilience and sustainability of development in the NWSAS region.

Algeria's National Climate Plan includes the following short-term actions for 2025–2035 that are of importance for the NWSAS region:

- optimisation and rehabilitation of irrigation systems

- development and expansion of drip irrigation
- integrated project for the restoration of drylands (green dam area), tackling of desertification and soil protection in the context of climate change
- rehabilitation of rangelands by creating 'exclusion' or 'protected' areas
- tackling of silting and providing vulnerable areas with targeted means to deal with it
- provision of areas vulnerable to silting with de-silting methods.
- adaptation of infrastructure in the south to heat waves
- use of unconventional water sources in arid areas
- national study on reusing treated wastewater
- reuse of demineralised drainage water in agriculture: Rig Wadi
- selection and genetic improvement of crop varieties (cereals, pulses, fodder, market gardening and arboriculture)
- enhancement and improvement of the climatic resilience of oasis populations and landscapes in Algeria
- deployment of photovoltaic solar energy for water pumping and irrigation systems on farms in southern Algeria.

Libya has no strategic documents for climate change adaptation but it has joined a series of regional initiatives and programmes (Global Environment Facility (GEF), FAO, etc.) aimed primarily at natural resource management and the sustainable use of water and energy in agriculture.

Through its nationally determined contribution (NDC) (2015), Tunisia plans to intensify the CO_2 absorption capacities of forests and arboriculture by scaling up reforestation actions, consolidating and increasing carbon reserves in forest and pastoral environments. The carbon balance of agriculture will also be improved by using fewer emissions-generating practices: optimising the diets of domestic animals, promoting organic farming or conservation farming practices, recovering energy from animal waste, etc. In terms of adaptation, Tunisia plans to use the following practices: reusing treated wastewater, adapting mixed crop-livestock production systems to climate change in vulnerable regions, conserving and enhancing the local genetic heritage to adapt crops to climate change and develop innovative field crop systems, managing rangeland and degraded esparto grassland in the central and southern regions, ensuring biological consolidation of works to tackle silting in southern Tunisia, and supporting the implementation of regional action plans to tackle desertification.

The strategic direction of the NWSAS countries' action on climate has much in common (developing unconventional water sources, tackling desertification, improving the resilience of agriculture, using solar energy in agriculture, etc.) and this can be built on to establish joint transboundary actions based on a synergy between the correlated sectors of the water-food-energy-ecosystems nexus.

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Annex 1: Plant species in the NWSAS region

Source: Convention of Biological Diversity Website. Available at: https://www.cbd.int/

Plant species		
Algeria	**Tunisia**	**Libya**
Algae (which ones)	*Stipa tenacissima*	*Arthrocnemum glaucum*
Ammosperma cinereum	*Apium graveolens*	*Halocnemum strobilaceum*
Anabasis articulata	*Arthrocnemum*	*Limoniastrum*
Antirrhinum ramosissimum	*Arthrocnemum indicum*	*Limoniastrum monopetalum*
Astragalus armatus	*Arthrophytum schmittiamum*	*Salsola karoliniana*
Atripex halimus	*Arthrophytum scoparium*	*Salsola vermiculata*
Cleoma arabica	*Astragalus armatus*	*Suaeda fruticosa*
Composeae	*Astragalus corrugatus*	*Suaeda mollis*
Cynodon dactylon	*Athrophyton sp.*	*Suaeda pruinosa*
Datura	*Atriplex portulacoides*	*Tamarix*
Diplotaxix harra	*Beta macrocarpa*	*Zygophyllum album*
Euphorbia guyoniana	*Calligonum sp.*	
Fagonia microphylla	*Caraceae*	
Phragmites	*Carex hispida*	
Frankenia thymifolia	*Ceratophyllum demersum*	
Juncus acutus	*Characeae*	
Gramineae	*Corchorus olitorius* (molokhia: corette)	
Guyonianium	*Coronopus lepidioides*	
Halocnemum strobilaceum	*Cynanchum acutum*	
Haloxylon articulatum	*Cyperus laevigatus*	
Haloxylon sp.	*Dactyloctenium aegyptiancum*	
Rush	*Diplotaxis harra*	

Plant species		
Algeria	**Tunisia**	**Libya**
Jujube	*Eruca sativa*	
Juncus sp.	*Halocnemum strobilaceum*	
Nerium oleander	*Helosciadium nodiflorum*	
Limoniastrum	*Hordeum sp.*	
Limoniastrum feei	*Juncus fontanesii*	
Limoniastrum guyonianum	*Juncus maritimus*	
Limonium tunetanum	*Juncus pygmaeus*	
Moricandia arvensis	*Lawsonia inermis* (henna)	
Navicula	*Ligium sp.*	
Oudneya africana	*Linaria laxiflora*	
Peganum harmala	*Lycium sp.*	
Phoenix dactylifera	*Malcorisa africana*	
Phragmites australis	*Megastoma pusillum*	
Phragmites communis	Nigella	
Pitunathos chloranthus	*Nitraria sp.*	
Retama	*Olea europaea*	
Reed	*Panicum repens*	
Salsola	*Phragmites communis*	
Salsola vermiculata	*Plantago major*	
Scenedesmus quadricauda	*Potamogeton nodosus*	
Scripes	*Retama raetam*	
Sinuatum pruinosum	Reed	
Tamarix	*Rubia tinctorum*	
Tamarix gallica	*Ruppia*	
Tetragona	*Salicornia*	

Plant species		
Algeria	**Tunisia**	**Libya**
Thymelaea microphylla	*Salicornia arabica*	
Typha angustifolia	*Salicornia europaea*	
Traganuml nudatum	*Salicornia perennis*	
Tunetanum thouini	*Scirpus holoschoenus*	
Typha elephantina	*Scirpus littoralis*	
Vinux sp.	*Stipa sp.*	
Ziziphus lotus	*Suaeda mollis*	
Zygophyllum album	*Suaeda sp.*	
Zygophyllum cornutum	*Suaeda mollis*	
	Tamarix	
	Tamarix africana	
	Tamarix boveana	
	Tamarix panciovulata	
	Thymilia sp.	
	Traganum sp.	
	Trigonella	
	Typha	
	Typha angustifolia	
	Typha ceratophyllum demersum	
	Verbena supina	
	Zannichellia palustris	
	Ziziphus sp.	
	Zygophyllum cornutum	
	Zygophyllum album	

Annex 2: Birds in the NWSAS region

Source: Convention of Biological Diversity Website. Available at: https://www.cbd.int/

Common name	Scientific name	Status
Algeria		
Bonelli's eagle		
Little egret		
Anas platyrhynchos		
Osprey		
Black-tailed godwit		
Sandpiper		
Little stint	*Calidris minuta*	
Marsh harrier		
Buzzard		
Northern pintail		
Eurasian wigeon		
Northern shoveler		
Mallard		
Ruff	*Philomachus pugnax*	
Little owl		
Ciconia ciconia		
White stork		
Kestrel		
Black-winged stilt	*Himantopus himantopus*	
Ericius		
White heron		
Falcon		
Common kestrel		
Greater flamingo	*Phoenicopterus ruber roseus*	

Common name	Scientific name	Status
Coot		
Fuligules nyroca		
Great cormorant		
Plover		
Little grebe		
Great crested grebe		
Grey heron		
Dryland passerine		
Common moorhen		
Hen (short-legged)		
Sultan chicken		
Marbled duck	*Marmonetta angustriostris*	
Ruddy shelduck		Legally protected in Algeria since 1983
Common shelduck		
Tadorna ferruginea		
Tadorna tadorna		
European turtle dove		
Tunisia		
Rufous-tailed scrub robin	*Cercotrichas galactotes*	Migratory nesting in oases
Little egret	*Egretta garzetta*	Wintering
Desert horned lark	*Ercucophila bilapha*	
Desert lark	*Ammomanes deserti*	
Common pochard		
Ferruginous pochard	*Fuligule nyroca*	On the IUCN Red List
Little stint	Temminck's stint	
Common snipe	*Gallinago gallinago*	Wintering

Common name	Scientific name	Status
Western yellow wagtail	*Motacilla flava*	Migratory passage
Ortolan bunting	*Emberiza hortulana*	
Corn bunting	*Miliaria calandra*	Wintering
Striolated bunting	*Emberiza striolata*	Sedentary nesting in oases
Common bulbul	*Pycnonotus barbatus*	Accidental
Marsh harrier	*Circus aeruginosus*	Wintering
Long-legged buzzard	*Buteo rufinus*	Sedentary nesting in the vicinity of oases and regularly observed there
Northern pintail	*Anas acuta*	
Eurasian wigeon	*Anas penelope*	
Northern shoveler	*Anas clypaeta*	
European goldfinch	*Carduelis carduelis*	Accidental
Comon greenshank	*Tringa nebularia*	
Ruff	*Philomachus pugnax*	
Green sandpiper	*Tringa ochropus*	
Wood sandpiper	*Tringa glareola*	
Little owl	*Athene noctua*	Sedentary nesting in oases
Barn owl	*Tyto alba*	Sedentary nesting in oases
White stork	*Ciconia*	Migratory passage
Crested lark	*Galerida cristata*	Sedentary nesting in the vicinity of oases and regularly observed there
Common cuckoo	Cuculus canorus	Migratory passage
Cream-coloured courser	*Cursorius cursor*	Accidental
Fulvous babbler	*Turdoides fulvus*	Sedentary nesting in the vicinity of oases and regularly observed there
Zitting cisticola	*Cisticola juncidis*	Sedentary nesting in oases
Streaked scrub warbler	*Scotocerca inquietta*	

Common name	Scientific name	Status
Black-winged stilt	*Himantopus*	
European nightjar	*Caprimulgus europaeus*	Migratory passage
White-headed duck	*Oxyura leucocephala*	Rare, critically endangered species
Common starling	*Sturnus vulgaris*	Wintering
Spotless starling	*Sturnus unicolor*	
Common kestrel	*Falco tinnunculus*	Sedentary nesting in the vicinity of oases and regularly observed there
Lanner falcon	*Falco biarmicus*	Sedentary nesting in the vicinity of oases and regularly observed there
Eurasian blackcap	*Sylvia atricapilla*	Wintering
Garden warbler	*Sylvia borin*	Migratory passage
Tristram's warbler	*Sylvia deserticola*	
Common whitethroat	*Sylvia communis*	Migratory passage
Sardinian warbler	*Sylvia melonocephala*	Wintering
Western orphean warbler	*Sylvia hortensis*	Migratory nesting in oases
Subalpine warbler	*Sylvia cantillans*	Migratory passage
Nesting greater flamingos	*Phoenicopterus ruber*	
Eurasian coot	*Fulica atra*	Accidental
Common pochard	*Aythya ferina*	
Spotted sandgrouse	*Pterocles senegallus*	
Collared pratincole	*Glareola pratincola*	
Collared flycatcher	*Ficedula albicollis*	Migratory passage
Spotted flycatcher	*Muscicapa striata*	Migratory nesting in oases
Red-breasted flycatcher	*Ficedula parva*	Accidental
European pied flycatcher	*Ficedula hypoleuca*	Migratory passage

Common name	Scientific name	Status
Common raven	*Corvus corax*	Sedentary nesting in the vicinity of oases and regularly observed there
Kentish plover	*Charadrius alexandrinus*	
Song thrush	*Turdus philomelos*	Wintering
Common crane	*Grus grus*	
European bee-eater	*Merops apiaster*	Migratory bird that nests in the vicinity of oases and is regularly observed there
Black-crowned night heron	*Nycticorax nycticorax*	
Grey heron	*Ardea cinerea*	Wintering
Squacco heron	*Ardeola ralloides*	Migratory passage
Purple heron	*Ardea purpurea*	Migratory passage
Pharaoh eagle-owl	*Bubo ascalaphus*	
Eurasian scops owl	*Otus scops*	Migratory passage
Barn swallow	*Hirundo rustica*	Migratory bird that nests in the vicinity of oases and is regularly observed there
Common house martin	*Delichon urbica*	Migratory passage
Sand martin	*Riparia riparia*	Migratory passage
Eurasian hoopoe	*Upupa epops*	Sedentary nesting in oases
Icterine warbler	*Hippolais icterina*	Migratory passage
Eastern olivaceous warbler	*Hippolais pallida*	Migratory nesting in oases
Ibis		
Wader		
Common linnet	*Acanthis cannabina*	Wintering
Eurasian golden oriole	*Oriolus oriolus*	Migratory passage
Alpine swift	*Apus melba*	Migratory bird that nests in the vicinity of oases and is regularly observed there
Common swift	*Apus apus*	Migratory passage

Common name	Scientific name	Status
Pallid swift	*Apus pallidus*	Migratory bird that nests in the vicinity of oases and is regularly observed there
Common kingfisher	*Alcedo atthis*	Wintering
Ring ouzel	*Turdus torquatus*	Wintering
Blue rock thrush	*Monticola solitarius*	Wintering
Common blackbird	*Turdus merula*	Sedentary nesting in oases
Black kite	*Milvus migrans*	Migratory passage
House sparrow	*Passer domesticus*	Sedentary nesting in oases
Rock sparrow	*Petronia petronia*	Wintering
Eurasian stone-curlew	*Burhinus oedicnemus*	Accidental
Greylag goose		
Greater white-fronted goose		
Houbara bustard		
Barbary partridge	*Alectoris barbara*	Accidental
Little ringed plover	*Charadrius dubius*	
Sedge warbler	*Acrocephalus schoenobaenus*	Migratory passage
Woodchat shrike	*Lanius senator*	Migratory nesting in oases
Iberian grey shrike	*Lanius meridionalis*	Sedentary nesting in the vicinity of oases and regularly observed there
Common chaffinch	*Fringilla coelebs*	Sedentary nesting in oases
Red-throated pipit	*Anthus cervinus*	
Tree pipit	*Anthus trivialis*	Migratory passage
Meadow pipit	*Anthus pratensis*	Wintering
Willow warbler	*Phylloscopus trochilus*	Migratory passage
Wood warbler	*Phylloscopus sibilatrix*	Migratory passage
Common chiffchaff	*Phylloscopus collybita*	Wintering
Common moorhen	*Galinula chloropus*	Wintering

Common name	Scientific name	Status
Eurasian reed warbler	*Acrocephalus scirpaceus*	Migratory passage
Great reed warbler	*Acrocephalus arundinaceus*	Migratory passage
Trumpeter finch	*Bucanetes githagineus*	Accidental
Common nightingale	*Luscinia megarhynchos*	Migratory passage
European robin	*Erithacus rubecula*	Wintering
Common redstart	*Phoenicurus phoenicurus*	Migratory passage
Moussier's redstart	*Phoenicurus moussieri*	Wintering
Black redstart	*Phoenicurus ochruros*	Wintering
Eurasian teal	*Anas crecca*	
Marbled duck	*Marmaronetta angustirostris*	Rare and endangered species on the IUCN Red List
European serin	*Serinus serinus*	Sedentary nesting in oases
Greater hoopoe-lark	*Alaemon alaudipes*	
Dupont's lark	*Chersophilus duponti*	
Ruddy shelduck	*Tadorna ferruginea*	Rare species
Common shelduck	*Tadorna tadorna*	
Western swamphen	*Porphyrio porphyrio*	Rare species
African stonechat	*Saxixola torquata*	Wintering
Eurasian wryneck	*Jynx torquilla*	Migratory passage
European turtle dove	*Streptopelia turtur*	Migratory nesting in oases
Laughing dove	*Streptopelia senegalensis*	
Laughing dove	*Streptopelia senegalensis*	Sedentary nesting in oases
Red-rumped wheatear	*Oenanthe moesta*	
Northern wheatear	*Oenanthe oenanthe*	Accidental
Black-eared wheatear	*Oenanthe hispanica*	Accidental
Black wheatear	*Oenanthe leucura*	
European greenfinch	*Caeduelis chloris*	Wintering

Annex 3: Wildlife in the NWSAS region

Source: Convention of Biological Diversity Website. Available at: https://www.cbd.int/

Mammals	Amphibians	Reptiles	Fish
Algeria			
Camilus	Toads	Grass snake	Barbot du désert
Golden jackal (*Canis aureus*)	Frogs	False cobra	Local barbus
Sand cat (*Felis margarita*)		Bell's dabb lizard (*Uromastyx acanthinurus*)	Bighead carp
Fennec fox (*Canis zerda*)		Lizard	Silver carp
Fennec fox (*Fennucus zerda*)		Serpentése	Royal carp
Dorcas gazelle		Desert monitor (*Varanus griseus*)	Roach
Jerboa		Viper	
Val's gundi (*Ctenodactylus vali*)			
North African hedgehog (*Atelerix algirus*)			
Hyena (uncommon, observed in small numbers everywhere)			
Hare (*Lepus capensis*)			
Ovis longipes			
Phenias			
Wild boar (*Sus scrofa* in large population)			
Tanis			
Tunisia			
Jackal	*Bufo viridis*	*Acanthodactylus boskiarus*	*Thermosbaena mirabili* (crustacean) (probably extinct since its discovery)

Mammals	**Amphibians**	**Reptiles**	**Fish**
Dorcas gazelle (extremely rare and close to extinction)	*Rana ridibunda perezi*	*Acanthodactylus inortus A. longipes*	*Gambusia affinis holbrooki*
Gazella leptoceros (very rare, near extinction)		*Acanthodactylus pardalis*	*Astatotilapia desfontainesi*
Fox		*Agama mutabilis*	*Hemichromis bimaculatus* (in Kebili only)
Wild boar		*Agama tournevillei*	*Sarotherodon nilotica* (in Kebili only)
		Cerastes cerastes	Tilapia (introduced species)
		Cerastes vipera	*Mugil auratus* (introduced species)
		Chamaeleo chamaeleon	
		Eumeces schneiderii	
		Lytorhynchus diadema	
		Malpolon moilensis	
		Mesalina guttulata	
		Mesalina olivieri	
		Natrix maura	
		Ophidia	
		Psammophis schokari	
		Scincus scincus	
		Sphenops boulengeri	
		Stenodactylus petrii	
		Stenodactylus sthenodactylus	
		Tarentola mauritanica	
		Tarentola neglecta	

Mammals	Amphibians	Reptiles	Fish
		Tropiocolotes tripolitanus	
		Uromastyx acanthinura	
		Varanus griseus (extremely rare)	

Annex 4: Ramsar sites in the NWSAS region

Source: Convention of Biological Diversity Website. Available at: https://www.cbd.int/

Ramsar site	Year established	Area (ha)	Governorate/Wilaya
Algeria			
Tamantit and Sid Ahmed Timmi Oasis	2001	95,700	Adrar
Ouled Saïd Oasis	2001	25,400	
Sebkhet el Melah	2004	18,947	Ghardaïa
Chott Aïn el Beïda	2004	6,853	Ouargla
Chott Oum el Raneb	2004	7,155	Ouargla
Chott Aïn el Beïda	2004	6,853	Ouargla
Chott Melghir	2003	551,500	El Oued, Biskra, Khenchela
Chott Merrouane and Khrouf Wadi	2001	337,700	El Oued
Tunisia			
Dekouk Wadi	2012	5,750	Tataouine
Bahiret el Bibane	2007	39,266	Mednine
Gulf of Boughrara	2012	12,880	Mednine
Jerba Bin El Ouedian	2007	12,082	Mednine
Jerba Ras R'mel	2007	1,856	Mednine
Jerba Guellala	2007	2,285	Mednine
Sebkhet Oum Ez-Zessar and Sebkhet el Grine	2013	9,195	Mednine
Kebili Oasis Wetlands	2007	2,419	Kebili
Chott El Jérid	2007	586,187	Tozeur, Kebili
Sabket Sidi Mansour			Gabès
Sebkhet El Hamma			Gabès

Ramsar site	Year established	Area (ha)	Governorate/Wilaya
Sebkhet Nouaïel			Kebili (classified Important Bird and Biodiversity Area)
Sebkhat Jemna			Kebili
Sebkhet (Chott) Blidet			Kebili
Sebkhet South Douz			Kebili
Sebkhet West Douz			Kebili
Sebkhet Snam			Kebili
Sebkhet Ghidma			Kebili
Sebkhet Douz Laâla			Kebili
Bir El Keb Lake			Tataouine
Libya			
Ain Elshakika	2000	33	
Ain Elzarga	2000	33	

Annex 5: Characteristics of NWSAS countries

Source: http://www.fao.org/nr/water/aquastat/;2012–2016 data.

	Algeria	Libya	Tunisia	Total
AREA				
Area of the country (1,000 ha)	236,174	175,954	16,361	428,489
Agricultural area	41,432	15,355	10,079	66,866
As a percentage of the country's area	17	9	62	16
Permanent grassland and pasture	32,967	13,300	4,830	51,097
Cultivated area	8,465	2,055	5,249	15,769
As a percentage of the country's total area	4	1	32	4
Arable land (temp. crop + grassland and fallow land)	7,545	1,720	2,839	12,104
Permanent crops	920	335	2,410	3,665
POPULATION				
Total population (in thousands of inhabitants)	39,929	6,298	10,997	57,224
Of which rural population (%)	25	21	33	26
Population density (inhab./km²)	17	4	67	13
ECONOMY AND DEVELOPMENT				
GDP (millions USD/year)	214,000	41,119	47,129	302,248
Agricultural value added (% of GDP)	10	2	8.7	8.7
Per capita GDP (USD/inhab.)	5,360	6,550	4,286	5,282
Human Development Index (highest = 1)	0.717	0.725	0.721	
Gender Inequality Index (equality = 0, inequality = 1)	0.425	0.134	0.265	
ACCESS TO IMPROVED DRINKING WATER SOURCES				
Total population (%)	84	71	97	
Urban population (%)	84	72	100	
Rural population (%)	82	68	90	

RENEWABLE WATER RESOURCES				
Average rainfall (in mm/year)	89	56	207	
Average rainfall (in millions of m^3/year)	212,000	98,530	33,870	344,400
Internal renewable water resources (million m^3/year)	11,250	700	4,195	16,145
Total renewable water resources (million m^3/year)	11,670	700	4,615	16,985
Dependency Index (%)	4	0	9	
Total per capita renewable water resources (m^3/year)	292	112	419.7	297
Total capacity of dams (million m^3)	8,300	389.89	2,677	11,367