



# Water assessment in transboundary river basins: the case of the Medjerda River Basin

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## Abstract

Water resources in the Middle East and North Africa (MENA region) face over-exploitation and over-pollution due to population growth, climate change and the lack of advanced water governance approaches. These challenges become more serious in transboundary river basins and may lead to conflict between riparian countries. The main objective of this paper is to assess water resources and needs at the Medjerda River Basin (MRB), shared by Tunisia and Algeria using the Water Evaluation and Planning (WEAP) system between 2020 and 2050. Four scenarios were built to assess the current and future status of the water supply and demands in both countries. The results show that water demands, and shortages are increasing, and some demand sites will face real water scarcity in the future due to climate change and development practices. Therefore, new allocation and management plans should be examined at the regional level based on real collaboration among all stakeholders.

**Keywords** Tunisia · Algeria · Sustainability · Stakeholders · WEAP system · Climate change

## Introduction

Decisions on water management and allocation that are made at international and national levels rely on national and subnational organizations for their implementation and rely on civil society and/or local communities for their acceptance and legitimization (Earle and Neal 2017). These decisions depend on the local and regional water governance systems. Water governance can be policies, regulations, public institutions, informal networks, or private-sector mechanisms that regulate the interaction between water, ecosystem and stakeholders (Fauconnier et al. 2016).

There is no clear sector strategy for the provision of water and sanitation services in Tunisia. A strategy for the water sector up to 2030 was formulated in 1998 by the Ministry

of Agriculture and Water Resources and a new strategy up to 2050 is currently being developed, with no clear indication as to its finalization and adoption. Based on the online library of the Organisation for Economic Cooperation and Development (OECD), a study by the OECD and the Global Water Partnership Mediterranean (GWP-Med) identified the need for a clear, updated, and comprehensive strategy for the water sector, covering the relevant sub-sectors and issues like (water resources management, drinking water supply, sanitation, water quality, and conservation), physical infrastructure like (wastewater treatment plants, distribution systems, boreholes, etc.) water supply and sanitation, and time-bound action plan. Now, due to the country's political transition, the sectoral strategy is being reformulated. A strategy for a green economy, including the water sector, is also being developed (OECD 2014).

Algeria relies heavily on expensive water management solutions. Therefore, its water management strategy focuses on making the most of existing water resources through redistribution and increased storage and desalination capacity (Stratfor Worldview 2016). Under the supervision of the Ministry of Water Resources, the following are the most effective organizations related to water management in Algeria: National Dams and Transfers Agency; National Hydraulics Resource Agency; Algerian for Water; National Agency for Sanitation; National Agency of Irrigation and Drainage;

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National Agency for Integrated Water Resources Management; Technical Control Office of Hydraulics; Watershed agencies; and Water police (Fanack Newsletter 2019).

Tunisia and Algeria share the waters of several trans-boundary rivers, notably the Medjerda River, which accounts for 37% of the Tunisia's surface water and 22% of its renewable water resources. To improve access to this shared resource, the governments of the two countries have established a Joint Technical Committee (JTC) for water resources planning and management, exchange of information and data management, including monitoring water use, pollution, and environmental conditions (Louati and Bucknall 2010). The missions and the activities of the JTC includes establishing a monitoring system to track pollution and water volumes at the Medjerda River Basin (MRB); using and distributing the water resources between the two countries; and monitoring the aquifer and managing it in a cooperative way to minimize negative impacts. The JTC holds annual meetings to discuss the previously mentioned issues, however, the JTC is not very active (Abidi et al. 2019).

The Medjerda River (Wadi Medjerda) originates in the Tell Atlas, part of the Atlas Mountains, in North-Eastern Algeria and flows eastwards Tunisia, then entering the Gulf of Utic of the Mediterranean Sea (Hamdi et al. 2016). The MRB, Fig. 1, begins in Eastern Algeria (near Souk Ahras) and extends into Tunisia where it extends from the North–West to the North–East with a total area of 23,175 km<sup>2</sup>, of which 7700 km<sup>2</sup> is in Algeria. This watershed produces more than one Mm<sup>3</sup> of surface water per year, which is used to irrigate an area of 33,173 ha. Cultivated crops are orchards, cereals, legumes, and fodder. The upstream bedrock was characterized by colluvium, calcareous crusts, encrusted pebbles, while the downstream by marl and cretaceous limestone. The yearly average precipitation in the basin is about 350–600 mm and the average rainy days range

from 40 to 70 days. The rainy season extends from September to May with intense precipitation in autumn (Etteieb et al. 2017). The most common irrigation method is surface accounting for 38% of the total irrigated areas. The surface irrigation is of low efficiency (50–70%) comparing to others spray (80–85%); and drip (90–95%).

MRB faces many challenges, including:

- (1) The lack of a proper water management upstream in Algeria causes floods in Tunisia. This situation is expected to increase due to climate change (Zahar et al. 2008);
- (2) The use of traditional irrigation techniques in some parts of the basin will increase drought probability (Hamdi et al. 2016);
- (3) Land-use change in the MRB causes erosion during intense precipitation events, which has enhanced the desertification in many parts of the basin and altered its hydrological characteristics (Jebari et al. 2012);
- (4) Salinity is a serious obstacle to crop selection throughout much of the MRB (Abidi et al. 2015) and farmers are restricted to a limited number of profitable salt-tolerant crops; and
- (5) Problems of floods and sedimentary transport are critical. In fact, the changes in the downstream flow regime have appeared in the form of a decrease in the flow rate since the commissioning of the Sidi Salem dam in 1981 in the Medjerda basin. This decrease has lowered the Wadi's capacity to transport the sediments and to favour their deposit. This caused a fattening of the bed, and consequently increased competition from the floods (Gharbi 2016).
- (6) The periodical occurrence of droughts increased the exploitation of groundwater to fulfil water demand (Guellala et al. 2012).

Assessing water resources, water productivity, water uses and planning through computer models has received a lot of attention over the world to predict changes under different management and climatic scenarios (Yomo et al. 2019; Durodola et al. 2020). The Water Evaluation And Planning (WEAP) system, <https://www.weap21.org>, was developed by the Stockholm Environment Institute (SEI) to enable evaluation of planning and management issues associated with water resources development. The WEAP system can be applied to both municipal and agricultural systems and can address a wide range of issues including sectoral demand analyses, water conservation, water rights and allocation priorities, streamflow simulation, reservoir operation, ecosystem requirements and project cost–benefit analyses (Mourad and Alshihabi 2016; Metobwa et al. 2018).

At the level of MRB, limited research work using hydrological, climatological, and sedimentological measurements

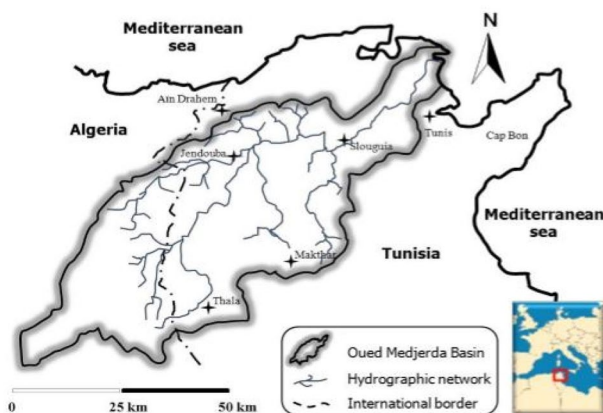


Fig. 1 Medjerda River Basin (Newsletter 2019)

have been undertaken due to the lack of training and skills related to relevant technologies in the field of “climate change-security” analysis and transboundary water management. Therefore, there is a need for co-operation between Tunisia and Algeria to develop knowledge in the water resources security, transboundary water management to ensure water sustainability in the basin and gain from better adaptation to climate variability.

In this paper, the WEAP system was used to assess water resources and demands at the MRB considering local water governance practices and the potential of climate change

impacts. The outcomes of this paper highlight possible actions regarding climate change resilience and sustainable management of transboundary water resources, which can help in addressing issues like enhancing capacity building, promote sustainable development and release opportunities associated with transboundary water co-operation.

## Materials and methods

### Hydro-climatology of the study area

These data were collected from four stations (Souk Ahras, Tebessa, Le kef and Jendouba) in the Medjerda watershed, Fig. 2, covering the period between 2000 and 2019 using New\_LocClim, [http://www.fao.org/nr/climpag/pub/en3\\_051002\\_en.asp](http://www.fao.org/nr/climpag/pub/en3_051002_en.asp).

#### Temperature

The monthly average temperature, Fig. 3, ranges between 16 and 22 °C and the monthly mean temperature in these months (July and August) is from 24 to 27 °C, and then, the monthly mean maximum temperature reaches 33–37 °C.

#### Precipitation

The mean annual rainfall on the watershed, Table 1, is about 550 mm in Souk Ahras, while it is about 350 mm in Tebessa and Le Kef. The highest precipitation rates occurring in December and January and the lowest in July and August.

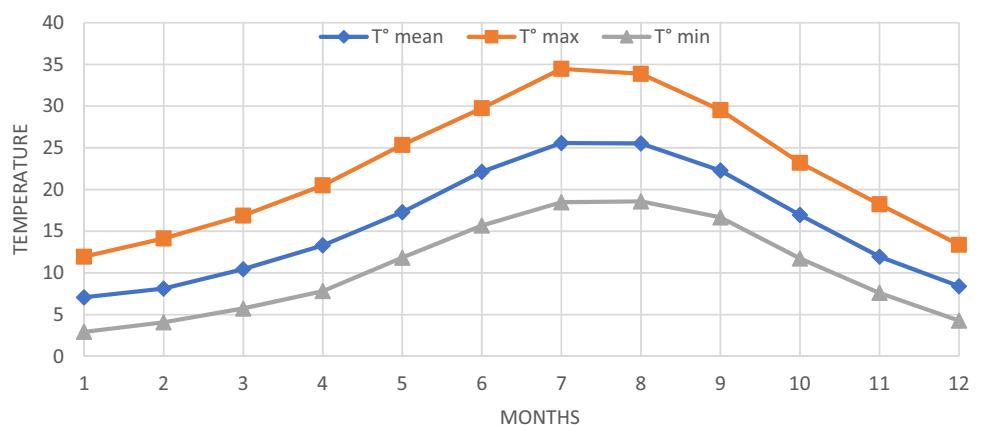
#### Evapotranspiration

The evapotranspiration increases from 35 mm in December and January (the winter period) to about 200 mm in July, Fig. 4.



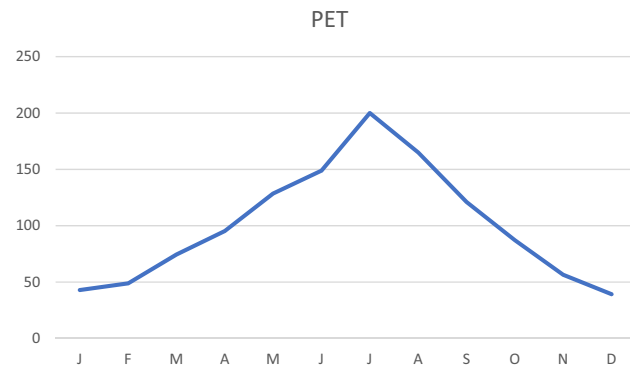
Fig. 2 The positions of the meteorological stations at the MRB

Fig. 3 The monthly average temperature variation in the four stations



**Table 1** The different rainfall in the four stations of Medjerda Watershed

	Souk Ahars	Tebesse	Le Kef	Jendouba
Mean (mm)	547	355	357	414
Max (mm)	882	624	628	741
Min (mm)	170	185	58	204

**Fig. 4** The monthly evapotranspiration in the MRB

## Water resources and uses

The MRB has eight main surface dams that are used for domestic, agriculture and hydropower use, Table 2.

Groundwater resources at the Northern Tunisia (Medjerda watershed) are estimated at 978 Mm<sup>3</sup>. Among these resources, 372 Mm<sup>3</sup> are phreatic groundwaters and 306 Mm<sup>3</sup> are deep groundwaters and the rest are from shallow aquifer. The evolution of these resources is monitored using a piezometric network consisting essentially of surface wells and piezometers. These piezometric networks in Northern Tunisia have nearly 1460 monitoring points composed as follows:

- 1125 surface wells
- 329 piezometers

**Table 2** Dams at the MRB. Source (Ahmadi et al. 2017)

Dams	Watershed Km <sup>2</sup>	Capacity (Mm <sup>3</sup> )	Useful capacity (Mm <sup>3</sup> )	Utilization
Nebeur	10,300	182.2	44.4	Irrigation, hydropower, flood control
Ben Metir	103	61.63	57.63	Drinking water, hydropower
Lkhamès	127	8.22	7.22	Irrigation
Kasseb	101	81.09	69.62	Drinking water, hydropower
BouHeurtma	390	117.5	109.8	Irrigation
Sidi Salem	18,000	814	674.48	Irrigation, hydropower, flood control
Siliana	1040	70	53.04	Irrigation
R'Mil	232	4	4	

- Piezometric monitoring began in the North of the country in 1912 at the level of the Morang slick (Ben Arous governorate), then in 1938 at Cap Bon at the level of the Grombalia slick.
- Among other things, the piezometric network in the North has benefited from a study optimization that proposed the elimination of tracking points and the addition of new representative piezometers in areas where no piezometers are available.

In the Tunisian part, groundwater is used for agricultural, domestic, industry and tourism. In the Algerian part, boreholes are the main source of the groundwater, with a total flow of 44.26 Mm<sup>3</sup>/year (Stamboul 2017), Table 3.

## Modelling

Among several models for water resources management, the WEAP was chosen to assess water supply and demands between 2019 and 2050. The data collected and reported in WEAP is related to:

Demand sites with their location: urban (City), culture area, tourist reception area, industrial area, collective area and the other various area.

Resources/supply sites: dams, river routes, groundwater resources and the other resources.

**Table 3** Groundwater uses in Algerian part of MRB (Mourad and Alshihabi 2016)

Uses	No of boreholes	Capacity (Mm <sup>3</sup> /year)
Drinking water	93	42.53
Irrigation	5	0.95
Industry	1	0.78
Total	99	44.26

**Table 4** Year's climatic type

Water year type	Relative to a normal water year
Very dry	0.7
Dry	0.8
Normal	1
Wet	1.3
Very wet	1.45

**Table 5** The distribution of *future year scenario*

Year	Hydrological types	Year	Hydrological types
2020–2023	Normal	2037–2039	Wet
2024–2025	Wet	2040	Very wet
2026–2028	Normal	2041–2043	Normal
2029–2030	Dry	2044	Dry
2031	Very wet	2045	Normal
2032–2033	Normal	2046–2048	Wet
2034–2036	Dry	2049–2050	Normal

For future projections, four scenarios have been identified based on the current development programmes of the Ministry of water Resources, water resources and demands in Algeria and Tunisia as the following:

- High population growth
- Water year method
- Extended dry climate sequence
- Industrial development

These scenarios represent the impacts of the different assumptions or policies on water availability and uses in the future at the MRB. To assess climate change impacts on water resources, Water Year Method's scenario was created defining different climatic regimes (very dry, wet, very wet, normal) and its relation to the normal year, Table 4, based on WEAP tutorial. And the climate sequence for the future year scenario is given from the climate data as shown in Table 5.

**Table 6** Water demands at the study sites

Study sites	Population	Water demand (m <sup>3</sup> /year)				
		Agriculture (m <sup>3</sup> /year)	Domestic	Industry	Tourism	Collective
Jendouba	444,772	68,690,000	8747,000	251,000	413,000	1248,000
Le Kef	274,757	16,460,000	5501,000	98,000	15,000	781,000
Siliana	306,478	5000,000	5154,000	97,000	4000	642,000
Beja	329,931	53,090,000	8953,000	506,000	11,000	1035,000
Souk Aharas	438,127	20,000,000	19,509,795.31	857,143	31,601	802,403

## Results and discussion

### Water uses at the MRB

All different water demands at the five study sites are presented in Table 6. The agricultural sector is the largest consumer of water. The exploitation rate of irrigated perimeters is 73% and the intensification rate of existing perimeters is 80%. Moreover, 60% of the dam water is used for irrigation.

Domestic water is provided by the National Water Distribution Utility (Société Nationale d'Exploitation et de Distribution des Eaux: SONEDA) and the General Directorate of Rural Engineering and Water Exploitation (DGGREE) in Tunisia and the Algerian Water Authority (ADE) under the supervision of the Ministry of Water Resources (MRE) in Algeria. The study area is one of the areas with high tourist potential, we have identified 77 reception and restoration establishments in the Tunisian part. The average water need for the tourism is about 350 l/day/tourist.

The collective uses sector includes commerce, municipal and administration uses. The volume of the collective use is estimated at 46 Mm<sup>3</sup>.

Based on (Central and de la Planification et Etudes Generales, Société National d'Exploitation et de Distribution des Eaux 2018).

### Water assessment using WEAP

The results of the application of the WEAP 21 model in the MRB are presented in cartographic and graphical form by considering the four scenarios (Reference; Climate; High population growth and Industrial Development scenario).

### Groundwater and vulnerability

Groundwater provides most of the drinking water supply in the watershed. It is exploited by SONEDA and ADE. Figure 5 shows groundwater inflow at the MRB under the reference scenario, while Fig. 6 shows groundwater flow under dry climate scenario.

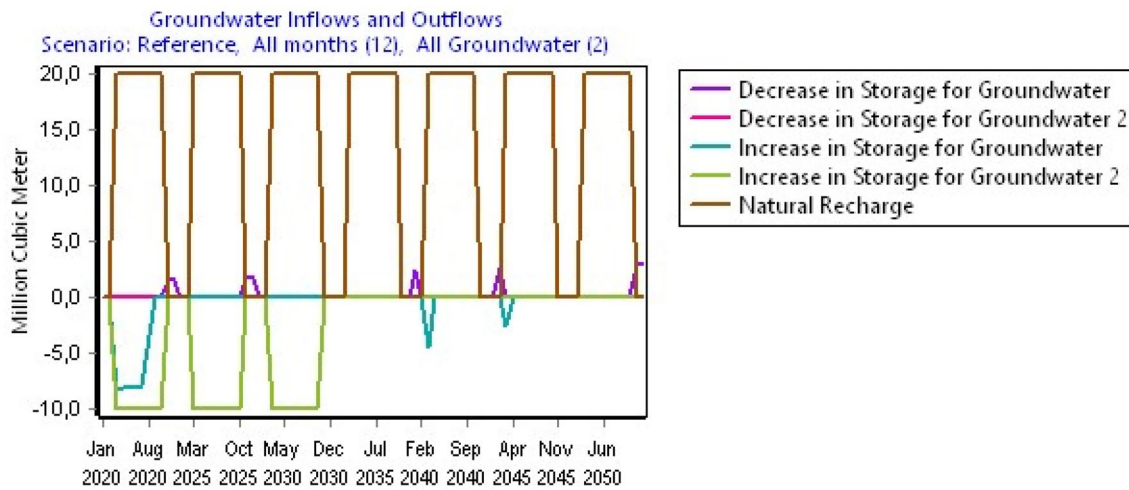


Fig. 5 Groundwater inflow in the reference scenario

In Algeria, groundwater is an essential capital water resource. The repeated dryness put forward the weakness of balance between resources regarding the surface water and the needs.

In Tunisia, groundwater use has given rise to several term of short- and medium-term socio-economic benefits, by providing a basis mainly for extension of the irrigated agriculture areas and domestic areas in remote rural areas.

Groundwater management is affected by uncertainties related to climate change, socio-economic growth, and the inefficient governance structures. These challenges have affected the use of the resources, the protection and the implementation of alternative strategies needed to achieve sustainable management.

Climate change impact on the water resource has already appeared through the reduction in the rivers flow, the low level of filling dams and the global fall of the piezometric level of the principal country aquifers. In the future, the current deficits of the water resources will increase.

Figures 5 and 6 enable us to analyse the variations in groundwater storage, discharge, and recharge. From these figures, we can notice that under the Reference and the Dry climate sequence scenarios, the increase in groundwater storage varies from 0 to 10 Mm<sup>3</sup>.

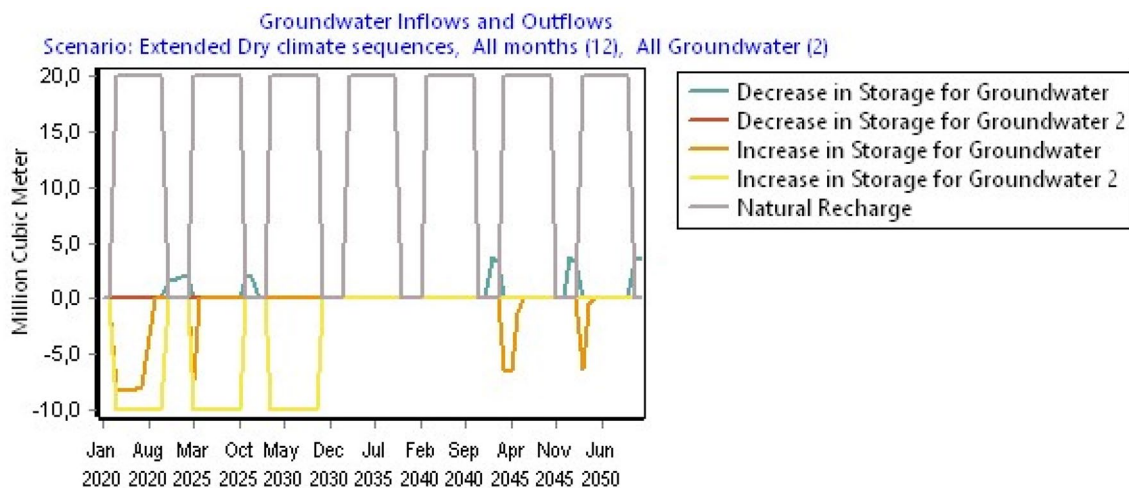


Fig. 6 Groundwater inflow (dry climate sequence)

## Surface water and vulnerability

Most of the surface water in the basin is used for agriculture, domestic and industrial use. To study this vulnerability, three scenarios, Dry climate sequence, Reference and flow requirement have been developed based on different key assumptions considering high population growth, irrigation water needs, domestic water uses and storage capacity for each reservoir.

The analysis shows that under the dry climate sequence scenario, there is an increase in river flow that can reach a peak of 480 Mm<sup>3</sup> in 2025. While this peak will be achieved in 2040 under the reference scenario. On another hand, under the flow requirement scenario showed a very low flow of 13.55 Mm<sup>3</sup> in 2030.

Water demand at each dam is calculated by WEAP to assess inflows, losses, and distributions according to the conceptual design of each reservoir. Figure 7 shows the streamflow outlets of the Sidi Salem dam, the core of the water mobilization system of Northern Tunisia.

WEAP calculates the evolution of water volumes in the dams for the study period. The variation of the water volume at the Sidi Salem dam is very readable especially during the February 2012 flood where the water stock reached about 750 Mm<sup>3</sup>. The Ghardimaou station located on the Medjerda river recorded a flow of 1500 m<sup>3</sup>/s during this flood.

## Water quality

Figures 8, 9 and 10 show the quality of the water and the evolution of the quality of water at the river and at some of the demand sites. The Biochemical oxygen demand (BOD) concentrations in the Medjerda river rise above the

constraint (13.5 mg/l) for the demand site intake during the month of January every year.

Figure 9 shows high levels of BOD concentrations at some demand sites. In general, pollution from agriculture practices increases in spring and summer months when the farming systems are active, Fig. 10. All demand sites had acceptable BOD levels except for sites 2 and 4 during the summer period under the effect of accident pollution and site 5 during both periods under the effect of diffuse pollution. The temporal evolution shows higher weight in summer than in winter under the effect of BOD, which follows the same increasing gradient from winter to summer.

The evolution of the river water quality distribution in the main river (Oued Medjerda) varies from the 0.01 g/l up to 0.2 g/l of the BOD, Fig. 10, which means that the water of the Medjerda river is critically polluted as the dissolved Oxygen (DO) decreases and the BOD increases as the river flows towards the centre of the city. In this regard, (Barour 2015) found that the microbiological quality in MRB is not good of and, therefore, does not comply with the international standards.

## Water demand assessment

The projected demands for all users under the studied scenarios are shown in Table 7.

## Water budget

Water balance can be estimated by subtracting the outflow from the inflow. For example, in 2020, under the reference scenario, the inflow into the basin (water resources) was estimated at 137.5 Mm<sup>3</sup>, while the total water withdraw (consumed by the users) was estimated at 217.5 Mm<sup>3</sup>, which

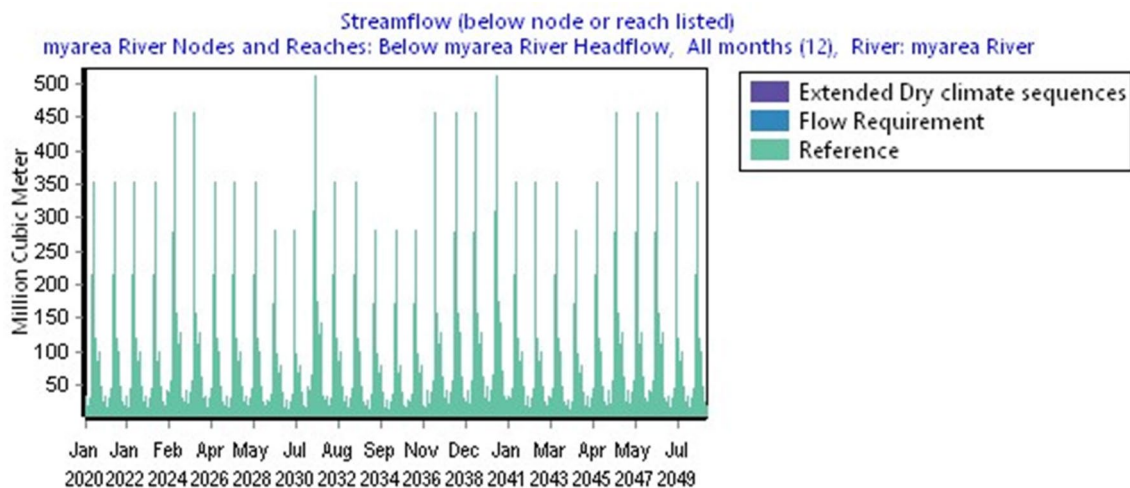


Fig. 7 Evolution of surface water flows

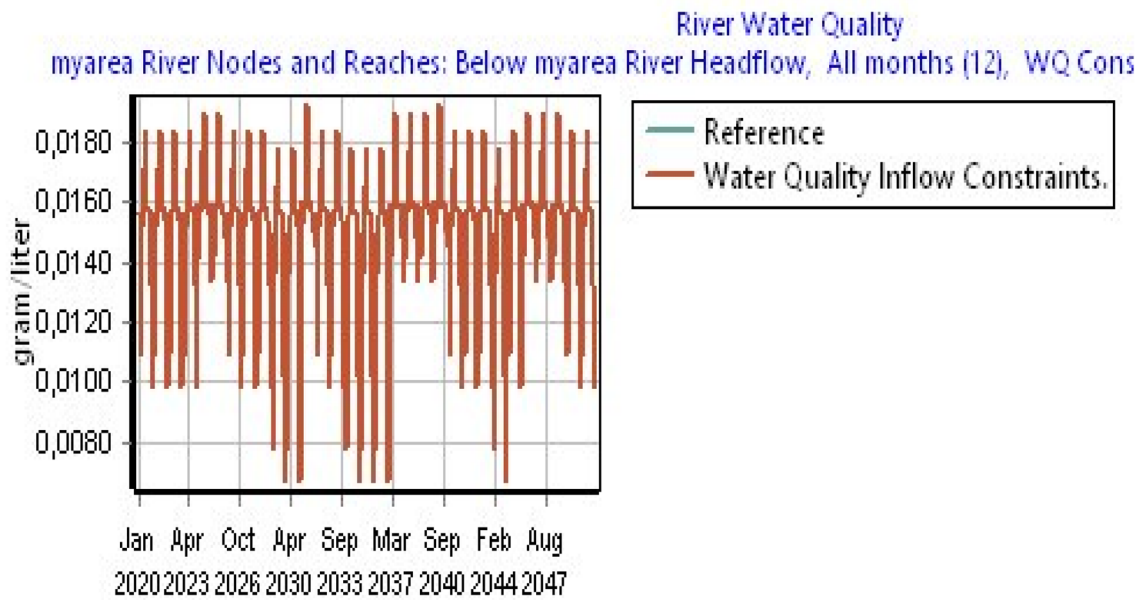


Fig. 8 Evolution of water quality in Oued Medjerda

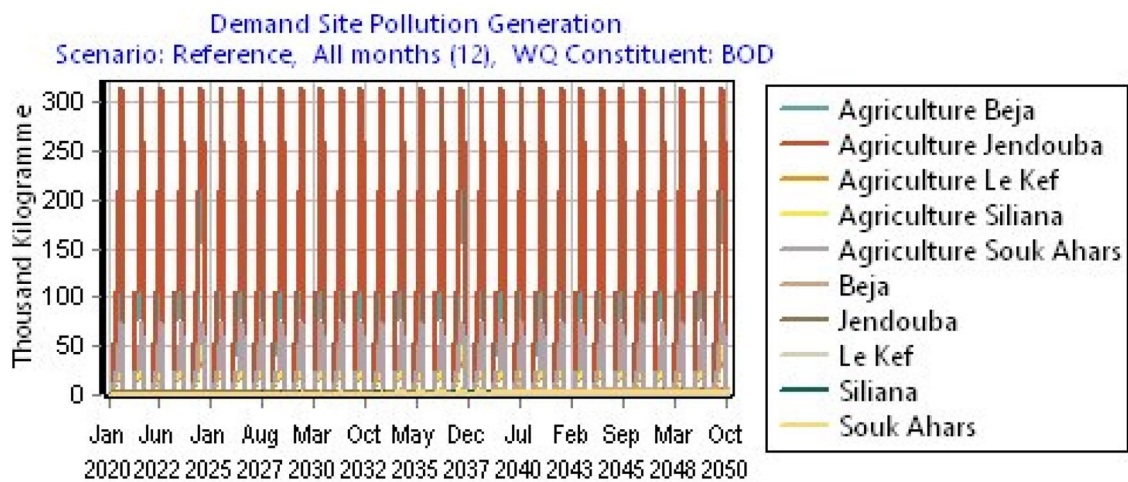


Fig. 9 The evolution of the pollution of the demand site

implies a negative water balance (water shortage) equals to 80 Mm<sup>3</sup> as shown in Table 8.

Water demands in MRB in 2020 and 2050, were estimated at 217.5 Mm<sup>3</sup> and 509 Mm<sup>3</sup>, respectively. The projected water demand reflects a lack of sustainable management of the available resources; therefore, applying the integrated water resources management approach, which is based on the equitable and efficient management and sustainable use of water, can be a possible solution as it recognises that water is an integral part of the ecosystem, a natural resource, and a social and economic good. The

integrated water resources management approach aims to deploy efforts for development of water resources and the reduction of water demand, and to achieve and maintain a supply and demand situation to meet the sustainable water budget to the possible extent (Bouklla-Hassane 2011).

Water resources are estimated at 137.5 Mm<sup>3</sup> for all the scenarios between 2020 and 2050 in the MRB. This water resources are the total of the water delivered in the MRB like the surface water from river and reservoir, from groundwater in Algerian part and in Tunisian part; and from the other sources used in the MRB. An active management of water



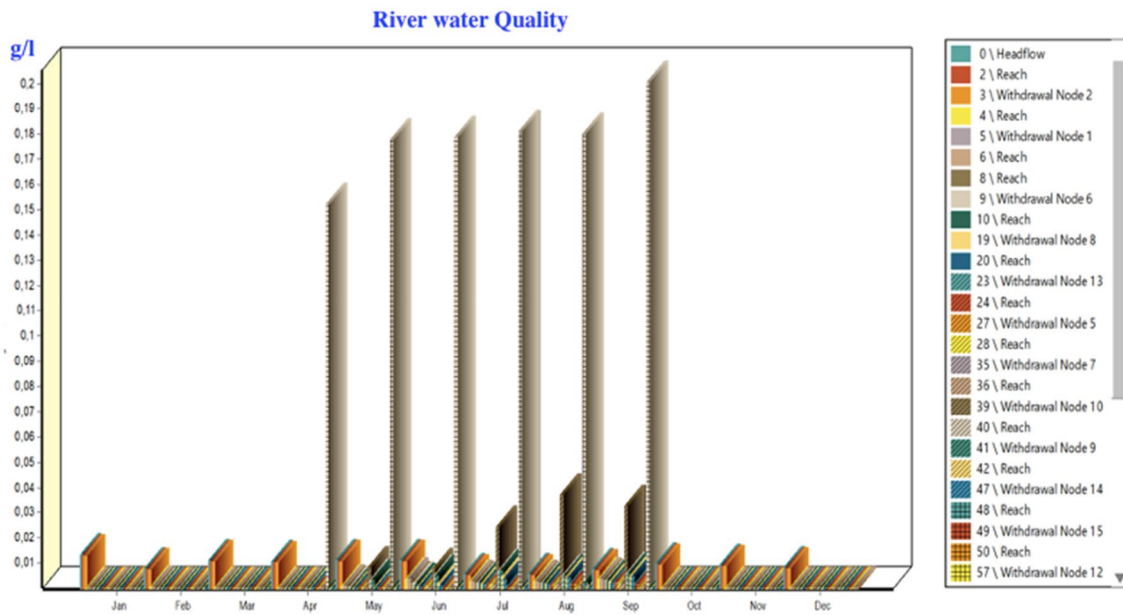


Fig. 10 The evolution of the river water quality distribution in the Oued Medejrda

Table 7 Projected water demand at MRB in Mm<sup>3</sup>

Year	2020	2025	2030	2035	2040	2045	2050
Extended dry climate sequence	217.5	248.7	283.5	326.9	376.2	437.8	509
Flow requirement	217.5	241	265.3	294.2	323.9	358.9	395
High population growth	217.5	248.7	283.5	326.9	376.2	437.8	509
Industrial development	217.5	241	265.3	294.2	323.9	359	395.6
Reference	217.5	241	265.3	294.2	323.9	358.9	395
Reservoir added	217.5	241	265.3	294.2	323.9	358.9	395

Table 8 Water balance at the MRB

Scenarios	2020 Mm <sup>3</sup>		2050 Mm <sup>3</sup>		Water balance Mm <sup>3</sup>	
	Water demand	Water resources	Water demand	Mm <sup>3</sup>	2020	2050
Extended dry climate sequence	217.5	137.5	509	137.5	-80	-371.5
High population growth	217.5	137.5	509	137.5	-80	-371.5
Reference	217.5	137.5	395	137.5	-80	-257.5
Reservoir added	217.5	137.5	395	137.5	-80	-257.5

resources allows for water saving and reduces water deficit in the cities (reduction of the loss in the water distribution networks, recycling of water used by industrial companies, awareness campaigns of the population to reduce the losses of drinking water etc.).

Simulating the unmet demands based on the Reference and the High Population Growth scenarios for 2020 and 2050 shows that most demand sites are satisfied. The unmet demands vary from 80 to 182 Mm<sup>3</sup> (high population growth and climate scenarios) and to 143 Mm<sup>3</sup> for the reference scenario. For the years of the scenarios of climate and the

high population growth, the water demand varies from 218 to 509 Mm<sup>3</sup> and for the reference scenario vary from 218 to 395 Mm<sup>3</sup> in 2020 and 2050, respectively, which means water demand is insufficient for consumption, especially during prolonged periods of drought, in the case of climate change.

Table 8 shows that water shortage in MRB will increase from 80 Mm<sup>3</sup> in 2020 to 257.5 Mm<sup>3</sup> in 2050 both scenarios Reference and Reservoir Added.

The annual water budget of the MRB in the Algerian part from 2020 to 2050 varies depending on each scenario. For the reference scenario, the water demand from 2020 to 2050

**Table 9** Water balance in the Algerian part

Scenarios	2020 Mm <sup>3</sup>		2050 Mm <sup>3</sup>		Balance Mm <sup>3</sup>	
	Demand	Resources	Demand	Resources	2020	2050
Climate change sequence	41.2	34.6	122	34.6	-6.6	-87.4
Reference	41.2	34.6	75.7	34.6	-6.6	-11.2

**Table 10** Water balance in the Tunisian part

Scenarios	2020 Mm <sup>3</sup>		2050 Mm <sup>3</sup>		Balance Mm <sup>3</sup>	
	Demand	Resources	Demand	Resources	2020	2050
Climate change sequence	176.7	103.2	387	103.2	-73.5	-283.8
Reference	176.7	103.2	319.3	103.2	-73.5	-216.1

is estimated at 75.7 Mm<sup>3</sup>, Table 9. For the Climate and the High Population Growth scenarios, water demands are estimated at 41 Mm<sup>3</sup> and 122.24 Mm<sup>3</sup>, respectively.

The annual water budget of the MRB in the Tunisian part from 2020 to 2050 varies as well depending on each scenario. For the reference scenario, the water demand from 2020 to 2050 is estimated at 319 Mm<sup>3</sup>, Table 10. For the Climate and the High Population Growth scenarios, water demands are estimated at 177 Mm<sup>3</sup> and 387 Mm<sup>3</sup>, respectively.

The unmet demands in 2020, 2030, 2040 and 2050) are presented in Table 11.

The results show an increase in water demand at all scenarios (Fig. 11). Comparing these scenarios, we found that water demand is projected to have more increase under the climate and the high population growth scenarios than the reference and the industrial development scenarios.

The results of the Unmet Demand for the current account (year 2020) as well as for the year 2050 under the Reference and high population growth scenarios show that the demand sites are satisfied. Most domestic and commercial demand sites are satisfied in both countries according to the reference scenarios, while other agricultural demand sites face a water shortage.

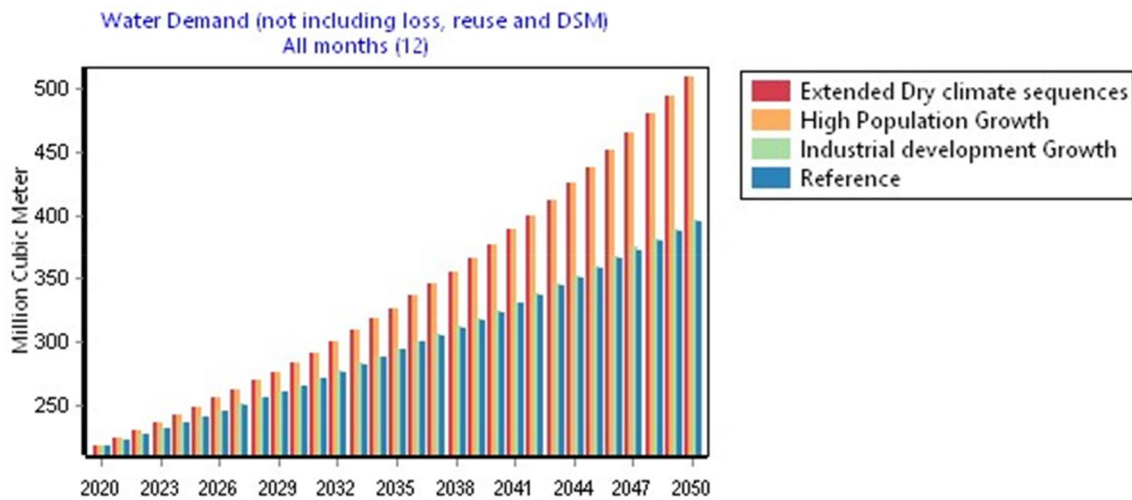
For water demand, the application of this model shows that for the years of the climate and the high population growth scenarios, water demand varies from 218 to 509 Mm<sup>3</sup> and for the reference scenario the water demand varies from 218 to 395 Mm<sup>3</sup> in 2020 and 2050, respectively, which means water demand is insufficient for consumption, especially during prolonged periods of drought, in the case of climate change.

The sites in Souk Ahars in the Algerian part, show an increase in water demand between 2020 and 2050, which were estimated at 38 Mm<sup>3</sup> and 36 Mm<sup>3</sup> for domestic and agriculture uses, respectively. The sites in Jendouba in the Tunisian part, show an increase in water demand between 2020 and 2050,

**Table 11** The unmet demand in Mm<sup>3</sup>

Demand site (Mm <sup>3</sup> )	2020	2030	2040	2050
Agriculture Beja	26.5	32.3	39.4	48
Agriculture Jendouba	20	25	30.6	37
Agriculture Le Kef	5	6	7	8
Agriculture Siliana	1.5	1.8	2	2.7
Agriculture SoukaAhars	6	7	9	10
Beja	4	5	6	8
Collective uses Beja	0.9	0.88	0.84	0.82
Collective uses Jendouba	1	1	1	1
Collective uses Le Kef	0.6	0.6	0.6	0.6
Collective uses Siliana	0.5	0.5	0.05	0.5
Collective uses SoukaAhras	0.6	0.6	0.6	0.6
Industry Beja	0.15	0.19	0.22	0.27
Industry Jendouba	0.12	0.11	0.11	0.13
Industry Le Kef	0.09	0.011	0.014	0.17
Industry Siliana	0.009	0.011	0.014	0.017
Industry Souk Ahars	0.085	0.1	0.12	0.15
Jendouba	2.6	3.2	4	5
Le Kef	1.6	2	2.5	3
Siliana	1.5	1.9	2.3	2.9
Souk Ahars	5.8	7	9	11
Tourism Beja	0.006	0.006	0.006	0.006
Tourism Jendouba	0.3	0.2	0.2	0.2
Tourism Le Kef	0.02	0.02	0.02	0.02
Tourism Siliana	0.003	0.003	0.003	0.003
Tourism Souk Ahars	0.025	0.025	0.025	0.025
Sum	80	97	117	143

which was estimated at 17 Mm<sup>3</sup> and 124 Mm<sup>3</sup> for domestic and agriculture uses, respectively. This means most water uses in the MRB is for the agriculture in the Tunisian part Jendouba followed by Beja then Souk Ahars. According to Stamboul (2017), water demand is satisfied from 2015 to 2030 for the different consumption centres according to all scenarios in



**Fig. 11** Increasing water demand at MRB

the Algerian part of MRB. The three periods of the time of horizon: 1998–2006, 2006–2015 and 2015–2030, there is an evolution of the balance for all scenarios. From 1998 to 2015, he found an increase of the use of groundwater for irrigation. For the third period, water demand was satisfied from 2015 to 2030 for the various consumption centre's according to all scenarios (Stamboul 2017).

Issam and Larbi (2020) found that drinking water demands will increase in the Ghedir El Golla demand site due to the growing demographic weight of the governorates supplied in Greater Tunis in Medjerda Tunisian part. They also found that out of the 16 studied demand sites, there were only 2 sites that had fluctuations in satisfaction (1) the Lakhmess perimeter that is fed from the Lakhmes dam and (2) the Rmil perimeter that is fed from the Rmil dam. The comparison between the observed and simulated balances of the studied dams showed an overestimation of the inflows for the Sidi Salem and Mellègue dams and consistency for the other dams. Among the simulation results, the evolution of water volumes in the dams was established for the study period (Issam and Larbi 2020).

The results of this paper showed that the BOD in Medjerda river waters ranges from 4.5 to 13.5 g/l. These results are similar to the results of Etteieb et al. (2017), who found that most of the river water is limited to plants with high salt tolerance and the continues irrigation may increase the toxicity problems at some locations of the MRB in Tunisia.

## Conclusions

Managing water resources requires socio-economic acceptance and strong governance system that has clear roles and responsibility framework through policies, strategies, and

sustainable plans (Mourad 2020; Jama and Mourad 2019), by which all users/sectors can work together to set proper allocation plans at national and regional levels to reduce water-related conflicts and increase water sustainability.

This paper aimed at assessing water resources and uses at the MRB, shared between Tunisia and Algeria, using WEAP model. Four scenarios were represented, namely, High Population Growth; Water year Method; Extended Dry Climate Sequence and Industrial Development. The results showed unmet demands in many sites in Tunisia and Algeria. The unmet demands vary from 80 to 182 Mm<sup>3</sup> (high population growth and climate scenarios) and to 143 Mm<sup>3</sup> for the reference scenario. However, some of the unmet demands were not significant and can be solved through a proper use of the resources. Moreover, the estimation of water balance in each country showed an increase in water shortage, under Climate Sequence scenario, up to 87, 284 Mm<sup>3</sup>, in Algeria and Tunisia, respectively.

Assessing water resources is the main step towards the development of any water plans and transboundary co-operation plans. These plans should consider the current challenges that face the MRB, mainly, climate change, overuse, pollution, and the population growth.

The WEAP system is very favourable for assessing water resources and establishing a water resources management plan, considering vulnerability and different scenarios. WEAP model offers an opportunity for possible studies on sectoral analyses. Therefore, knowing that agriculture consumes most of the surface water resources and 77% of the ground waters in the MRB, future research about agricultural water and changing crop patterns in each sub-basin using WEAP and crops productivity models can be the next approach to tackle water shortage in the MRB, by which new water allocation and management plans can be considered.

The paper showed that the industrial water demand, the third highest consumer of water in the MRB, has been increasing based on industrial development, which has increased the pressure on groundwater resources due to the lack of an effective regulation and coordination among regulatory agencies.

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## Declarations

**Conflict of interest** The authors declare no conflict of interest, the funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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