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Status of water resources and Climate change in Maghreb regions (Mauritania, Morocco, Algeria, Tunisia and Libya)

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Abstract

The Maghreb regions (Mauritania, Morocco, Algeria, Tunisia and Libya) are facing increasing water scarcity amplified by inefficient water use and overexploitation of water resources. There is evidence that surface water is diminishing and that ground water levels are lowering rapidly. The countries are affected by climate change as rainfall is more erratic and there are longer lasting and more severe periods of drought, alternated with severe rains and catastrophic flooding. The projected climate change impact on agriculture in the Maghreb will most likely increase further. This is accompanied by salinization of soils and ground water, even strengthened by over-fertilization of soils, combined with a general low productivity and misuse of water.

This paper summarized the country profile of the Maghreb regions (Mauritania, Morocco, Algeria, Tunisia and Libya) of key information that gives an overview of the water resources and water use at the national level. It can support water-related policy and decision makers in their planning and monitoring activities as well as inform researchers, media and the general public. Information in the report is organized by sections: All sources used to compile the country profile are also reported in the last section of the document.

Key Words*:* Water, Climate Change, Agriculture; Maghreb regions

Etat des ressources en eau dans les régions du Maghreb (Mauritanie, Maroc, Algérie, Tunisie et Libye)

Résumé

Les régions du Maghreb (Mauritanie, Maroc, Algérie, Tunisie et Libye) sont confrontées à une pénurie d'eau croissante amplifiée par une utilisation inefficace de l'eau et la surexploitation des ressources en eau. Il existe des preuves que les eaux de surface diminuent et que les niveaux des eaux souterraines baissent rapidement. Les pays sont touchés par le changement climatique car les précipitations sont plus irrégulières et il y a des périodes de sécheresse plus longues et plus sévères, alternant avec des pluies abondantes et des inondations catastrophiques. L'impact projeté du changement climatique sur l'agriculture au Maghreb va très probablement encore augmenter. Ceci s'accompagne d'une salinisation des sols et des nappes phréatiques, voire renforcée par une surfertilisation des sols, combinée à une faible productivité générale et une mauvaise utilisation de l'eau.

Ce document résume le profil de pays des régions du Maghreb (Mauritanie, Maroc, Algérie, Tunisie et Libye) des informations clés qui donnent un aperçu des ressources en eau et de l'utilisation de l'eau au niveau national. Il peut aider les décideurs et les responsables des politiques liés à l'eau dans leurs activités de planification et de suivi et informer les chercheurs, les médias et le grand public. Les informations contenues dans le rapport sont organisées par sections : Toutes les sources utilisées pour compiler le profil du pays sont également rapportées dans la dernière section du document.

Mots clés : Eau, Changement Climatique, Agriculture ; Les régions du Maghreb .

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INTRODUCTION

Maghreb (meaning "land of the sunset") is the Northwest region of Africa (Figure 1) that includes Mauritania, Morocco, Algeria, Tunisia and Libya, all members of the Arab Maghreb Union, and Ceuta and Melilla (Spanish). The Arab Maghreb Union was founded in 1989 to strengthen the ties between the five Northwest African Arab countries and to promote sustainable growth through harmonizing policies and more flexible flows of persons, services, and goods. This African region is the closest to Europe and acts as a bridge with Europe and the Middle East. The total population in the Maghreb countries Algeria, Libya, Mauritania, Morocco and Tunisia was ca. 100 million inhabitants in 2018. There has been a steady growth since. Currently, the growth rate is low (around 1 to 2 percent) in Algeria, Tunisia and Morocco, the three focus countries of this report. A large part of the population is dependent on agricultural activities for their income. Morocco and Tunisia a large part of the country is cultivated (>20%). In Algeria, mainly the coastal zone is cultivated. The ratio of arable land areas and permanent crop differs per country. Tunisia, for example, has a relatively large part in use for permanent crops. The estimated gross domestic product (GDP) of all Maghreb countries, amounted to approximately 1,210 billion international dollars in 2019(Gaaloul, 2021).

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

Climate varies highly in the Maghreb, and the region is divided in a Mediterranean (temperate) climate region in the north, and the arid Sahara in the south. The Atlas Mountains in Morocco are regarded as one of the Water Towers of Africa, and receive more rainfall than their lower surroundings). The Sahara Desert in the south receives little or no rainfall. With extreme variations in geographic features, proximity to the coast, etc, precipitation in the Maghreb is highly variable both in space and time. The largest rainfall variation is seen in Morocco. With amounts of more than 800 mm in the northern mountain areas (resulting in a rainfall surplus compared to evapotranspiration) to less than 300 mm in the south (rainfall deficit compared to evapotranspiration). Rainfall occurs mainly in wintertime (Gaaloul, 2021).

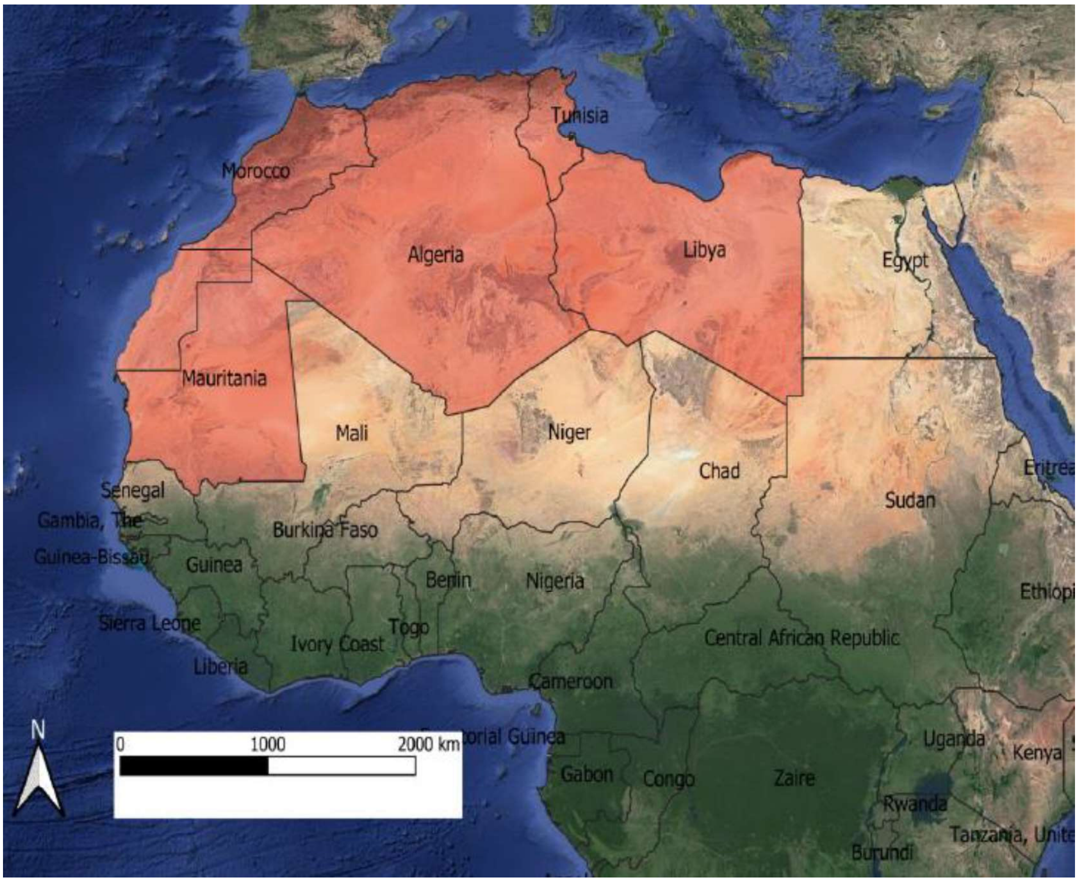

Figure 1. Overview of the Maghreb region, indicated in red.

WATER RESOURCES IN MAGHREB REGIONS (MAURITANIA, MOROCCO, ALGERIA, TUNISIA AND LIBYA)

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

Surface water: Surface water is unevenly distributed, due to the topography and rainfall distribution. More is available in the north of the Maghreb and downstream of the atlas mountain range. Surface water reservoirs in the Maghreb are widespread and store large quantities of water. Sedimentation of reservoirs due to upstream soil erosion is one of the key issues since it negatively affects the storage capacity in the reservoirs. Also, evaporation losses are high. In several regions, surface waters (e.g. streams) are known to be polluted by untreated municipal and industrial wastewater. Loads from intensive agricultural management practices have also resulted in high phosphorous, nitrate and pesticide concentrations. In addition, various surface waters in West Algeria have shown heavy metal concentrations above the WHO standards (Gaaloul, 2021).

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

Groundwater: There are three transboundary aquifer systems shared between Morocco, Algeria and Tunisia:
1) The Errachidia Basin between Algeria and Morocco. With the extent of 60.000 km², it is a relatively small transboundary basin. Rainfall rates are low (200 – 80 mm). Abstraction of groundwater causes water quantity problems in this basin due to reduced groundwater recharge rates (Gaaloul, 2021).
2) The Tindouf basin is mainly shared between Algeria and Morocco and to a lesser extent with Mauritania. With an extent of 210.000 km², it is also a relatively small transboundary basin. There is a low demographic density in this basin. Due to low rainfall rates (extreme climatic conditions), active recharge to the aquifer is extremely low (Gaaloul, 2021).
3) Algeria and Tunisia (and Libya) are relying strongly on the transboundary aquifer of the North Western Sahara Aquifer System (NWSAS). The NWSAS is the largest transboundary groundwater reserve in North Africa, extending over 1 million km². However, its water resources are largely non-renewable (and can therefore be considered a fossil groundwater resource). Over the last decades the agricultural and industrial development in the basin, as well as the technological advances in well drilling led to steadily growing water abstraction.
The NWSAS is composed of two major water-bearing layers, the Continental Intercalary (CI) and the Terminal Complex (CT). From the 1970 to the 2000s, abstraction by drilling has risen from 0.6 to 2.5 billion m^3/year. This rate of abstraction involves many risks: strong impact on neighbouring countries, salinization, elimination of artesianism, drying up of outlets, etc. (OSS, 2004). For more information on this, see the country specific chapters. Today, the rate of withdrawals from the aquifer far exceeds the rate of its replenishment. The water abstraction is currently standing at three times the aquifer's natural recharge rate (1 billion m^3 per year) (Gaaloul, 2021).

Water quality: Ground water quality in the Maghreb region is variable. In all three countries, some of it is fresh, but all countries also suffer from salinized ground water. The salinization of groundwater is also predicted to get worse in the future (Gaaloul, 2021). The salinity threshold at which water is generally classified as moderately saline is 1.5 to 3 dS/m. These levels can affect salt sensitive crops and require careful management practices. Water with an Electrical Conductivity (EC) from 3 dS/m up to 7.5 dS/m may cause severe salinity effects and only salt tolerant crops on permeable (i.e. containing a high fraction of sand) soils with careful management practices are suitable for the use of this type of water. Salinization is not new to the Maghreb and as such, farmers have learned to deal with it, at least to a certain extent. When brackish water is not used properly, there is a risk of salinizing, and thereby possibly degrading the soil, especially in the case of clay soils. In areas with very low rainfall this is a significant risk since there is no sufficient rain to leach accumulated salts away from the rootzone of crops. However, when irrigation is done properly (sustainable leaching and drainage to control rootzone salinity, maintain good soil health) conventional crop production is possible with most of the average salinity levels. For most levels of salinity, suitable crops and crop varieties can be selected. With the high (max) values, EC values of 12 dS/m or higher, only a very limited number of specific halophytic crops can be cultivated. For the agricultural sector (for example for vegetable production), the pH of the water is also an important factor. This is highly dependent on the bicarbonate concentration of the water source. There is little information available on the bicarbonate concentrations of water resources in the Maghreb countries, and the agricultural sector could be supported with a widespread mapping exercise on the pH (or bicarbonate concentrations) and salinity concentrations.

Water demand agricultural sector: There are considerable differences between Maghrebcountries. For example, we can see that the contribution of domestic water uses to total water use ranges from 9 to 36%. Other numbers are much more comparable between the countries, such as the use of fresh water by industry in the three countries. There are large water losses in the agricultural sector for different reasons. Losses due to non-functional or broken irrigation conveyance systems, or evaporation losses in sprinkler systems, or even an over application of irrigation water regarding the water need of the crop. For example, the agricultural sector of Morocco, using nearly 87% of the countries water resources, still has an efficiency rate of only 48%. Also, the system of drinking water pipes experiences water losses, with a performance rate of less than 70%, meaning water losses close to a third. Food losses in the stage of harvesting, storage and transport could also be considered water lost. All of these steps need improvement to reduce indirect water losses.

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

Mauritania

Mauritania, in the north-western Africa (Figure 2) between the 15th and the 27th parallel north, is bounded on the west by the Atlantic Ocean and extends along a coastline of 600 km. The country covers an area of 1,030,700Km²(National Office of Statistics, 2011. Annuaire Statistique 2011, Ministry of Economic Affairs & Development, Mauritania) and most of the northern half of the country is desert and sparsely populated. The Sahel stretches from west to east in a band 200 km across the south of the country. In the center and north, the terrain consists of mountains, such as those of Adrar and Tagant, going up from 400 to 800m. With the exception of the alluvial plain of the Senegal River in the south, called Chemama, the rest of the country is, in large part, flood plains. The estimated population in 2011 stood at 3.43million inhabitants, 37% of rural areas

Climate: The climate is generally hot and dry, with a Saharan climate in the north and Sahelian in the south. Maximum temperatures exceed 44 °C in May-June, and minimum temperature can go down to 10 °C in January and February. Winds, predominantly north-east, are very frequent and favor the progression of silting. The rainy season is very irregular in time and space. It generally extends over a period of four months, from June to September, with a north-south gradient in rainfall amount ranging from a few millimeters to 450 mm/year. Most of the country receives a rainfall of less than 300 mm/year. There were major droughts in 1984-85 and 1991-92, when rainfall was 35 to 70 % lower than average (Gaaloul, 2021).

Hydrology: The only perennial river in Mauritania is the Senegal River, which forms its southern border. Other rivers are ephemeral and short. The main ephemeral rivers are the Gorgol in the Tagant area, the Garfa and Niorda in the Assaba area, and the Karakoro along the Mali border. In addition to these, there are wadis (smaller ephemeral tributary rivers) that include: Seguelil from Atar at the confluence of Adrar and Amsaga; El Abiod from the south; Khatt depression between Adrar and Tagant; and Tayaret, which is hundreds of kilometers long and is purported to be the oldest stream network, dating back to the Holocene (Friedel, 2008).

There are two primary lakes and numerous sebkhas (ephemeral lakes), such as Lake Aleg, which receives water from the Ketchi wadi, and Lake R'Kiz, which receives water from the Senega River (Friedel, 2008). There are a few small dammed reservoirs in the center and south of the country. Perennial springs occur in a few isolated areas.

Figure 2. Hydrological networks and location map of Mauritania

The climate in this region is of Saharan type. It is characterized by high daily temperatures and less than 70 mm/year of rainfall. The rainfall is highly variable both in space and time. Furthermore, since 1970, the annual rainfall has decreased by 35%as in most parts of North Africa. Most of Mauritania receives very little rainfall at any time of year, but the very southern edge reaches the semi-arid band called the Sahel and has a wet season between July and September when up to 200 mm of rain fall per month.

The current situation in terms of water resources, water use and water reuse

Water resources in Mauritania are divided between groundwater and surface water. There are significant groundwater resource sin terms of quantity and quality, however, characterized by large geographical disparities. The main continuous sheets are located in the coastal sedimentary basin (Trarza Bennichab and Boulenoir) and in the southern part of the basin Taoudenni (water Dhar). The underground renewable water resources are estimated at 0.3billion m^3. The surface water resources (Transboundary water resources) are estimated to total renewable 11.1billion m^3/year, consisting essentially of the Senegal River, which forms the border between Mauritania and Senegal, and its tributaries, and dam reservoirs scattered throughout the southern parts and central planning. Of the total 11.1billion m^3/year, only 0.1billion m^3 is generated internally. The total capacity of dams is estimated at about 0.9billion m^3, of which 0.5billion m^3 for the dam Foum Gleita. The Organization for the Development of the Senegal River (OMVS), which includes Mali, Mauritania and Senegal, was founded in 1972 and follows the Inter-State Committee for the Development of the Senegal River Basin (1963-1968) and then to the United States along the Senegal River (ESRO) from 1968 to 1972. Its mandate is to contribute to the economic development of the Member States for the purposes of exploitation of the resources of the Senegal River Basin. In 2000, water withdrawals were estimated at 1.698 billion m^3, of which 1.5 billion for agriculture (88 %), 150 million for domestic use (9 %) and 48 million for industry (3 %). Surface water is mainly used for irrigation; navigation, drinking and hydro power generation (Table 1 and Table 2)

Table 1. Water resources in Mauritania

Renewable freshwater resources		
Precipitation (long-term average) (mm/yr)		92
Precipitation (long-term average) (10^9 m^3/yr)		94.35
Internal renewable water resources (long-term average) (10^9 m^3/yr)		0.4
Total actual renewable water resources (10^9 m^3/yr)		11.4
Dependency ratio (%)		96.49
Total actual renewable water resources per inhabitant (m^3/yr)	2004	3 826
Total dam capacity (10^6 m^3)	1994	900

Table 2. Water use in in Mauritania

Water withdrawal		
Total water withdrawal (10^6 m^3/yr)	2000	1 698
Irrigation + Livestock (10^6 m^3/yr)	2000	1 500
Municipalities (10^6 m^3/yr)	2000	150
Industry (10^6 m^3/yr)	2000	48
per inhabitant (m^3/yr)	2000	642
Surface water and groundwater withdrawal (10^6 m^3/yr)	2000	1 696
as % of total actual renewable water resources (%)	2000	14.9
Non-conventional sources of water		
Produced wastewater (10^6 m^3/yr)		
Treated wastewater (10^6 m^3/yr)	1998	0.7
Reused treated wastewater (10^6 m^3/yr)	1998	0.7
Desalinated water produced (10^6 m^3/yr)	1990	1.7
Reused agricultural drainage water (10^6 m^3/yr)		

According to the Water Strategy set by the Ministry of Water and Sanitation in May 2012, the rate of sanitation coverage is 46% in 2010 at the national level. Access to sanitation in rural and urban areas appears as follows: a) 40% of households have access to sanitation rural sanitation by autonomous, and b) 60% of households have autonomous systems of urban sanitation. In this section, coverage is computed as the number of households connected/number of households in city or town or wilaya or moughataa. Mauritania is defined by very scarce and poorly documented water resources. Mauritania's water resources are far from insignificant, with an average of 2,800 m^3 / inhabitant / year in 2014, but they are very unequally distributed and difficult to mobilize, effectively resulting in extreme scarcity. Such resources comprise:

Surface water (97 % of renewable resources) concentrated along the southern border in the Senegal River, the only sustainable river in the country, and in countless ephemeral wadis. *Groundwater (3 % of renewable resources),* mostly in facture aquifers with low yields and high drilling failure rates, and, in some parts of the country, in more productive continuous porous aquifers. The lack of good water resources knowledge, planning and management affects the sustainability of current withdrawals and impairs the development of new resources. As Mauritania is located in one of the regions most affected by climate change, temperature increase and rainfall variability are certain to accelerate the depletion and degradation of water resources.

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Morocco

Morocco is located in the northwestern corner of Africa across the Mediterranean Sea and the Strait of Gibraltar from Spain (Figure 3). Morocco has an area of 446,300 square kilometers, not including 250 square kilometers of coastal waters, which makes it slightly larger than California. Western Sahara, claimed by Morocco, has an area of about 266,000 square kilometers.

Climate: The Rif and Atlas Mountain ranges divide Morocco into two climatic zones: one that receives the westerly winds from the Atlantic and one that is influenced by the proximity of the Sahara Desert. Western and northern Morocco have a Mediterranean (subtropical) climate, with mild winters and hot, dry summers. On the Atlantic Coast, the mean temperature is 16.4º C to 23º C. By contrast, the climate is more extreme in the interior, where it is subject to wide seasonal variation, with temperatures ranging from 10º C to 27º C. The pre-Saharan south has a semiarid climate. Rainfall varies from moderate in the northwest to scanty in the south and east. The rainy seasons are April–May and October–November. Only the mountains receive rain in the summer. Because of its inconsistent rainfall, Morocco is subject to periodic droughts, which take a considerable toll on agriculture.

Hydrology: Morocco has the most extensive river system in North Africa (Figure 1.18). Its two most important rivers are the Moulouya, which flows into the Mediterranean Sea, and the Sebou, which flows into the Atlantic Ocean. This is a list of rivers in Morocco; this list is arranged north to south by drainage basin, with respective tributaries indented under each larger stream's name:

Atlantic Ocean: Loukkos River; Sebu River (Guigou River) (Baht River, Oued Rkel, Ouegha River, Inaouen River; Lebne River; Fes River); Bou Regreg; (Grou River, Korifla River); Oued Nefifikh; Oued Mellah; Rbia River; Tessaoute River; Lakhdar River; El-Abid River; Tensift River; Nfis River; Ourika River; Oued Ksob; Oued Tamri ; Sous River ;Massa River ; Noun River (Assaka River); Draa River (Dadès River; Ouarzazate River, Imini River).

Mediterranean Sea: Laou River, Rhîs River, Nekor River, Kert River, Río de Oro, Moulouya River (Za River, Msoun River, Melloulou River)

Sahara Desert: Oued Guir, Ziz River (Oued Rheris, Oued Todrha)

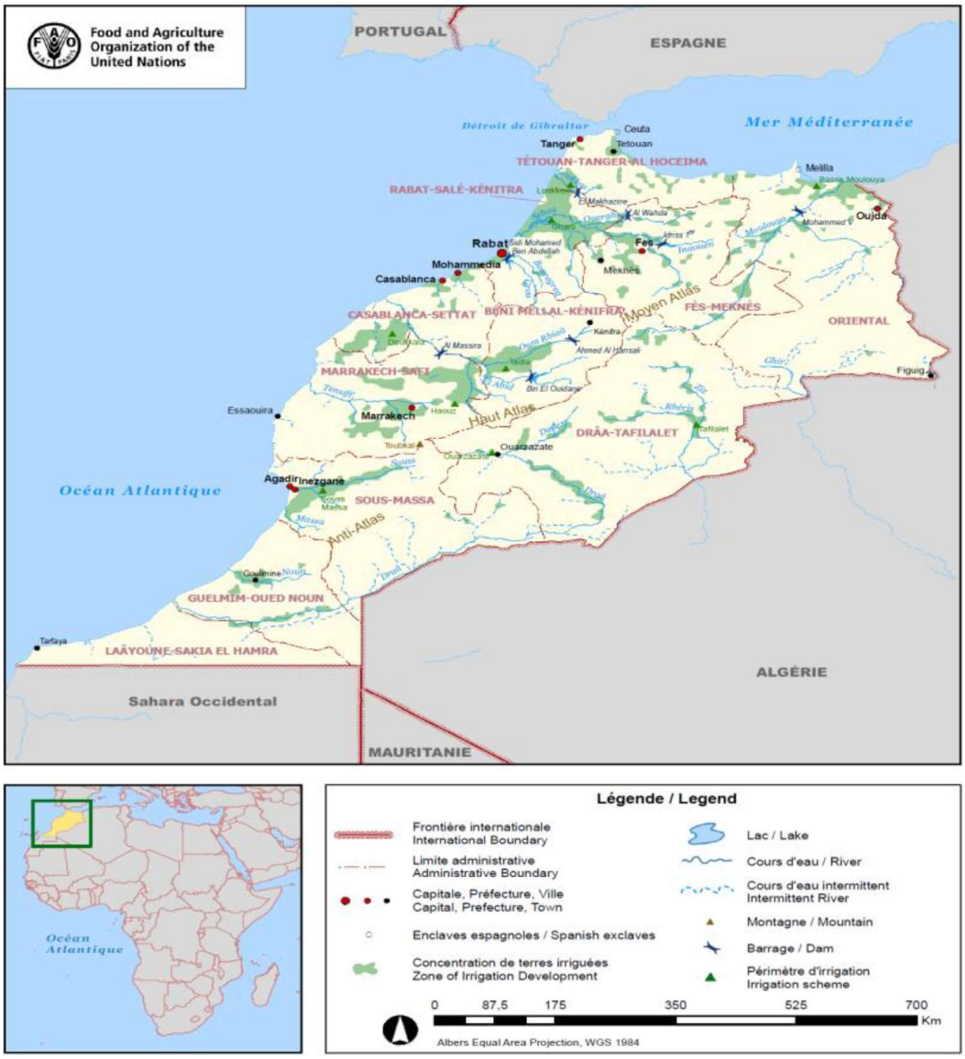

Figure 3. Hydrological networks and location map of Morocco.

Morocco is characterized by the uneven distribution of water both spatially (asymmetry may be observed among water basins in the course of the hydrological year) and temporally (annual precipitation may diverge significantly, almost o n a 1:10 ratio), and this is the main feature of the hydrological regime. Furthermore, Morocco has experienced severe droughts in recent decades with occasional extreme precipitation episodes and disastrous flash floods. The most rainfall occurs between October and May. Higher annual precipitation occurs in the mountainous areas of the north-west, in the Loukkos river basin, Tangier and the Mediterranean coast, at more than 1,000 millimetres per year (mm/yr). Conversely, precipitation is less than 300 mm/yr in the Moulouya, Tensift, Souss-Massa and South Atlas basins. In the sub-Saharan region, it is even lower, at less than 100 mm/yr.

Morocco is divided into seven major river basins, as shown in Table 3, as well as a number of smaller basins. Freshwater recharge is estimated at 22 billion m³ per year, of which 18 billion m³ per year come from surface water and 4 billion m³ per year from groundwater. Surface water resources are characterized by high variability: resources for nine years out of ten, or four years out of five, are significantly below this average. Surface water inflows reach several million cubic meters for basins with the least water in average years. This runoff is largely due to rapid and powerful floods. They are generally recorded during an average estimated period of 20 to 30 days for the basins in southern Morocco, and two to three months for basins in northern Morocco and the Moulouya River region. In a drought year, water inflow can drop to under 30 % of this mean value. Managing the uneven distribution of water resources in time and space has involved the construction of large dam reservoirs for storing the inflow from wet years to be used in dry years and transferring water from regions with surplus water to regions with water shortages in order to encourage balanced economic and social development across the whole of Morocco. The mobilized potential still available from conventional surface water sources is rather limited. It is certain that between 80 and 90% of economically accessible surface water resources have already been regulated through dams and interannual storage reservoirs in Morocco.

Table3. River basins in Morocco

Name of basins	*Surface area (Km²)*	*Average surface water runoff (mm³/yr)*
Loukkos, Tangier and Mediterranean coastlines	12,800	3,600
Sebou	40,000	5,600
Moulaya, Figuig, Kert, Isly and Kiss	76,664	1,610
Bou Regreg and Xhawia	20,470	847
Oum Er-Rbia and El Jadida-Safi	48,070	3,447
Tensift and Ksob-Igouzoulen	24,800	872
Souss-Massa-Draa	126;480	1,398

The current situation in terms of water resources, water use and water reuse

According to estimates, Morocco has an average annual renewable water resource potential of almost 22 billion m³, of which approximately 18 billion m³ are surface water and 4 billion m³ groundwater. Average annual rainfall is 140 billion m³, but can vary from 50billion m³ to 400 billion m³. The country's internal annual renewable freshwater resources per capita are 899 m³ (2011) and are projected to decrease to 508 m³ in 2020, which is well below UNDP's 1,000 m³ scarcity threshold. Evapotranspiration is high: evaporation and transpiration losses are, on average, 118 billion m³ per year.

Potential groundwater resources are estimated at around 4,105 million m³ per year, of which 1,017 million m³ per year come from irrigation water returned via surface water in particular. Groundwater has been consumed at a high rate of around 4.2 billion m³ per year, a value 10 % higher than the average annual replenishment, leading to water destocking estimated at 0.9 billion m³ per year. This extraction has led to a rapid drop in the water table, at a rate of 2 m per year on average. Unsustainable abstraction rates have been used in several aquifers (Saïss, Souss, Témara, Haouz and South Atlas). Aquifer overexploitation is endangering the socioeconomic development of rural areas, creating a dysfunctional ecological situation, and increasing desertification (Table 4).

Table 4. Water resources in Morroco

Renewable freshwater resources		
Precipitation (long-term average) (mm/yr)		346
Precipitation (long-term average) (million m³/yr)		154 500
Internal renewable water resources (long-term average) (million m³/yr)		29 000
Total actual renewable water resources ((million m³/yr)		29 000
Dependency ratio (%)		0
Total actual renewable water resources per inhabitant (m³/yr)	2013	879
Total dam capacity (million m³)	2015	17 500

Wastewater potential is evaluated at around 485 million m³ for 2010 and 700 million m³ for 2030, of which approximately 60% is discharged directly into the sea. Morocco is only just starting to produce freshwater by desalination or demineralization. For the moment, this is only used for urban water supply in the Saharan provinces (El Aaiun, Tarfaya, Smara and Boujdour). Overall production capacity is already around 16,500 m³ per day. In addition, around a quarter of groundwater is, either in whole or in part, brackish water. This water is mostly situated in the country's desert and semi-desert regions (Table 5).

Since the 1960s, Morocco has adopted an appropriate policy of water resources development focused on the construction of dams, which has provided drinking water supply security for all the towns and cities in the country and made it possible to develop approximately 1,500,000 ha of irrigated land, of which approximately 700,000 ha are part of large irrigated areas.

Table 5 Water use in Morroco

Water withdrawal		
Total water withdrawal (million m³/yr)	2010	10 580
Irrigation + Livestock (million m³/yr)	2010	9 156
Municipalities (million m³/yr)	2010	1 063
Industry (million m³/yr)	2010	212
per inhabitant (m³/yr)	2010	334
Surface water and groundwater withdrawal (million m³/yr)	2010	10 515
as % of total actual renewable water resources (%)	2010	36
Non-conventional sources of water		
Produced wastewater (million m³/yr)	2012	700
Treated wastewater (million m³/yr)	2011	166
Reused treated wastewater (million m³/yr)	2008	70
Desalinated water produced (million m³/yr)		
Reused agricultural drainage water (million m³/yr)	2000	7

Up until the beginning of the 21st century, public investments in urban water in Morocco focused mainly on universalizing access to drinking water, leaving aside the disposal and treatment of wastewater. However, informal reuse of raw water was common in many city peripheries including Mekne`s, Marrakesh, and Settat (Dugué and Valette, 2015; Tanouti, 2013; Mayaux and Massot, 2019). This changed markedly with the launching of the national sanitation plan in 2006 *(French acronym PNA)*. The plan aimed to increase the overall treatment rate from a mere 8%–60% by 2020. This required building—and rehabilitating—some 187 plants by 2020, a target later increased to 330 by 2030, 145 of which were effectively operational in 2015 (CREM, 2018). This opened up new opportunities for water reuse. The national water plan *(French acronym PNE)*, released in 2009, forecasts a total volume of reusable wastewater of 424 Mm³ by 2020 and 935 Mm³ by 2030. The plan aimed to achieve a reuse rate of 19% by 2020 and 31% by 2030; at that time, this amounted to a total volume of reused water of 300 Mm³, later increased to 325 Mm³.

In 2017, 47.5 Mm³ were effectively being reused in 24 different projects (l'Economiste, 2017); by far the most for golf resorts. The Cherifian Office of Phosphates also reuses treated water to wash its mineral rocks, while some cities, including Ouarzazate, use their treated water to irrigate their green spaces and green belts. After a number of small-scale experiments dating back to the early 1990s (Belghiti, 2013), three projects for agricultural use of treated water are now underway with treated water in Tiznit, Settat, and Oujda.

Aside from the national water plan, three different planning documents in 2017 dealt with wastewater reuse. The National Sanitation program for rural areas *(French acronym PNAR)* was prepared by the Ministry of the Interior. The National Plan for treated wastewater reuse *(French acronym PNRUE)* was drafted by the Water Department of the Ministry of Energy, Mines and Sustainable Development, and the National Plan for wastewater reuse in Agriculture *(French acronym PDREUTI)* issued by the Ministry of Agriculture. In 2018, these plans were merged into a single, comprehensive National Plan for Integrated Sanitation *(French acronym PNAM)*. The new plan aims to reuse some 428 Mm³ of water by 2025, 474 Mm³ by 2030, and 573 Mm³ by 2040. This includes an objective of 134 Mm³ for agriculture to eventually irrigate a surface area of 15,363 ha.

Promising though these figures may seem on chapter, they overlook the fact that a significant amount of water is already being reused informally. Therefore, the claim that wastewater represents a previously "untapped" resource should be examined critically. As mentioned above, part of the difficulty involved stems from the lack of official, aggregate data on illegal uses. However, case studies in Settat, Marrakesh, and Tiznit have all shown that at least part of the raw wastewater is already used downstream. The new projects (for golfing resorts in Marrakesh, for agriculture in Settat and Tiznit) are undoubtedly safer, as they are formally organized around treatment plants. But they all entail some reallocation from previous users to new beneficiaries, and in one case at least (i.e., Marrakech) this reallocation clearly shifted upward, targeting wealthy international consumers. However, to go beyond such anecdotal evidence, we would need better aggregate data on all current uses, including information on the types and numbers of beneficiaries, and the incomes they derive from wastewater, whether directly (through productive uses) or indirectly (through the rental value of their land).

Algeria

Algeria is located in northwestern Africa (Figure 4), bordering the Mediterranean Sea between Morocco and Tunisia. Algeria has an area of almost 2.4 million square kilometers, more than four-fifths of which is desert. Nearly 3.5 times the size of Texas, Algeria is the tenth largest country in the world and the second largest in Africa.

Climate: The coastal lowlands and mountain valleys are characterized by a Mediterranean climate, mild winters, and moderate rainfall. In this densely populated region, temperatures average between 21°C and 24°C in the summer and drop to 10°C to 12°C in the winter. Average temperatures and precipitation are lower in the intermountain High Plateaus region. The desert is hot and arid. Most of the country experiences little seasonal change but considerable diurnal variation in temperature. Rainfall is fairly abundant along the coastal part of the Tell, ranging from 400 to 670 millimeters annually, with the amount of precipitation increasing from west to east. Precipitation is heaviest in the northern part of eastern Algeria, where it reaches as much as 1,000 millimeters in some years. Farther inland the rainfall is less plentiful.

Hydrology: Algeria's largest river is the Chelif, flows 725 kilometers from the Tell Atlas into the Mediterranean Sea (Figure 1.5). The country is divided into 17 major hydrographical basins, of which five are transboundary: the Medjerda basin is shared with Tunisia, and the Tafna, Draa, Guir and Daoura basins are shared with Morocco. The Seventeen principal wadis are:

Mediterranean Sea: Tafna River (Isser River), Hammam River (Habra River) (Macta River) (Sig River, Mebtouh River), Chelif River (Mina River, Djediouia River,Ghiou River (Riou River),Sly River, Tsighaout River, Fodda River,Rouina River (Zeddine River), Ebda River, Massine River, Deurdeur River, Akoum River, Nahr Ouassel River,Touil River), Mazafran River; Harrach River; Reghaïa River; Boudouaou River;Isser River (Malah River); Sebaou River; Soummam River (Amassine River, Bou Sellam River,Sahel River); Kebîr River (Jijel) (Enndja River; Rummel River); Guebli River; Safsâf River; Kebir River (Skikda); Seybouse River (Cherf River); Kebîr River (El Taref); Medjerda River (Mellègue River, Ksob River (Chabro), Meskiana River

Sahara: Sebkhet el Melah (Oued Saoura (Oued Zousfana, Oued Guir (Oued Béchar) Oued Messaoud (Oued Tilia); Chott Ech Chergui (Oued el Korima):;Chott el Hodna (Oued Leham); Chott Melrhir (Oued Djedi, Oued Zeribet, Oued el Arab, Oued el Mitta, Oued Ittel, Oued el Kherouf); Sebkhet Safioune (Oued Zegrir, Oued Mya); Sebkha Mekerrhane, Oued Tsaret, Asouf Mellene, Oued Tasendjanet); Aharrar (Oued Igharghar, Oued Tafassasset, Oued Ti-n-Tarabine, Oued Igharghar, Oued Zazir, Oued Ti-n-Amzi, Oued Tamanrasset); Grand Erg Occidental (Oued Namous).

Rainfall is fairly abundant along the coastal part of the Tell, ranging from forty to sixty-seven centimeters annually, the amount of precipitation increasing from west to east. Precipitation is heaviest in the northern part of eastern Algeria, where it reaches as much as 100 centimeters in some years. Farther inland the rainfall is less plentiful. Prevailing winds that are easterly and northeasterly in summer change to westerly and northerly in winter and carry with them a general increase in precipitation from September to December, a decrease in the late winter and spring months, and a near absence of rainfall during the summer months.

The annual amount of rain is 100 billion m^3, of which 80 % evaporate into the atmosphere. The water resources are estimated at 19.3 billion m^3/year, of which 12.4 billion of surface water and 6.9 billion of underground water. Only 6 billion could be mobilized by dams. For the moment only four billion are mobilized by nearly 110 dams.

From the 6.7 billion of groundwater resources, 5.1 billion are located in Sahara. The rest, i.e.1.6 billion m^3, is already mobilized at a rate of 80 %, principally by wells and boreholes.

The North West and the North east of Algeria, have been passed in the last decade more episodes of drought. Dam's volumes and water table levels are decreased. The drought in those regions is Meteorological, caused by the continuous reducing of average rainfall (Rahmani et al., 2015). The Algerian steppes have great importance in the National Development Strategy (Higher Plate Development Program). The rapid demographic growth applies a high pressure on water resources. Since the last few decades, water resources in steppe were limited in terms of quantitative availability and quality. (Rahmani et al., 2020)

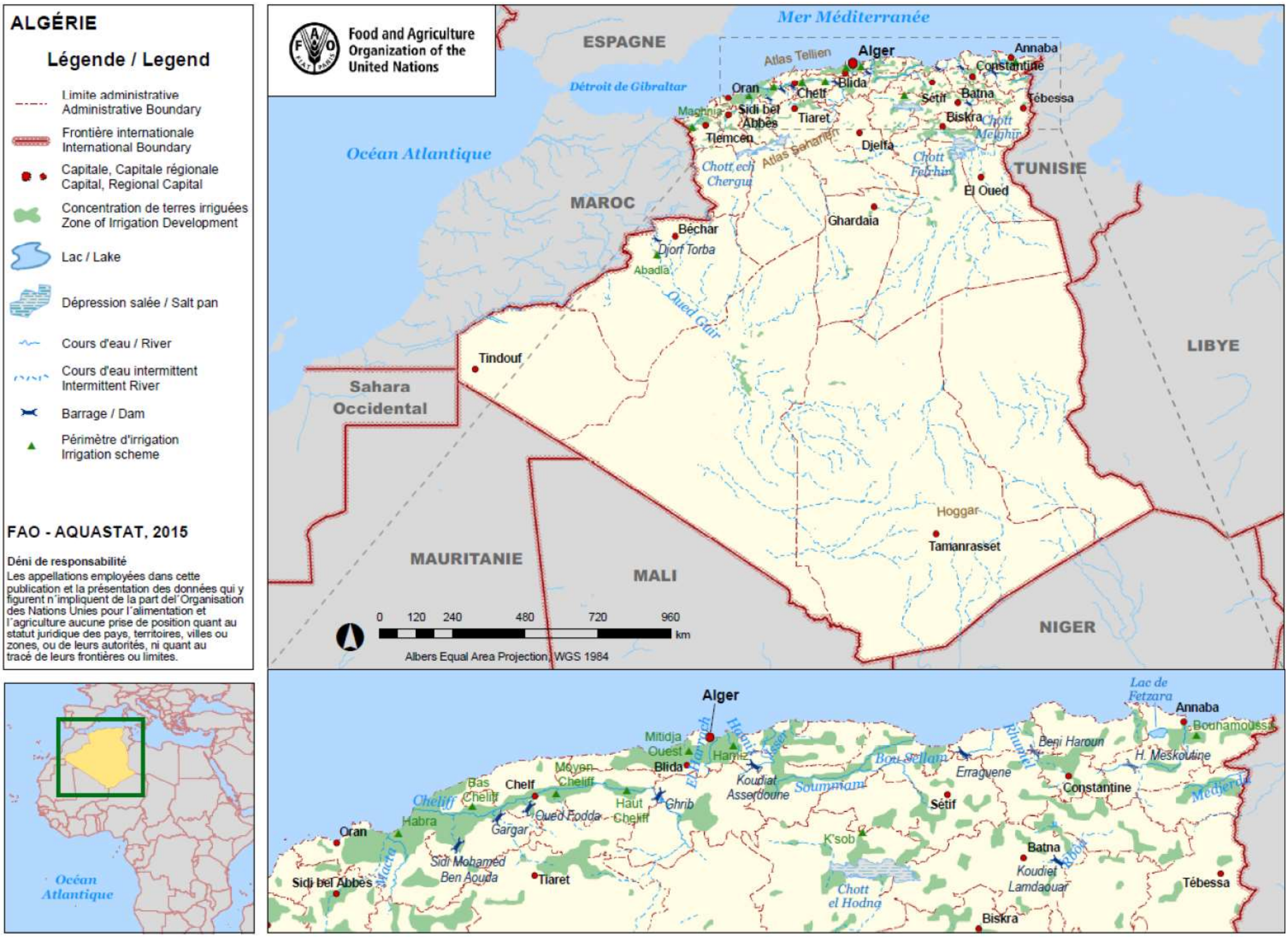

Figure 4. Hydrological networks and location map of Algeria

The current situation in terms of water resources, water use and water reuse

Algeria is Africa's second most water scarce country (after Libya), with only 297.6 m^3 available per person per year, well below the 1,000 m^3 per year international water scarcity threshold. Water shortages, aggravated by regular droughts, are a major problem and a limiting factor in the availability of safe drinking water (Table 6)

Table 6.. Water resources in Algeria

Renewable freshwater resources		
Precipitation (long-term average) (mm/yr)		89
Precipitation (long-term average) (million m³/yr)		212 000
Internal renewable water resources (long-term average) (million m³/yr)		11 250
Total actual renewable water resources ((million m³/yr)		11 670
Dependency ratio (%)		4
Total actual renewable water resources per inhabitant (m³/yr)	2014	292
Total dam capacity (million m³)	2015	8 300

Potential water resources in Algeria are 19.2 billion m^3 (surface water 12.4 billion m^3 and underground water 6.92 billion m^3, mainly in the Sahara). The national average rainfall is around 89 mm per year, well below the level required to sustain rain-fed agriculture. The average annual water crop is estimated at 100 billion m^3, of which approximately 80 % is lost as evapotranspiration. The underground aquifers in the north are exploited to 90%, with 2 billion m^3 per year. The lack of surface water resources has culminated in the overexploitation of coastal aquifers and their contamination from saltwater intrusion. The Oranie and Cheliff water basins are the most affected by this phenomenon. Consequently, salinity affects irrigated agricultural land, which, in some instances, has become irreversibly sterile. In the Sahara region, the extracted volume is valued at 1.7 billion m^3 (Table 7).

In June 2018, total production of domestic wastewater in Algeria was 1596Mm³. Table 8 lists forecast indicators for the 2035 horizon based on the National Water Plan, which is used as a tool for water resources management in Algeria ((Ministère des ressources en eaux ,2010). In 2018, the total volume of wastewater produced and managed by the Algerian wastewater treatment office (ONA) was more than 577Mm³. The number of treatment plants also monitored by ONA was 148 for a treated volume of 123Mm³.

Table 7. Water use in Algeria

Water withdrawal		
Total water withdrawal (million m³/yr)	2012	8 425
Irrigation + Livestock (million m³/yr)	2012	4 990
Municipalities (million m³/yr)	2012	3020
Industry (million m³/yr)	2012	415
per inhabitant (m³/yr)	2012	219
Surface water and groundwater withdrawal (million m³/yr)	2012	7800
as % of total actual renewable water resources (%)	2012	67
Non-conventional sources of water		
Produced wastewater (million m³/yr)	2012	820
Treated wastewater (million m³/yr)	2012	324
Reused treated wastewater (million m³/yr)	2012	10
Desalinated water produced (million m³/yr)		
Reused agricultural drainage water (million m³/yr)	2012	615

Table 8. Predicted increase in the quantity of wastewater in Algeria (Ministère des ressources en eaux ,2017).

Horizon	*Total wastewater (Mm³/yr)*	*Plant capacity (Mm³/yr)*	*Treated wastewater (Mm³/yr)*
2020	1190*	1060	650
2025	1360	1320	820
2030	1570	1510	1020
2035	1780		1625

* The expected volume was reached in 2012

The first legislative framework for the treatment of wastewater, named "Concession for the use of treated wastewaters for irrigation purposes," dates from May 23rd, 2007 and provides a general framework for using these waters (definition of wastewater, sanitary controls, and financial agreement). An interministerial decree published in January 2012 lists the required properties of treated wastewater for irrigation purposes. It defines thresholds for microbiological parameters, physical parameters, chemical parameters, and heavy metals. These thresholds are inspired by WHO (World Health Organization) standards and are probably too inflexible for the Algerian context. Today, the number of treatment plants officially concerned by wastewater reuse is 17 and the volume reused is 8Mm³.The total irrigated area covers more than 11,000 ha, particularly fruit trees (palm dates, olive, etc.) and some cereals. The most emblematic cases for controlled water reuse are Hennaya-Tlemcen in the North West and Guelma-Bouchegouf in the north east, with 912ha and 6980ha of irrigated land, respectively. In both cases, water is released from an activated sludge plant into a river and then pumped to the plots.

Tunisia

Tunisia is a country in the Maghreb region of North Africais, situated to the south of the Mediterranean; it is bordered by Libya in the southeast, Algeria in the west (Figure 5). Tunisia's surface area is of 164,000 km², its coastline totals 1300 km, its average altitude is 700 m and its highest point is the Jebel Châambi (1540 m). Tunisia country share many common features in terms of climate, water and land resources and development issues. These include arid and semi-arid climate, limited water resources, agricultural development limited by water availability and high economic and social value of water.

Climate: Tunisia's geographical situation, bordering the Mediterranean on the east and north and stretching to the Sahara in the south, gives it an arid diversified climate. The climate is varying from Mediterranean to semi-arid and arid, ranging from humid in the extreme North to desert-type in the extreme south. The climate is Mediterranean, ranging from humid in the extreme North to desert-type in the extreme south. In the north and along the coast, the climate is Mediterranean; inland and in the south, it is semi-arid to arid. The hottest month is August with a mean monthly temperature of 26ºC, and a highest monthly temperature of 28.7ºC. January is the coolest month having a mean monthly temperature of 10.7ºC and a lowest value of 8.4ºC. The mean annual temperature in Tunisia varies between 15ºC in the North to 21ºC in the South. The climatic and geomorphologic characteristics define three major agro-ecological zones:

- The North, constitutes a sylvo-agricultural region (mainly forests and annual crops); its average rainfall is between 400-600 mm and its main topographic features are mountain pasturelands in the north-west and fertile plains in the north-east.
- The Centre, constitutes an agro-pastoral region (pasturelands and crops); its rainfall is between 200-400 mm, and its morphology is composed of a low steppe to the east with fertile plains interrupted by depressions and a high steppe with mountain pasturelands and plains.
- The South, with irregular rainfall of 100-200 mm, is characterized by its aridity and vulnerability of its soils to desertification. This area is pastoral with oases.

Hydrology: This is a list of rivers and wadis in Tunisia (Figure 1.26). This list is arranged by drainage basin, with respective tributaries indented under each larger stream's name:

North Coast: Oued Zouara, Oued Sejenane (Oued Zitoun), Oued Joumine, Oued Tine, Oued Medjerda (Oued Siliana, Oued Tessa, Oued Mellègue (Oued Sarrath), Oued Miliane (Oued el Hamma))

East Coast: Oued el Hadjar, Oued Lebna, Oued Chiba, Oued Nebhana, Oued Zeroud (Oued Merguellil, Oued el Hattab Oued el Hajel (Oued el Fekka), Oued el Leben)

Interior: Oued el Melah (Oeud Sefioune, Oued el Kebir), Oued Jeneien

As an arid to semi-arid country, Tunisia is facing water shortages of increasing severity. Most regions in Tunisia have modest rainfall: only one-third of the territory benefits from 400 mm p er year, while t wo-thirds receive less than 4 00 mm per year. Rain is concentrated between May and September, with a limited number of days receiving rainfall. Two-thirds of the country, for example, receives an average of less than 50 days of rainfall. Tunisia, like all countries in the MENA region, is characterized by overall water scarcity. Even without the impacts of climate change, Tunisia already faces an increasing scarcity of water resources and a number of challenges in the water sector.
Tunisia is divided into seven river basin districts, which include several river basins:

- Basin 1, which covers the northernmost part of the country;
- Basin 2, which comprises the Cap-Bon watershed and the Miliene River;
- Basin 3, corresponding to the Medjerda River watershed, which is the most important river basin in Tunisia;
- Basin 4, which corresponds to the central part of the country (Zeroud, Merguellil and Nebhana rivers);
- Basin 5, which comprises the Sahel of Sousse and Sfax;
- Basin 6, which expands from the southern limit of Basin 4 and the Sahel up to the north of Chot el Jerid; and
- Basin 7, which covers the southernmost part of the country, up to the Algerian and Libyan borders.

Figure 5. Hydrological networks and location map of Tunisia.

The current situation in terms of water resources, water use and water reuse

Water resources in Tunisia are characterized by large variability in both time and space. In terms of spatial variability, mean annual precipitation ranges from 1500 mm on the peaks of the Kroumirie mountains in the north-western corner of Tunisia to less than 100 mm in the south. Variability in time is very high both within and between years. Mean total precipitation is 36 km^3 of which only 3 km^3 could be potentially collected as runoff water in large dams. Renew-able groundwater resources are estimated at 1.8 km^3. The water resources are about 4.8 billion cubic meters of which 2.7 billion cubic meters are from surface water and 2.1 billion cubic meters from groundwater. The annual total volume of exploitable water resources in Tunisia is about 4800 Million cubic meters of which about 56% (2700 MCM) is surface water and the remaining 44% (2100 MCM) groundwater (Gaaloul; 2021). The escalation of urban water demand has led to an increasing use of freshwater for domestic purposes and to the production of large volumes of wastewater. In turn, this has a significant impact on the allocation of water for crop irrigation: the agricultural sector is expected to face significant water quantity and quality problems, given that the volume of freshwater that becomes available for crop irrigation is decreasing. Furthermore, there is growing competition over available resources near large urban centers. In the above context, policy makers have been compelled to develop additional resources, and to take measures towards water resource conservation. Currently, the main components of the National Water Resources Management Strategy are gradually shifting towards surface water mobilization, soil and water conservation works, water harvesting, and the use of non-conventional water resources, such as the re-use of treated wastewater for crop irrigation and aquifer recharge.

The water distribution resources in the three geographical regions is quite different:

- Most surface water resources are localized in the Northern region (81.2%) which represents only 17% of the total Tunisian area,
- The biggest part of the ground water resources is in the south, particularly in deep-lying aquifers with fossil water form,
- The Center is the poorest region on water resources

Water resources are unevenly distributed across the country with around 60% located in the North, 18% in the Center, and 22% in the South. Water quality, especially salinity, is a serious constraint. Surface water has a generally low salinity (with the exception of the tributaries entering the Medjerda river from the south). Groundwater are badly affected with 84% of all groundwater resources having salinity levels of more than 1.5 g/L and 30% of the shallow aquifers more than 4.0 g/L.. Figure 6 shows a detailed classification of water resources in Tunisia according to their salinity. In Tunisia, 26% of surface freshwater, 91.6% of groundwater (shallow aquifers) and 80% of groundwater (deep aquifers) have got water salinity of over 1.5 g/L. It is clear that a large percentage of these waters need to be desalted before they can be exploited. Out of the modest quantities of water available, only a small portion meets the standards for potable water due to high salinity levels. Only 8.4 % of the total shallow groundwater has salinity levels inferior to 1.5 g/L (Gaaloul, 2021).

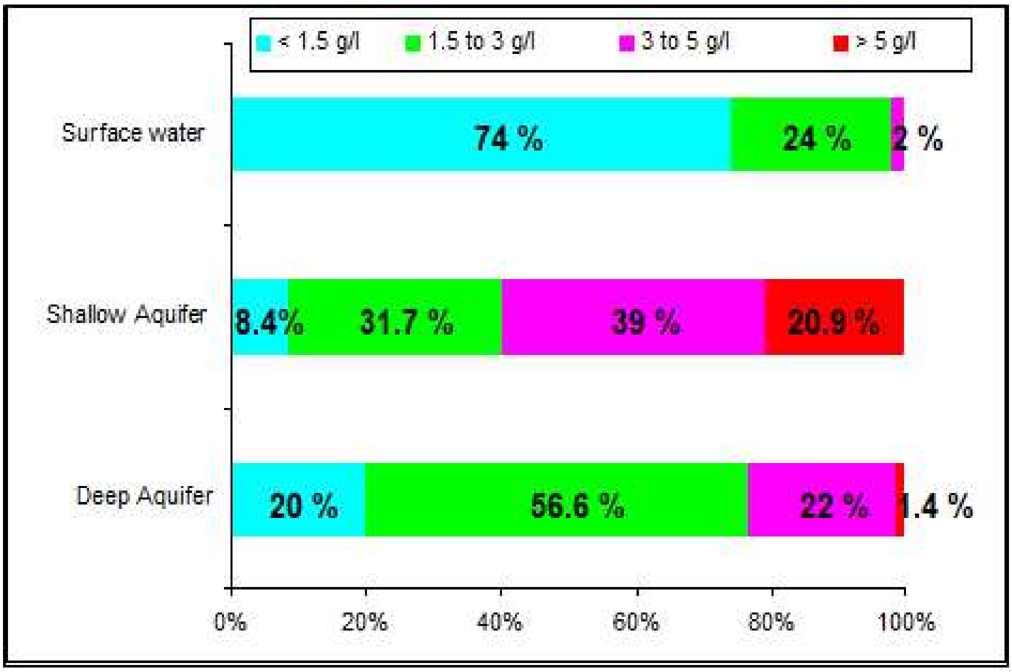

Figure 6 Tunisian water resources classification according to salinity levels.

On a national scale, water resources are distributed unequally (Table 9; Table 10 and Table 11). In most regions' precipitation is insufficient and unpredictable, and it is unevenly distributed across regions. Groundwater supplies a large part of water resources, whether for drinking or agriculture. The country belongs to the so-called variability group of countries in North Africa, which consists of countries that have more or less adequate quantities of renewable water at the national level, but with high levels of variation between different parts of the country and over time. The primary concern is therefore internal distribution, both geographically and temporally. Climate change is predicted to increase the natural variability of precipitation regimes in Tunisia, along with a predicted overall decrease in mean annual precipitation, which will make water management increasingly difficult for water and agriculture planners.

Table 9. Geographical distribution of different categories of water in Tunisia

Basin	*Far North*	*North*	*Center*	*South*	*Total*
Regional surface (%)	3			62	100
Supply of surface water (million m³)	960	1 230	320	180	2 700
Groundwater (million m³)		395	216	108	719
Deep Groundwater (million m³)		269	326	822	1 417
Total potential resource (million m³)		2 854	862	1 120	4 836
Percent		59	18	23	100

Tunisia, like any Mediterranean country, is subject to the vagaries of the climate with droughts more frequent forcing him to focus on water resources. In fact, it has for decades, public facilities for the storage, transfer and distribution of water, which allowed him a multiyear regulation of water resources and the needs of all economic and social sectors. Surface water intakes from four distinct natural regions by their climatic, hydrological and geomorphological and geological aspects; these are:

- The extreme north: Although its area presents only 3% of the total land area, it provides surface water intakes estimated on average to 960 million m³ / year, 36% of the total potential of the country.
- The North: presented by the basins of the Medjerda Cap Bon and Méliane and provides an average of 1,230 million m³ / year, 46% of the total potential surface water.
- The center: it includes the watersheds Nebhana, Marguellil, Zeroud and Sahel and presents annual resources estimated at an average of 320 million m³ / year, or 12%.
- The South: it content for about 62% of the total land area, it is the poorest region in surface water and has only very irregular resources, assessed at 190 mm³ / year, or 6% of the total potential.

Access to drinking water reached 100 % in urban areas in 2011 and 93.5 % in rural areas, connection rates that are close to those observed in OECD countries and very high compared with the average for the North Africa region.

Table 10. Water resources in Tunisia

Renewable freshwater resources		
Precipitation (long-term average) (mm/yr)		207
Precipitation (long-term average) (million m³/yr)		33 870
Internal renewable water resources (long-term average) (million m³/yr)		4 195
Total actual renewable water resources (million m³/yr)		4 615
Dependency ratio (%)		9
Total actual renewable water resources per inhabitant (m³/yr)	2013	419.7
Total dam capacity (million m³)	2012	2 677

Table 11 Water use in Tunisia

Water withdrawal		
Total water withdrawal (million m³/yr)	2011	3 305
Irrigation + Livestock (million m³/yr)	2011	2 644
Municipalities (million m³/yr)	2011	463
Industry (million m³/yr)	2011	165
Tourisme ((million m³/yr)	2011	33
per inhabitant (m³/yr)	2011	307
Surface water and groundwater withdrawal (million m³/yr)	2011	3 217
as % of total actual renewable water resources (%)	2011	70
Non-conventional sources of water		
Produced wastewater (million m³/yr)	2009	287
Treated wastewater (million m³/yr)	2010	226
Reused treated wastewater (million m³/yr)	2010	68
Desalinated water produced (million m³/yr)		
Reused agricultural drainage water (million m³/yr)	2012	19.7

Most residents of large urban centers have access to adequate sanitation systems and the wastewater treatment facilities generally follow conventional designs. The sanitation coverage in the sewered cities is about 78%; this rate, related to the whole urban population (5.8 million), is 61%. Concerning industry, compliance with the Tunisian standards to discharge wastewater into the sewerage system is required. So, preliminary treatment plants to fulfil the discharge requirements stated in the regulations must be implemented. Subsidies are given to equip industrial units with pre-treatment processes (Gaaloul, 2021).

Of the 240 Mm^3 of wastewater discharged annually, 140 Mm^3 (58%) are treated in 61 treatment plants (WWTP) of which around 41 have a daily capacity less than 3500 m^3 and 10 above 10 000 m^3, Choutrana being the largest with 120 000 m^3/d. Five treatment plants are located in the Tunis area, producing about 62 Mm^3/yr or 54% of the country's treated effluent. Several of the plants are located along the shoreline to protect coastal resorts and prevent sea pollution. Municipal wastewater is mainly domestic (about 88%) and processed biologically up to a secondary treatment stage. The treatment processes vary from plant to plant depending on wastewater origin and on local conditions. Out of 61 treatment plants, 44 are based on activated sludge (medium or low rate), 3 on trickling filters, 14 on facultative or aerated ponds. Sanitation master plans have been designed for several towns. The annual volume of reclaimed water is expected to reach 290 Mm^3 in the year 2020. The expected amount of reclaimed water will then be approximately equal to 18% of the available groundwater resources and could be used to replace groundwater currently being used for irrigation in areas where excessive groundwater mining is causing salt-water intrusion in coastal aquifers (Gaaloul, 2021).

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Libya

Libya is located in North Africa on the coast of the Mediterranean Sea (Figure 7). It is bordered on the east by Egypt; on the south by Sudan, Chad, and Niger; and on the west by Algeria and Tunisia. Libya's total area is 1,759,540 square kilometers of landmass, which is slightly larger than Alaska or approximately three times the size of France. Agriculture contributed 1.9 % to the GDP in 2008 (WB, 2016) and was similar in 2010 (WFP and FAO, 2011). It has declined over time as the importance of the oil rose. The sector employs around 6 % of the active population (GIA and UNDP, 2008). Most agriculturally productive land is limited to a strip along the Mediterranean Sea, where most rain falls. The two main areas of natural farmland are the high coastal plateau of Jabal al Akhdar in the north-east and the fertile coastal plain of Tripolitania and Cyrenaica in the north-west, where irrigation is still vital. There are some oases in the desert where water is available from shallow wells. Wheat and barley are the major cereals grown in the country. Other important crops include olives, grapes, dates, almonds and oranges. The main agricultural products exported are groundnuts, which represented about 50 % of all agricultural exports. Livestock is also important with poultry (24.8 million estimated in 2008), small ruminants (5.1 million sheep, 1.9 million goats) and cattle (210 000).

Climate: The Mediterranean Sea and Sahara Desert are the dominant climatic influences in Libya. In the coastal lowlands, where 80 % of the population lives, the climate is Mediterranean, with warm summers and mild winters. The climate in the desert interior is characterized by very hot summers and extreme diurnal temperature ranges. Along the Tripolitanian coast, summer temperatures range between 40.6°C and 46°C; temperatures are even higher to the south. Summer temperatures in the north of Cyrenaica range from 26.7°C to 32°C. The ghibli, a hot, dry, dust-laden desert wind, which can last one to four days, can change temperatures by 17°C to 22°C in both summer and winter. Precipitation ranges from light to negligible. Less than 2 % of the country receives enough rainfall for settled agriculture. The Jabal areas of the north receive a yearly average of 381 to 508 millimeters. Other regions get less than 203 millimeters. Rain usually falls during a short winter period and frequently causes floods. Winters can be bitterly cold, with temperatures below 0°C. Frost and snowfalls sometimes occur in the mountains. Evaporation is high, and severe droughts are common.

Hydrology: Libya has several perennial saline lakes but no significant perennial watercourses. The only permanently flowing river is the two-kilometer-long Wadi Kiam (Figure 7). The principal wadis are:

Tripolitania: Wadi Awwal (Wadi Tanarut, Wadi Maymun); Wadi Majer - near Zliten; Wadi al Mujaynin; Wadi Turghut (west); Wadi al Masid, Wadi Turghut (east); Wadi Labdah; Wadi Ki'am (Wadi Targhalat) - Libya's only perennial stream; Wadi Sawfajjin; Wadi Zamzam; Wadi Bey al Kabir; Wadi Thamit; Wadi Jarif; Wadi Tilal; Wadi ar Rijl (Wadi Matratin).

Fezzan: Wadi Tanezzuft, Wadi Barjuj, Wadi ash Shati, Wadi Umm al Ara'is, Wasi an Nashu

Cyrenaica: Wadi al Qattarah, Wadi Darnah, Wadi al Khalij, Wadi Husayn, Wadi al Mu'allaq, Wadi at Tamimi, Wadi al Farigh, Wadi al Hamim.

Libya has four main water basins (Figure 8):

- The western aquifer system, including three interconnected sub-systems: the Murzuq Basin; Jabal Hasawnah; and Al Hamadah al Hamra system;
- the Jefarah Plain system;
- the Al Sarir-Al Kufrah Basin system; and
- the Al Jabal al Akhdar system.

There are no permanent rivers in Libya, only ephemeral rivers or wadis. The main natural lakes are the Ubari lakes in the Ubari Sand Sea in the south, including the Gaberoun, Mandara and Mafo akes–, the protected Ouau en Namu lakes and the 23rd of July or Benghazi lake, which is actually a lagoon. There are two Ramsar sites since 2000: Ain Elshakika and Ain Elzarga totalling 83 ha. The Qattara Depression in the north-west of Libya lies under the sea level and is covered with temporary lakes, salt pans and salt marshes. Other large salt pans include Sabkhat al Hayshah close to the coast near the gulf of Sidra, and Sabkhat Shunayn and Ghuzayyil in the north-east.

Libya has a large number of natural springs in particular in the northern parts of the country, many of which are of good quality water. Some of the larger sources are Ayn Zayana, Ayn Kaam, Ayn Dabbousia and Ayn Tawargha (CEDARE, 2014).

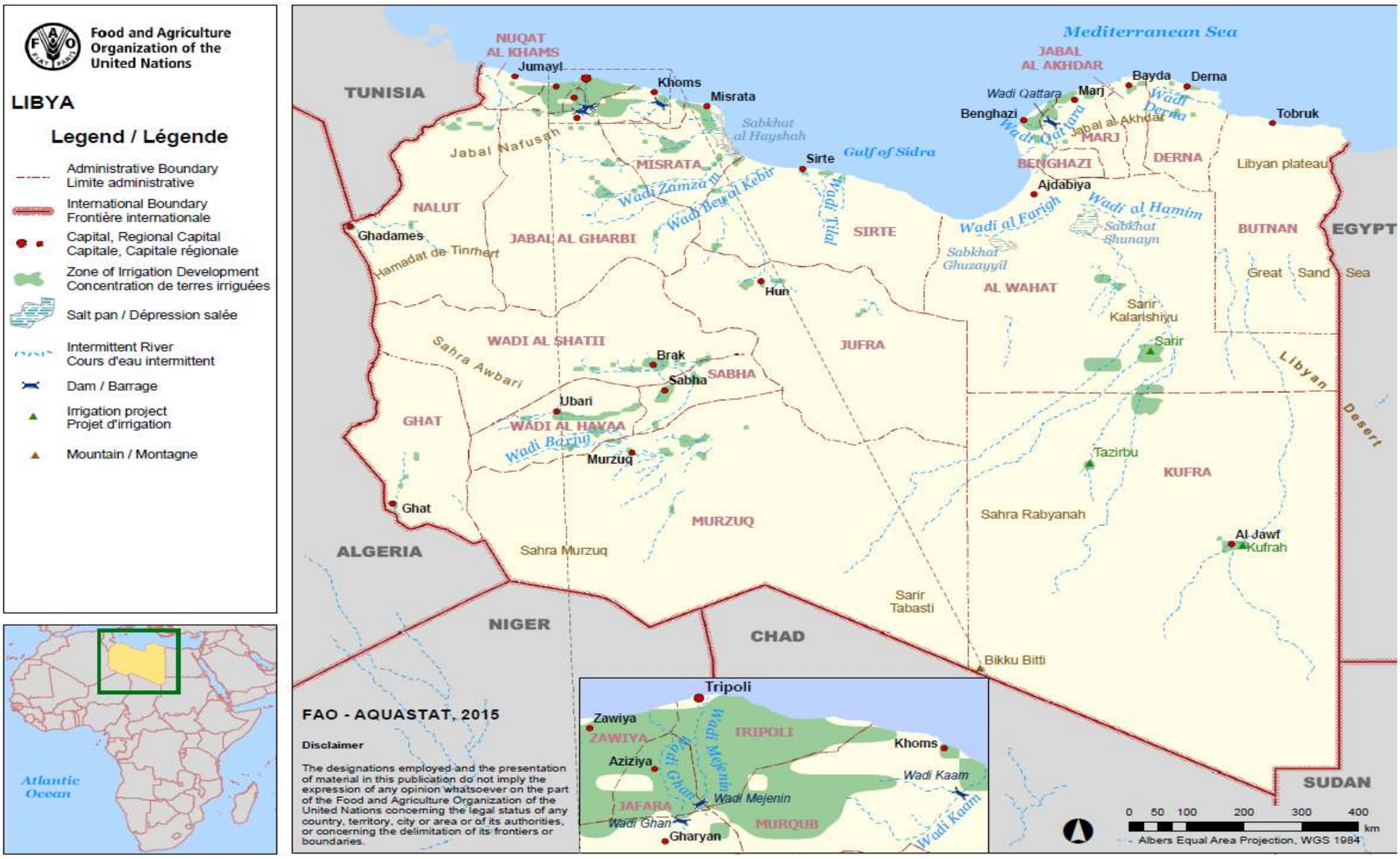

Figure 7. Hydrological networks and location map of Libya

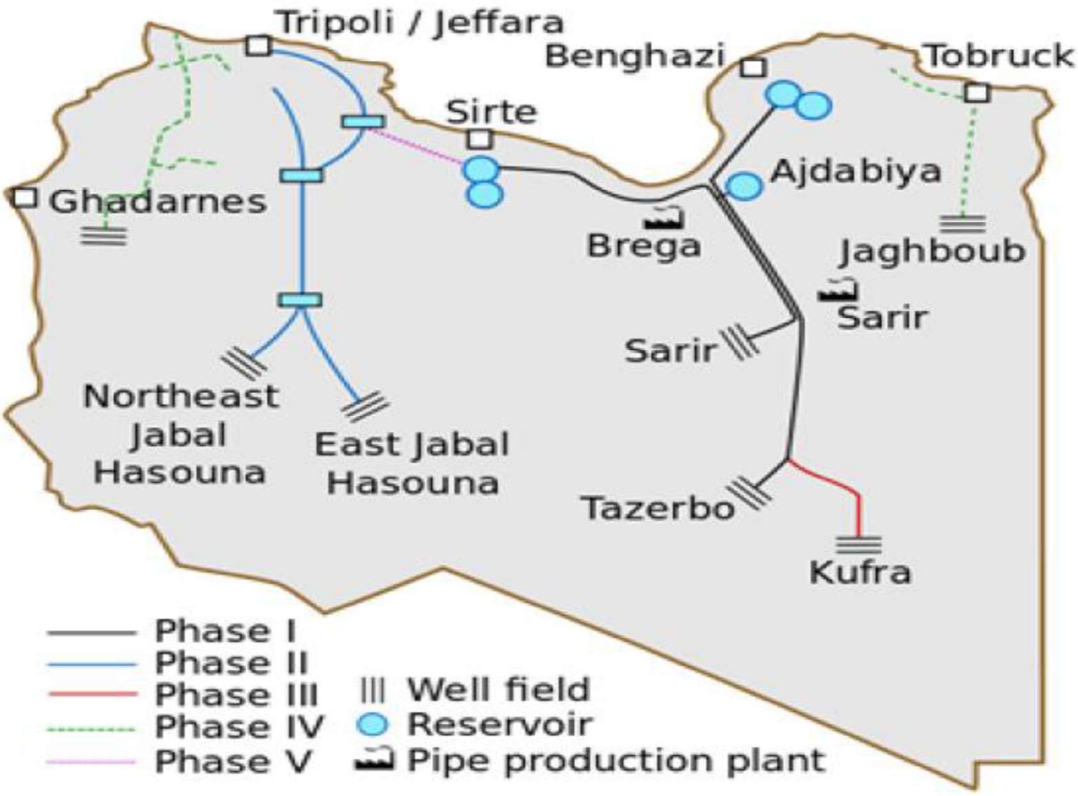

Figure 8. The Great Man-Made River (GMR) in Libya

The current situation in terms of water resources, water use and water reuse

With very limited perennial water resources, Libya relies almost completely on non-renewable, fossil, groundwater resources (MWR and CEDARE, 2014).

Five major aquifers underlie Libya. The first two aquifers are interconnected and form the Western Aquifer. Only the coastal aquifers, the Al Jefara in the north-west and the Al Jabal al Akhdar in the north east are shallow and naturally recharged from the rainfall, as well as part of the Al Hamada aquifer. Part of the Al Hamada, the Murzuq and the Al Sarir-Kufra aquifers, south of 29° North latitude, belong to the great sedimentary basins and are fossil water reserves where the water was stored during the Quaternary. The Al Sarir-Kufra aquifer is part of the Nubian Sandstone Aquifer System (NSAS), the largest aquifer in the world covering an area of about 2 million km² in Libya, Chad, Sudan and Egypt. The Al Hamada aquifer is part of the North Western Saharan Aquifer System (NWSAS) shared with Algeria and Tunisia and consisting of the shallow Terminal Complex sandstone and limestone aquifers and the deeper Continental Interlayer sandstone aquifer (Abdudayem and Scott, 2014).

The Libyan population increased from less than one million in 1955 to 6 million in 2005 and it is expected to reach more than 12 million by 2025 (NASID, 2006). As indicated in Table 12, the total available fresh water supplies on sustainable basis has been estimated at the fixed rate of 2279.5 million m^3 / year (GWA, 2000). According to these figures the national annual average per capita water availability decreased from 2280 m^3 in 1955 to 380 m3 in 2005 and is expected to reach 190 m^3 by the year 2025. Thus, the whole country is already experiencing water scarcity that is getting more severe with time.

Before the 1960s, water from the shallow coastal aquifers could be extracted through wells and traditional tools thanks to shallow water table. From the 1960s onwards, however, pumps were necessary due to falling water table coinciding with the oil boom (CEDARE, 2014). During the oil exploration in the 1950s and 1960s, the deep fossil aquifers were discovered. Their water was first used on site, to develop agricultural projects in the desert close to the wells, but water scarcity and the intense population concentration in the north coast triggered the need to their transfer, initiating the Great Man-made River Project (GMRP) in 1984.

Table 12. Sustainable Water Supplies from all Available Sources in Major Basins of Libya in million m^3 per year (MCM/Y) *Source General Water Authority (2000).*

Water Basin	*Surface Water Resources*	*Groundwater Resources*	*Unconventional Water resources*	***Total***
Jefara Plain	52	200	27.5	**279.5**
Jabal Alakdar	92	200	45.5	**337.5**
Alhamads Alhamra	48	230	50.5	**328.5**
Kufra and Sarir		563		**563**
Murzuk		771		**772**
Total	**192**	**1964**	**123.5**	**2279.5**

The Great Man-Made River (GMR), also called An-Nair Sinai, transports fossil water from the vast Nubian Sandstone Aquifer System in the south of Libya, northwards to the populated coastal cities. In 1983, GMR was originally intended to supply 67% of the agricultural sector's needs. It now provides about 75 % of Libya's annual water demand (urban plus agriculture), from 1,000 wells, through 4,000 km of buried 4-meter-diameter pipe, with some surface water impoundments for interim water storage.

GMR's first aquifer, the Kufra Basin in southeast Libya, has an estimated groundwater storage capacity of nearly 5,000 cubic miles, in the Libyan sector alone. GMR's first stage, completed in 1991, supplies Benghazi and fills coastal reservoirs. As mentioned below, desert reservoirs have huge risks of evaporation. GMR has supplied Tripoli's water since 1997. Ultimately GMR is expected to provide 3,000 Mcm annually from its 30,000 cubic kilometer aquifers. The goal is to sup 5 million cubic meters per day to coastal populations. Caveat: Global estimates of the availability of ground water often are optimistic; Libya is no exception. Water is priced by fiat; lowest (LYD 0.048) for agriculture, double that for domestic use (LYD 0.08), and highest for industry (LYD 0.796), according to the World Bank (2006). These prices are deeply subsidized, rarely adjusted, and fail to reflect the cost of production.

Although two-thirds of GMR water was originally allocated to irrigation, now 98 % of GMR water is consumed domestically. CEDARE (2014) estimates 225 years, assuming an acceptable drawdown of 100 meters (long since exceeded) and a planned future abstraction of 1,090 Mcm annually. Of course, water lifting and pumping costs rise sharply as the water levels decline. The International Atomic Energy Agency (IAEA) is active in dating groundwater in Libya to infer flow patterns and any recharge. Most desert aquifers are smaller than Libya's, and most are rapidly retreating worldwide under heavy pumping.

Could it be that the bigger constraint becomes the availability of fuel for pumping the water from ever-deeper levels? At present, pumping water from possibly as many as 1,000 wells, from as deep as 2 kilometers (km) up to the pipeline system, consumes much fuel. Once in the pipeline, gravity, supported by some pumps, feeds the demand centers. The pipelines are getting longer, water levels are falling and demand is soaring. Thus, the fuel consumed in pumping is already expensive for Libya and will become more so as global oil prices rise. Every barrel of oil needed for pumping costs Libya US$90 or more in foregone exports. (Salem, 1998; 1992).

Despite an estimated cost of over US$ 30 000 million, Libya relied only on national funding, especially from the oil sector. The final objective, after completion of the five phases, is to transfer 5-6 million m³/day to the northern cities through over 500 wells of 500 m deep and about 4 000 km of pipelines (Figure 8)

Phase 1 finalized in 1991, being able to convey up to 2 million m³/day of water for 1 600 km to two reservoirs in the Benghazi and Sirte areas.

Phase 2 brought up to 2.5 million m³/day along 1 227 km to Tripoli from 1997.

Phase 3 enabled to transfer an additional 1.68 million m³/day of water from the Al Sarir aquifer to Tobruk through 621 km of pipeline

Phase 4 will extend the distribution network from Gadamis (Jabal Nafusah and Al Jefara aquifers) to the coast west of Tripoli

Phase 5 is intended to join both the eastern and western systems into a single network. However, the civil unrest stopped further works and some NATO bombings destroyed some reservoirs. Initially allocated to irrigation, transferred water from the GMRP is used at 98 % by municipalities (EGA, 2013). Estimations of the availability of fossil water for this transfer vary greatly: between 50 years and over 4 000 years, depending on actual abstraction of water and sources.

Internal renewable surface water resources are estimated at 200 million m³/year and renewable groundwater resources at around 600 million m³/year, but 100 million m³/year is considered to overlap between surface water and groundwater, which gives a value of total internal renewable water resources (IRWR) of 700 million m³/year (Table 13). No surface water or groundwater is entering the country. The total renewable water resources are 700 million m³/year, or 111.5 m³/year per capita in 2015, Libya being thus well under the absolute water scarcity threshold of 500 m³/year per capita. Fossil groundwater water leaving the country to neighboring countries is estimated at 700 million m³/year.

Currently 19 dams are in operation, including a secondary dam on Wadi Qattara, for a total storage capacity of about 390 million m³ (Table 13). However, their average annual storage capacity is only about 61 million m³ and in fact, due to lower flow records or damage to some dams, it is estimated to even not exceed 30 to 40 million m³/year. Some 20 dams are planned for construction representing an additional 136.6 million m³ of storage and 45 million m³ of additional average annual storage.

Table 13. Water resources in Libya

Renewable freshwater resources		
Precipitation (long-term average) (mm/yr)		56
Precipitation (long-term average) (million m³/yr)		98 530
Internal renewable water resources (long-term average) (million m³/yr)		700
Total actual renewable water resources ((million m³/yr)		700
Dependency ratio (%)		0
Total actual renewable water resources per inhabitant (m³/yr)	2015	112
Total dam capacity (million m³)	2015	389.89

Desalination started in Libya in the early 1960s and installed capacity reached 226.3 million m³/year in 2006 for a total of more than 400 desalination plants, including 17 large ones (GEC, 2006). In 2012, the total desalinated water produced in Libya is estimated at 70 million m³/year aimed at municipal and industrial water demands and using both thermal and membrane technologies. Thermal desalination plants are located directly at electricity generation facilities.

Libya also has 79 wastewater treatment plants in 2010 for a total capacity of 74 million m³, all of which were designed to produce effluents suitable for irrigation. However, out of the 504 million m³ municipal wastewater produced in 2012, only 40 million m³ were treated and directly used in irrigation on 2 900 ha.

In 2000, the total water withdrawal was estimated at 4 268 million m³, of which 83 % was withdrawn for agricultural purposes, 14 % for municipal purposes and 3 % for industrial purposes. More than 30 % of the municipal water demand was supplied by the Great Manmade River Project (GMRP). In 2012, the total water withdrawal is estimated at 5 830 million m³, including 4 850 million m³ or 83 % for agriculture, 700 million m³ or 12 % for municipalities and 280 million m³ or 5 % for industries (Table 14).

Groundwater (including fossil groundwater) provides over 95 % of the water withdrawn or 5 500 million m³ in 2012. The remaining is divided between surface water, with a total controlled volume of 170 million m³/year (CEDARE, 2014), desalinated water and wastewater. The National Strategy for Sustainable Development of 2008 considered that a “sustainable” groundwater abstraction should not exceed 3 650 million m³/year, despite only 650 million m³/year comes from renewable groundwater and 3 000 million m³/year actually comes from fossil water–from the Jefara plains (25 million m³), the Jabal al-Akhdar (25 million m³), the Kufra and Sarir (1 300 million m³), the Hamada (150 million m³) and the Murzuq (1 500 million m³).

Table 14. Water use in Libya

Water withdrawal		
Total water withdrawal (million m³/yr)	2012	5 830
Irrigation + Livestock (million m³/yr)	2012	4 850
Municipalities (million m³/yr)	2012	700
Industry (million m³/yr)	2012	280
per inhabitant (m³/yr)	2012	947
Surface water and groundwater withdrawal (million m³/yr)	2012	5 720
as % of total actual renewable water resources (%)	2012	817
Non-conventional sources of water		
Produced wastewater (million m³/yr)	2012	504
Treated wastewater (million m³/yr)	2008	40
Reused treated wastewater (million m³/yr)	2008	40
Desalinated water produced (million m³/yr)		
Reused agricultural drainage water (million m³/yr)	2012	

Due to the fact that fossil groundwater is not included in the renewable water resources, the current water withdrawal is more than 8 times the annual renewable water resources. More than half of the domestic water supplies in 2012 were from the Great Manmade River Project (MWR and CEDARE, 2012).

In rural areas people depend to a large extent on private water supply wells, rainwater reservoirs, and springs. A large number of industries, such as the chemical, petrochemical, steel, textile and power generation industries, depend on private sources for water supply, including desalination of seawater (Table 15)

Table 15. Water resources in the major water basins in Libya

Water Basin	*Surface Water resources (million m³/yr)*	*Ground Water resources (million m³/yr)*	*Unconventional Water resources (million m³/yr)*	*Total (million m³/yr)*
Al Jefara Plain	200	52	27.5	279.5
Al Jabal al Akhdar	200	93	45.5	337.5
Al Hamada: al Hamra	230	48	50.5	328.5
Murzuq	563			563
Al Sarir-Kufra	771			771
Total	1 964	192	123.5	2 279.5

Libya does not share any surface water with other neighboring countries, but a most of its groundwater is shared (Table 16).

Table 16. Transboundary aquifers (Source: IGRAC, 2014; EGA, 2013)

Aquifer name	*Total aquifer area (km²)*	*Sharing countries and respective share (%)*
Nubian Sandstone Aquifer System (NSAS)	2 607 9995	Chad (11), Egypt (38), Libya (34), Sudan (17)
Murzuq-Djado basin	450 000	Algeria, Libya, Niger
Northwest Sahara Aquifer System (NWSAS)	1 189 533	Algeria (68), Libya (24), Tunisia (8)

The Joint Authority for Study Development of the NSAS was established in 1992 with its headquarters in Tripoli, Libya, initially between Egypt and Libya, and then joined by Sudan in 1996 and Chad in 2000. It coordinates the activities of the countries related to the NSAS and enhance cooperation for its management, in particular through two agreements to exchange updated data.

The Sahara and Sahel Observatory (OSS) hosts a light structure for the management of the NWSAS since 2002. In 2008, a consulting mechanism was formulated to sustainably manage the groundwater resource. It includes a permanent Technical Committee composed of the respective national water authorities, alternatively presided over for one year by the three countries, operating since 2008.

Photograph 1.1 Irrigation circles in the Libyan Desert

Photograph 1.2 Satellite image of irrigation circles at Khufa, Libya

CLIMATE CHANGE IN MAGHREB REGIONS (MAURITANIA, MOROCCO, ALGERIA, TUNISIA AND LIBYA)

The Middle East and North Africa region is experiencing a widening gap between freshwater supply and demand caused by population and economic growth and climate change. The region is diverse in its landscapes and climates, from the snowy peaks of the Atlas Mountains to the empty quarter of the Arabian Peninsula. The MENA region can be classified according to the aridity index, which is defined as the ratio between precipitation and ETref. On the basis of this index, the largest part of MENA can be classified as hyper-arid (<0.05) (World Bank, 2007). This hyper-arid area includes the inland in Northern Africa (Algeria, Libya, and Egypt). The coastal areas of Northern Africa, Iran, and the Western coastal region of the Middle East are defined as arid to semi-arid. Humid areas are found in the northern parts of Morocco, Algeria, Tunisia, Iraq, and Iran, and the western part of Syria and Lebanon.All the countries of the region are located on the coasts of the North Atlantic Ocean, the Mediterranean Sea, the Red Sea, the Gulf of Aden, the Persian Gulf, the Gulf of Oman and the Arabian Sea and, as such, there is no land-locked country in this region. The areas located along the Mediterranean coast lines display lower temperatures and more rainfall resulting in a more moderate climate when compared to the hot inland deserts.

Population densities in MENA are largest in semi-arid to humid regions, or where irrigation systems are present. Irrigation systems are mainly concentrated in the Nile Delta in Egypt, where it covers 60–80% of the surface area (World Bank, 2007), in the central part of Iraq, and scattered throughout Iran. Despite the presence of some humid regions and irrigation systems, the MENA region faces many challenges.

The countries of the Near East region have been grouped in three sub-regions based primarily on geographic and hydro-climatic similarities. These sub-regions are referred to as North Africa (Algeria, Egypt, Libyan Arab Jamahiriya, Mauritania, Morocco and Tunisia), Arabian Peninsula (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates and Yemen), and Middle East (Islamic Republic of Iran, Iraq, Jordan, Lebanon and Syrian Arab Republic). Even though hot and dry weather prevails across the Near East region, there is a great variety in the physical geography of this vast area. The region is characterized by the presence of long coastal lines, vast deserts, rivers, and mountain ranges with resulting diverse hydro-climatic conditions. Some of the main transboundary rivers in the region originate outside of the Near East with their water flows generated from places like eastern Turkey (Tigris-Euphrates) and the Ethiopian highlands and great lakes of humid Africa (River Nile).

The largest challenge in the MENA region is that countries have to manage an unusual combination of a low annual precipitation that is at the same time highly variable. Three groups of countries can be identified:

- *(i)* Countries that on average have adequate quantities of renewable water, but the within-country and within year variations are problematically large. These include Djibouti, Iran, Lebanon, Morocco, Tunisia, and the West Bank.
- *(ii)* Countries with consistently low levels of renewable water resources. Therefore, these countries are highly dependent on non-renewable groundwater sources and supplies by desalination of sea water. These countries include Bahrain, Gaza, Jordan, Kuwait, Libya, Oman, Qatar, Saudi Arabia, the United Arab Emirates, and Yemen.
- *(iii)* Countries that mainly dependent on the inflow of transboundary rivers such as the Nile, the Tigris, and the Euphrates. These countries include Syria, Iraq, and Egypt (World Bank, 2007).

In Figure 9, it is clear that in the majority of countries the annual precipitation sum for the current climate is low. Especially in Libya and Egypt the annual precipitation sum is very small (<25 mm). The wetter areas are the coastal areas of Morocco, Algeria, Tunisia, Lebanon, Syria, Iran, and Yemen. Decreases in precipitation are nearly seen in every country for the period 2020–2030, with the largest decreases found in southern Egypt, Morocco, the central and coastal areas of Algeria, Tunisia, central Libya, Syria, and in the central and eastern part of Iran. Decreases are in the range of 5–15% for most countries, with a decrease of more than 20% in southern Egypt. In several regions, also increases in precipitation are noticed. Increases are in the range of 0–20%. It should be noted that the annual precipitation sum in these regions is very low, meaning that an increase of, for example, 20% in southeast Libya means an annual increase of roughly 5 mm.

For 2040 through 2050 we see a larger decrease in precipitation for the majority of countries than for 2020 through 2030. Especially in Morocco, the central and northern part of Algeria, Tunisia, Syria, the southern and central part of Saudi Arabia, the northern part of Iraq, and in Iran, precipitation has decreased with respect to the current climate and 2020–2030. (Terink et al., 2013)

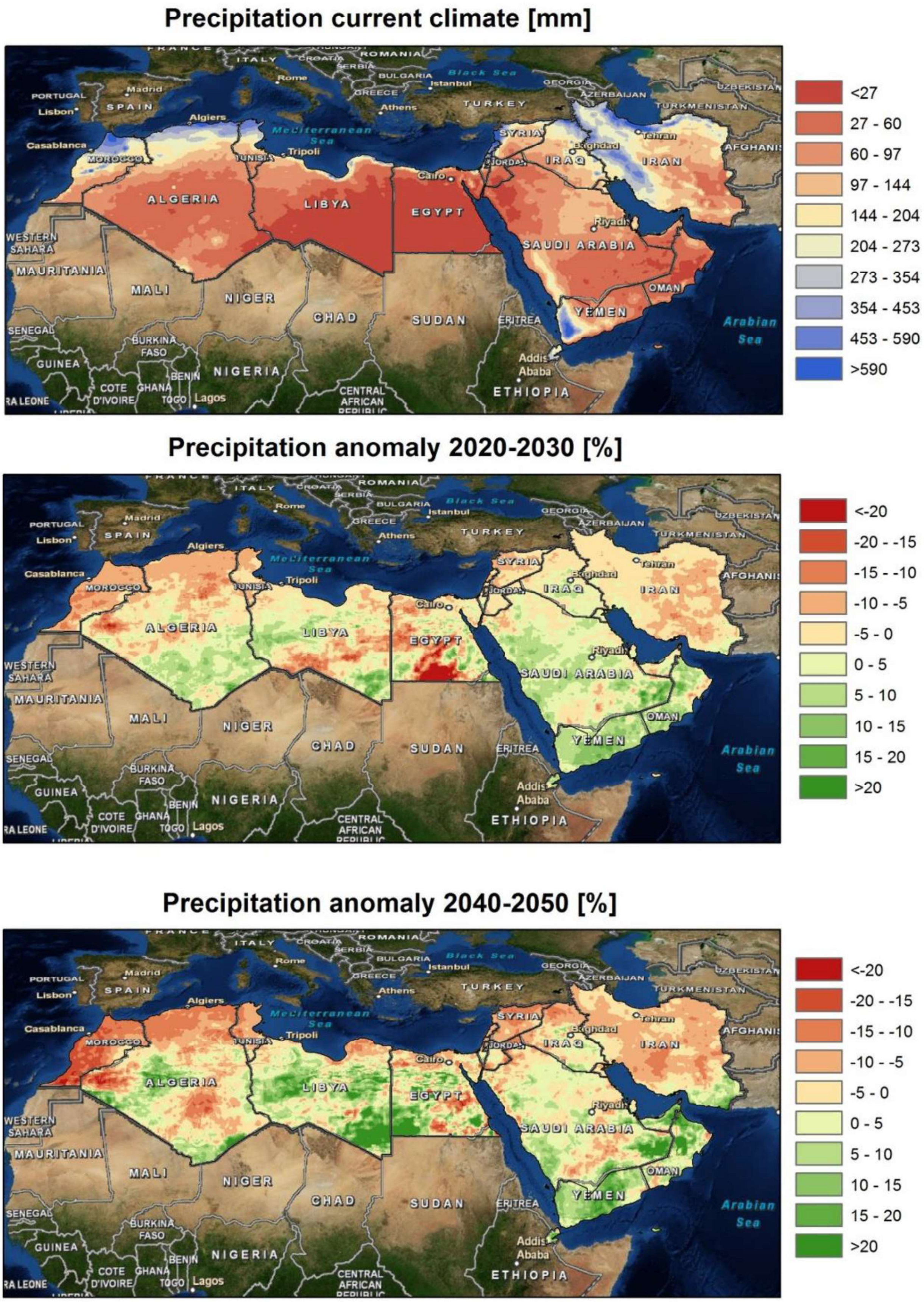

Figure 9 Spatial patterns of precipitation projections. Top: Average annual precipitation sum of the current climate. Middle: Precipitation anomalies of 2020–2030 with respect to the current climate. Bottom: Precipitation anomalies of 2040–2050 with respect to the current climate. (Walter et al., 2011).

If we consider the temperature projections (Figure 10) then it is clear that the MENA region is characterized by high average annual temperatures. Very high temperatures are found in the southwestern part of Algeria, the western and eastern part of Saudi Arabia, in Yemen, in Oman, and in the southern part of Iran. Temperature projections for 2020-2030 indicate a rise in temperature throughout all countries. The smallest increases in temperature (<0.15 °C) are found in North Libya, North Egypt, Israel, Lebanon, Jordan, and West Syria. The largest temperature increases (>0.65 °C) are found in the northern part of Morocco and Algeria, South Algeria, the southern part of Saudi Arabia and Iran, and in the central and northern part of Yemen and Oman.

Temperature projections for 2040-2050 indicate an even larger increase in temperature throughout the MENA region. An increase of more than 1.7 °C is not an exception. These findings are higher than the global average (Figure 1.3). The smaller temperature increases are found in the same regions as in the period 2020-2030. Large temperature increases (>1.5 °C) are found in the northern part of Morocco and Algeria, central and South Algeria, the central and southern part of Saudi Arabia, and in the northern part of Iraq, Iran and Yemen.

Much of the land area in the Near East region is covered by deserts. The Sahara Desert stretches from the Red Sea in the east to the Atlantic Ocean in the west, representing more than 90% of the landmass of Northern Africa. The Rub Al Khali Desert, known also as the Empty Quarter, covers an area 1,000 km long and 500 km wide in the South of the Arabian Peninsula. There is also the Nefud Desert in the northern part of the Arabian Peninsula. Other main deserts in the region include the Dasht-e Kavir and Dasht-e Lut deserts which cover large parts of east central and north sections, respectively, of the Islamic Republic of Iran. The Near East region has many internal mountains as well as several mountain ranges rising to various elevations. These include Tebetsy Mountain in Libyia with the highest peak of 3,000 meters. The Atlas Mountains range in North Africa which stretches across much of Morocco, northern Algeria and part of Tunisia has its peak in Morocco at an elevation of 4,165 meters. The Zagros mountain chain in the Islamic Republic of Iran reaches 4,432 meters at its peak. Other mountain ranges in the region include those in Lebanon and Yemen with highest elevations at just over 3,000 and 3,268 meters, respectively

Walter et al (2011) consider the anomalies for 2020-2030, then we notice a slight increase in annual reference evapotranspiration. This increase is in the range 0-1% for the largest part of the countries. Despite the lowest values of annual reference evapotranspiration found in the coastal areas, these areas are exposed to the largest (up to more than 9%) increase in annual reference evapotranspiration. In some countries, like for example in Algeria, Libya, Egypt and Jordan, we see a small decrease in annual reference evapotranspiration. This is caused by the range between the maximum and minimum temperature for the selected random year,

> For 2040-2050 there is an increase in annual reference evapotranspiration in all countries, except for some small regions in Morocco, Libya, and Egypt. Again, these decreases are very small. The highest increases are again found in the coastal regions, with increases of more than 9%.
>
> The MENA region is home to some of the poorest and most malnourished people in the world. An estimated 70% of the poverty is found in rural areas although only about 43% of the total population (over one billion) lives there. Cereals provide the largest component of the human diet in the region, while livestock production, often the major income earning activity in marginal areas, is increasingly dependent on supplementary feeding of grain.
>
> The region already has the highest level of imports of food grain globally. Demand will rise while regional production will be increasingly affected by water scarcity. In order to assess the scope and impacts of water scarcity and droughts in the MENA region, we should give an in depth assessment of the current situation with regards to water scarcity and droughts, and consists of data collection of information at river basin or local level, and we should give also give an inventory of measures taken by MENA countries to manage water scarcity and droughts in proactive and reactive ways.

The last climate variable of interest is the reference evapotranspiration (Figure 11). A clear pattern of annual reference evapotranspiration is observable for the current climate. The coastal areas have the smallest annual reference evapotranspiration, while moving inland the reference evapotranspiration becomes higher. The largest annual reference evapotranspiration values (>2200 mm) are found in South-West Algeria, South Egypt, Djibouti, the southeastern part of Saudi Arabia, the southern part of Iraq and Iran, North-East Yemen, and West Oman.

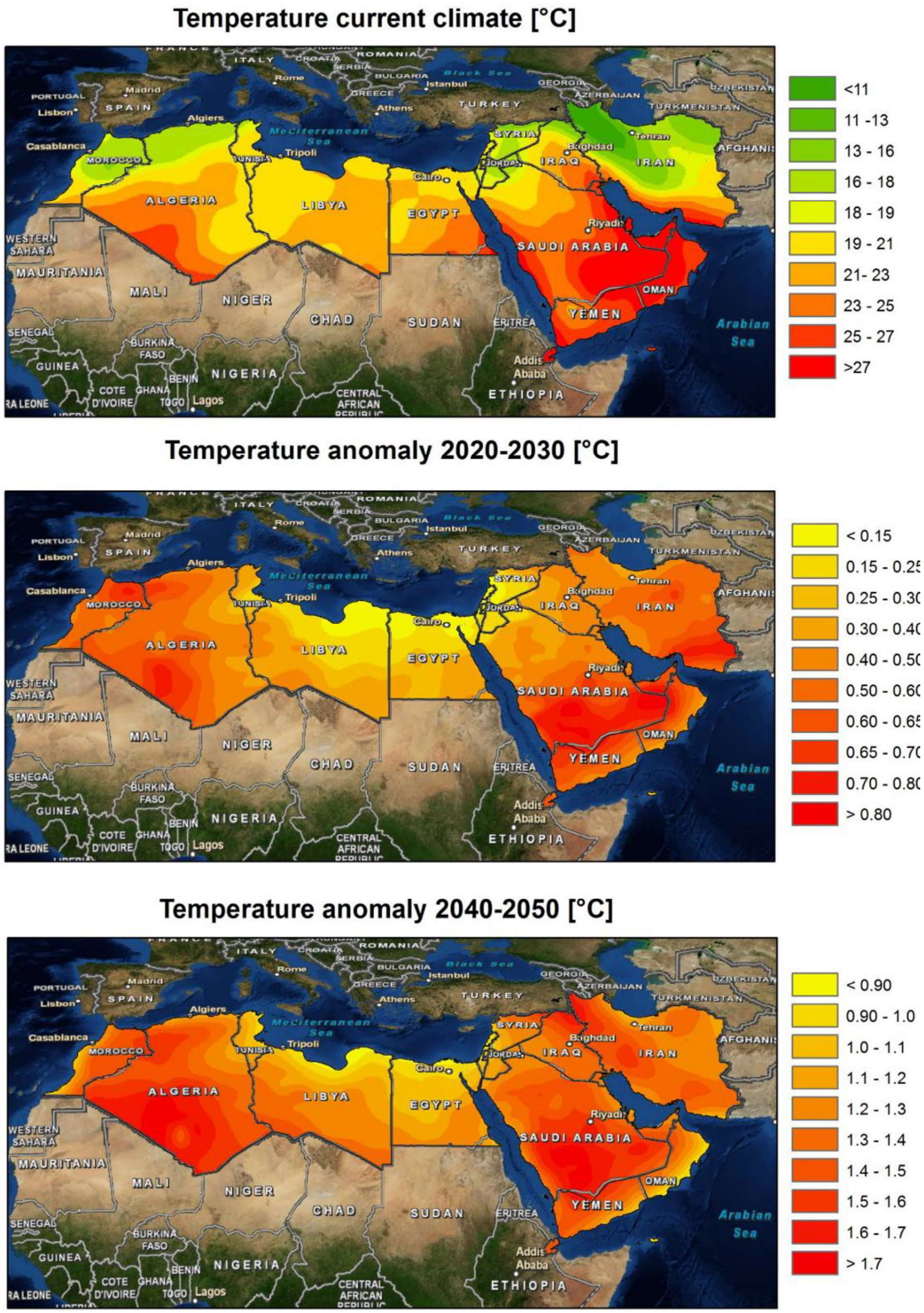

Figure 10. Spatial patterns of temperature projections. Top: Average yearly temperature of the current climate. Middle: Temperature anomalies of 2020-2030 with respect to the current climate. Bottom: Temperature anomalies of 2040-2050 with respect to the current climate. (Walter et al., 2011).

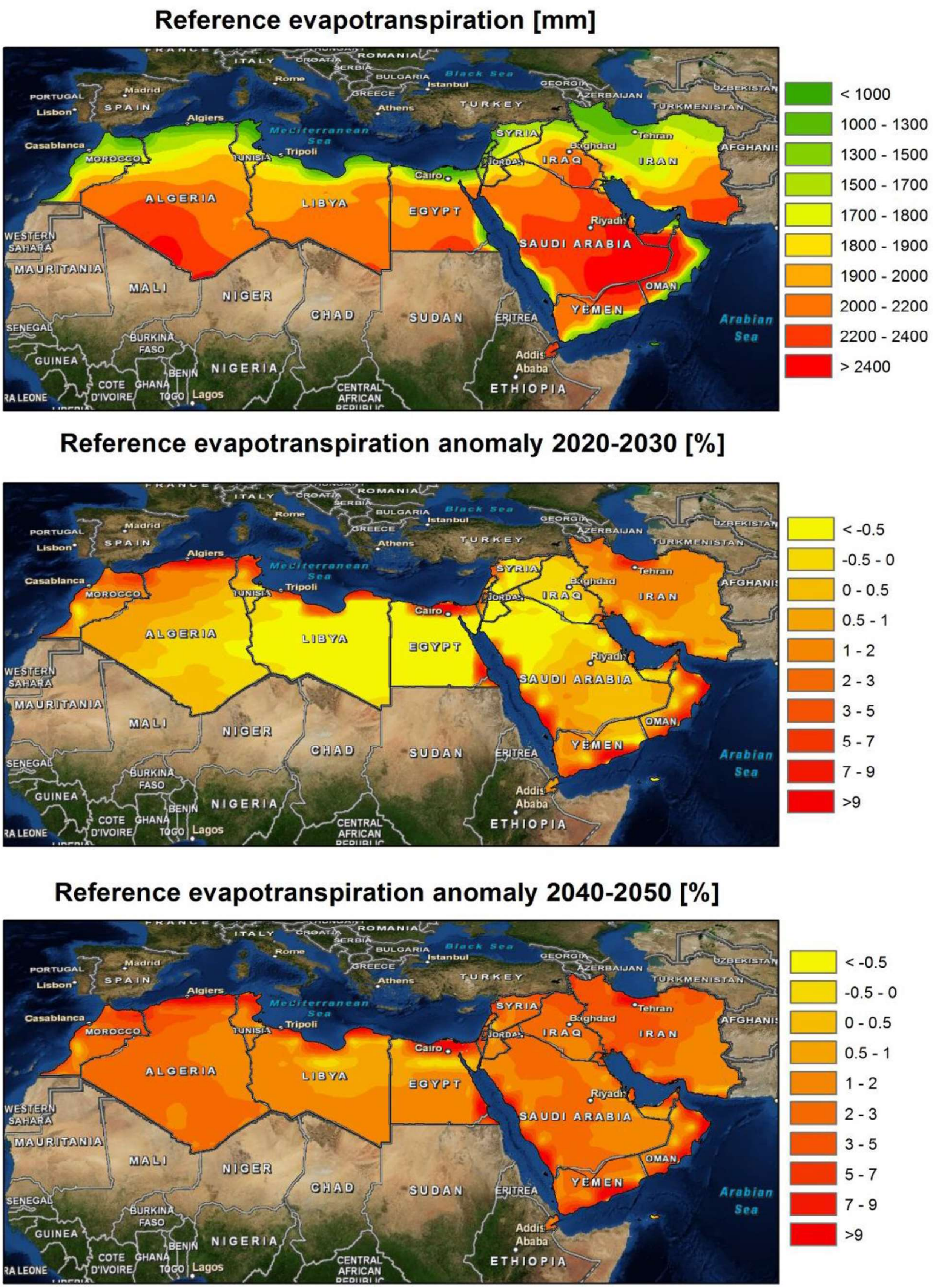

Figure 1.4 Spatial patterns of reference evapotranspiration projections. Top: Average yearly reference evapotranspiration sum of the current climate. Middle: Reference evapotranspiration anomalies of 2020-2030 with respect to the current climate. Bottom: Reference evapotranspiration anomalies of 2040-2050 with respect to the current climate. (Walter et al., 2011)

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