ORIGINAL PAPER

Assessing the impact of climate change on the Medjerda River Basin

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Abstract

Assessing the availability of water resources in the changing climate is needed to meet current and future water needs. This paper assesses the impact of climate change on the water resources of the Medjerda River Basin (MRB) (shared between Tunisia and Algeria) using the Water Evaluation and Planning (WEAP) model under two climatic scenarios of Representative Concentration Pathways: RCP 2.6 and RCP 6.0. The results showed that water demands will increase from 218 Mm^3 in 2020 to 395 Mm^3 in 2050, which means that water supply will be insufficient to meet water needs, especially during the prolonged periods of drought. In addition, water shortage in MRB increases three times compared with the reference scenario, which means that all vital sectors in MRB will be affected by climate change. Moreover, groundwater storage will be affected in diffrent areas, especially between 2045 and 2050. Therefore, national and regional stakeholder involvement is needed to build an integrated water resource management strategy, by which water resource allocation and adaptation plans can be addressed and assessed in each sector by experts to achieve sustainability.

Introduction

Climate change and population growth are the main challenges that are affecting water resources in many countries, especially in the Middle East and North Africa (MENA) region, which will increase the need for irrigation and decrease the availability of freshwater by 2 to 15% for 2 °C of warming (Zahar et al. 2008). The region is considered one of the hot spots in terms of extreme heat, drought, and aridity conditions under climate change, which will increase water demands (Waha et al. 2017). However, the intensity and characteristics of this impact may vary considerably from one region to another (Haddeland et al. 2014). On the other hand, the MENA region is very unique in terms of the relationship between climate change and political instability as climate change triggers, accelerates, and deepens the current instabilities (Sofuoğlu and Ay 2020). Moreover, water resources in the MENA region will be affected by global warming (Waha et al. 2017). Many studies found that water shortage is the root cause of some types of vulnerability in the region such as inappropriate water and food conditions (Namdar et al. 2021).

Water Evaluation And Planning (WEAP) system, https://www.weap21.org, is considered a good decision support tool to assess water resources and needs in a specific basin taking into account climatic conditions and human activities.

The evaluation of the available resources and the identification of the different users and their needs (agriculture, industry, tourism, drinking water, and the collective water uses) are very necessary before simulating water supply and uses in WEAP. Many researchers have used WEAP for assessing water resources at basin and national levels; examples include assessing water resources in Syria (Mourad and Alshihabi 2016); water demand simulation in Kenya (Metobwa et al. 2018); studying the vulnerability of water resources to climate change (Rakotondrabe 2007); and analysing the quantitative and qualitative state of surface

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and groundwater in the El Aouinet-Ouenza area (Wilaya of Tébessa) (Stamboul 2017).

This paper focuses on the Medejrda River Basin (MRB), which is shared between Algeria and Tunisia. July and August are the hottest months in the basin with high evaporation rates, low humidity, and limited precipitation. In addition to climate change, human practices have affected water availability throughout the MRB. Moreover, MRB faces problems related to poor water management, population growth, wastage due to the unbridled use of water, and pollution (Omrani and Ouessar 2012). Therefore, to better manage water resources at the MRB under possible climatic threats, this paper uses Water Evaluation and Planning System (WEAP 21) to assess the impact of climate change on water needs and resources in the MRB.

Study area

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 km², of which 7,700 km² in Algeria. This watershed produces more than 1.000 Million m³ 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 land area of Tunisia is occupying 9.8% in the basin. The yearly average precipitation range in the basin is about 350–600 mm and the average rainy days' ranges from 40 to 70 days between September and May (Etteieb et al. 2017). Surface irrigation is the most common irrigation method in the basin; however, some areas use other efficient irrigation systems such as drip irrigation.

The hydrological networks of the MRB originates in the heights of Souk Ahras, Algeria, at altitude of 1408 m and then flows towards the East. Wadi Medjerda has 26 big irrigated perimeters, however, the lower Medjerda watershed has 9 of the biggest irrigated perimeters, which are irrigated in two types of systems traditional and modernized (Rachid 2011).

MRB has eight main surface dams (Nebeur, Ben Metir, Lkhamès, Kasseb, Bou Heurtma, Sidi Salem, Siliana, and R'Mil) with a total water capacity of 1020 Million m³ (Ahmadi et al. 2017). Groundwater resources in the MEB are estimated at 1022 Million m³, 44 Million m³ of which are in Algeria (Stamboul 2017).

The agriculture sector is the largest consumer of water at the MRB as it consumes about 80% of the overall water volume followed by domestic water sector, 14% (FAO 2015). Domestic water is provided by the National Water Distribution Utility (SONEDA) and the General Directorate of Rural Engineering and Water Exploitation (DGGREE) in Tunisia and the Algerian Water Authority (ADE) in Algeria.
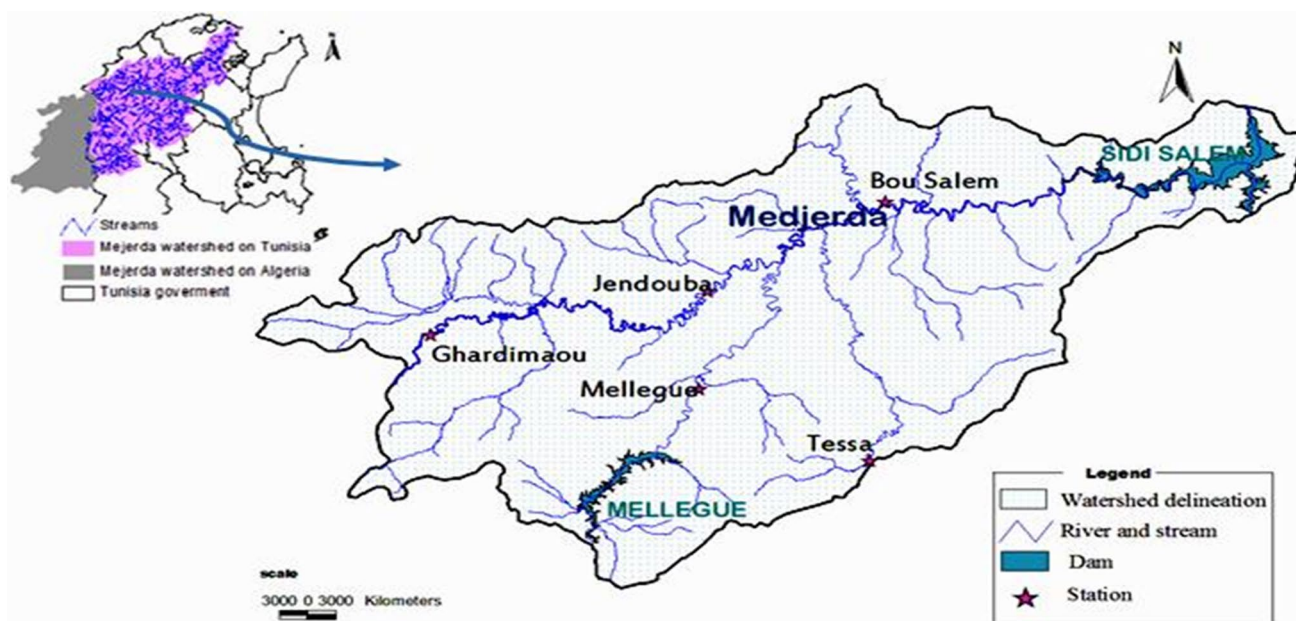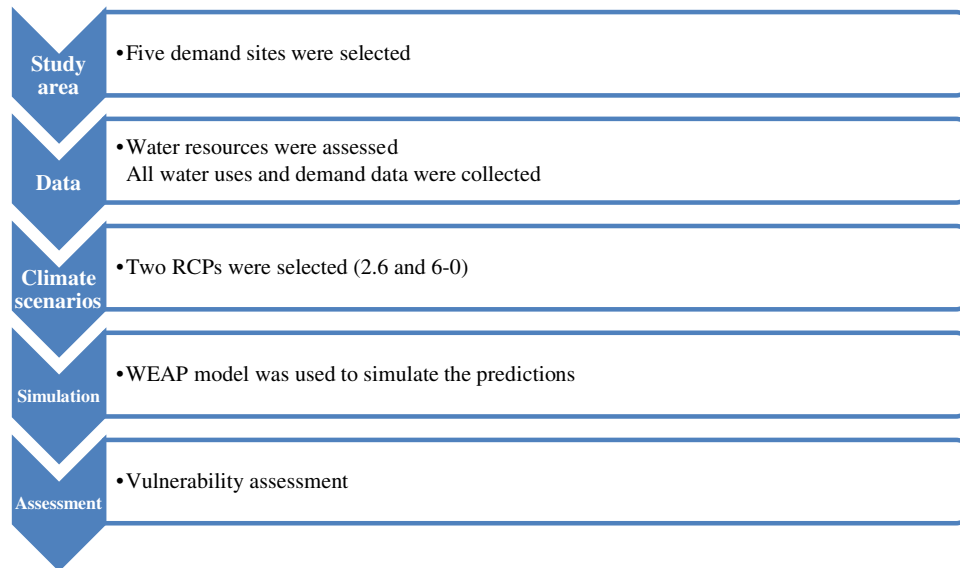

Fig. 1 The Medjerda River Basin (Abidi et al. 2014)

Methodology

The following flowchart describes the used methods.

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Study area    • Five demand sites were selected

Data          • Water resources were assessed
                All water uses and demand data were collected

Climate       • Two RCPs were selected (2.6 and 6-0)
scenarios

Simulation    • WEAP model was used to simulate the predictions

Assessment    • Vulnerability assessment
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Water resources and needs

Five demand sites were selected from 5 cities which are one in Algeria (Souk Ahars) and four in Tunisia (Jendouba, Beja, Siliana, and Le Kef). The assessed demands include five sectors agriculture, industry, domestic tourism, and collective uses sector. Water needs at the selected demand sites were collected from SONEDA, Tunisia, and ADE, Algeria, Table 1. Water resources that supply the demand sites were collected from Ahmadi et al. (2017), Table 2.

Hydro-climatology

Daily meteorological data were obtained from NewlocClim and the Directorate General of Rural Engineering and Water Exploitation (DGGREE) in Tunisia and the Coupled Model Intercomparison Project phase CMIP5, http://gismap.ciat.cgiar.org/MarkSimGCM/, for the Representative Concentration Pathways RCP 2.6 and RCP 6.0.

The main climatic parameters to assess the impact of climate change in WEAP model are temperature, rainfall, evaporation, wind, and CO_2.

- *Temperature*

In the study area, the annual average temperature ranges between 16 and 22 °C, while the monthly mean maximum temperature reaches in July–August 37 °C.

Table 2 Water resources at the MRB

Demand site	Surface water		Groundwater recharge (MCM)
	River flow m³/s	Surface dams Km²	
Jendouba	109.3	390	978
Le Kef	44.4	10,300	
Siliana	53.04	1040	
Beja	674.48	18,000	
Souk Ahars	6	350	44.26

Table 1 Water demand distribution at the MRB

Demand site	Population	Water demand m³/year			
		Agriculture	Domestic	Industry	Collective
Jendouba	444 772	68 690 000	8 747 000	251 000	1 248 000
Le Kef	274 757	16 460 000	5 501 000	98 000	781 000
Siliana	306 478	5 000 000	5 154 000	97 000	642 000
Beja	329 931	53 090 000	8 953 000	506 000	1 035 000
Souk Ahars	438 127	20 000 000	19 509 795.31	857 143	802 403

Fig. 2 The average monthly precipitation in the MRB in 2020
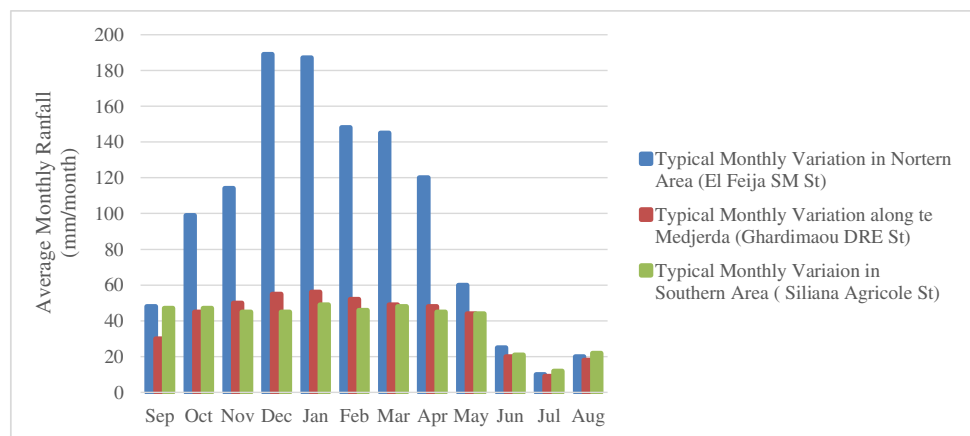
• *Rainfall*

Rainfall data were collected from Integrated Land and Water Information System (ILWIS), Local Climate Estimator (New_LocClim), and other national resources from 2000 to 2019. The reference evapotranspiration (ETo) was calculated using the FAO 56 method (Cramer et al. 2018).

In general, the average annual rainfall of the basin varies from 85 to 771 mm (Allen et al. 1998) with high spatial and temporal variability (Kotti et al. 2016), Fig. 2.

For the studied stations, the mean annual rainfall varies between 350 and 600 mm/year, Table 3.

• *Potential evaporation*

The data for monthly inter-annual evaporation are the monthly average values measured in the station in MRB, Table 4. The seasonal variation of evaporation is around 35–42 mm, observed in December and January (the winter period). However, the maximum evaporation is marked during the dry season with a value of 200 mm in July. Average annual evaporation is around 100.67 mm.

Table 3 The different Rainfall in the four stations of Medjerda Watershed

	Souk Ahars	Tebesse	Le Kef	Jendouba	Average
Mean (mm)	547	355	357	414	418.25
Max (mm)	882	624	628	741	718.75
Min (mm)	170	185	58	204	154.25

Climate modelling

The current account year is selected as the model base year. Then, the baseline scenario is established from the current account to simulate the likely evolution, without any interposition of other scenarios to assess the future effects, until 2050, of climate change on water resources and needs.

Climate impact assessment application often requires specific climate projections in order to capture small-scale climate variations. The temperature (mean, maximum, and minimum), the precipitation data, and evapotranspiration at the four stations (Souk Ahars, Tebessa, El kef, and Jendouba) over the period of 2000–2019 were used to simulate the climate sequence and the water year method scenarios.

Precipitation and evaporation were fed into the WEAP model using the monthly Temperature Series Wizard. The water year method was used to assess the impact of climate change by defining climatic regimes at the WEAP system (very dry, wet, very wet, normal) and its relations to the normal year by giving a value between 0.7, 0.8, 1, 1.5, and 1.45, respectively to each type of climate.

Climate sequence for the future year scenario is given from the climate data. A 50-year average (1956–2006) was taken as the basis for the definition of types for the years below (Table 5). The climate change scenario models were taken from 1960 to 2000 in the MRB (Abidi et al. 2017). Considering that the flow rate in a normal year, for example, if the wet year flow rate is greater than 25% compared to the normal year, the year is wet.

The RCP scenarios allow to model the future climate based on four different assumptions about the amount of

Table 4 Monthly average evaporation for the different stations in the MRB

Month	J	F	M	A	M	J	J	A	S	O	N	D
PET (mm/10 m)	42.9	48.9	74.5	95.3	128.6	148.9	200	165.1	121.1	87	56.5	39.2

Table 5 The distribution of year types

Year	Types of year hydrology	Year	Types of year hydrology
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

greenhouse gases that will be emitted in the coming years (period 2100), each RCP scenario gives a variant of the climate that is considered likely to result from the level of emissions chosen as working hypothesis. All Global Climate Model (GCM) data were downloaded from the CMIP5 web data portal at http://gismap.ciat.cgiar.org/MarkSimGCM/.

To explore the impacts of alternative climatic assumptions on water availability, four scenarios were analysed using the WEAP model:

The reference scenario The reference scenario takes the data from the current account within the specified project duration and serves as a benchmark for the other scenarios that have changes based on the selected key factors (Ahmadi et al. 2017). It was used for the current situation (2020) which is extended to the future (2020–2050). These scenarios are used for simulating water resources and uses of the MRB if no changes occur in the system.

Extended climate sequences It is constructed from the dry and wet sequences. It can be defined using the water year method (wet, dry, very dry, very wet). It is used for future projections until 2050 to assess the impact of climate variation on water resources in relation to user's needs.

RCP 2.6 scenario means that the radiative forcing level reaches 3.1 W/m^2 by mid-century but returns to $+2.6$ W/m^2 by 2100.

**RCP 6.0** scenario means that the radiative forcing level reaches 6.0 W/m^2.

Results and discussion

Groundwater and vulnerability:

Groundwater management is affected by uncertainties related to climate change and the governance structures regarding resources use, and the implementation of strategies and protection plans.

The main groundwater basin in the MRB was divided into two sub-basins, the first in Algeria and the second in Tunisia. The results show that both sub-basins are decreasing similarly in the period of 2020 to 2025 under the three scenarios (extended climate sequences, climate scenarios RCP 2.6, and climate scenario 6.0). Figure 3 shows a similarity in storage variation except for April 2025 and July 2050. For the decreasing storage, the flow varies 11.47 Mm^3 and 8.49 Mm^3 to 0 m^3 for the extended dry climate sequence. The increase in groundwater storage varies from 0 to 10 Mm^3 for the Tunisian subbasin and from 0 to 6 Mm^3 for the Algerian subbasin in the period of 2020 to 2050. For decreasing storage, the flow varies from 11.47 to 1 Mm^3 for the groundwater in Algerian part and 8.49 to 8 Mm^3 for the groundwater in Tunisian part in the period of 2020 to 2050. For the recharge, the basin aquifer receives no artificial recharge, whereas natural recharge varies from 0 to 20 Mm^3 for the three scenarios (Masoon 2018). Other scholars found that the lack of regulation of water uses has increased groundwater salinity in Tunisia (Lachaal et al. 2018). Houria et al. (2020) found that agriculture practices have affected ground water quality in the region.

Fig. 3 Groundwater storage trends up to 2050
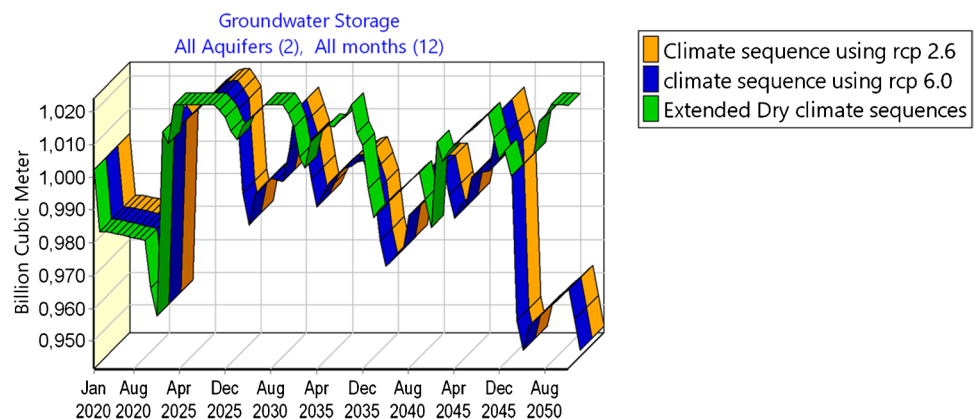
Infiltration and vulnerability

Runoff feeds river systems and groundwater reservoirs through efficient infiltration. To evaluate these resources, the flow condition scenario was introduced. The results show that the maximum runoff occurs in October and the minimum, almost zero, occurs in July, Fig. 4. Moreover, the simulation of the results shows that there will be a decrease in the runoff after 2045 (Rocha et al. 2020).

Evapotranspiration and vulnerability

The evapotranspiration rates were similar under the extended climate sequence and hydrological year method scenarios. However, it was higher under RCP 2.6 and RCP 6.0 scenarios, Fig. 5. For example, in August 2025, the flow for each climate scenario RCP 2.6 and RCP 6.0 is up to 262 m^3 and for the two scenarios (extended dry climate sequence and hydrological year method), the flow is up to 256 m^3. The maximum value of the evolution of the evaporation is about 293 m^3 in June of every year and the minimum value is 41 m^3 in January of every year for the two scenarios (scenario RCP 2.6 and RCP 6.0). For the extended dry climate sequences, the maximum value of the evolution of the evaporation is about 282 m^3 in July of every year and the minimum value is about 53 m^3 in January for the period of 2020 to 2050.

The evaporation in the basin will decrease due to the projected temperature both spatially and temporally. According to Rocha et al. (2020), the MENA region is expected to have higher temperatures and lower precipitation amounts, which will affect water availability and irrigation amounts.

Precipitation

Precipitation varies every year under RCP 2.6 and RCP 6.0. It varies from 195 mm in January 2020 to 287 mm for the RCP 2.6 and 290 mm for RCP 6.0 in December 2050, but every July, the precipitation decreases until 10 mm, Fig. 6.

For the extended climate sequence scenario, the precipitation is starting at 195 mm in January 2020 to 168 mm in December 2050. In July of all the years, the precipitation decreases until 90 mm.

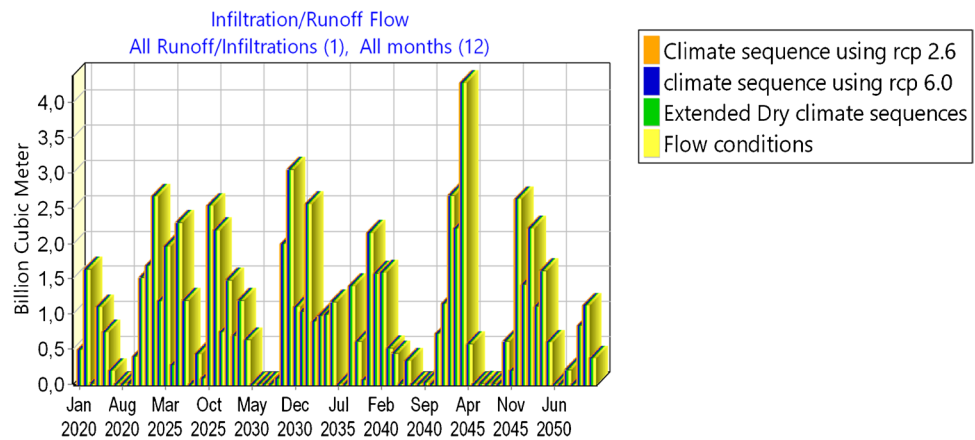**Fig. 4** Runoff/Infiltration rate in the period of 2020 to 2050

Fig. 5 Evolution of evapotranspiration in the period of 2020 to 2050
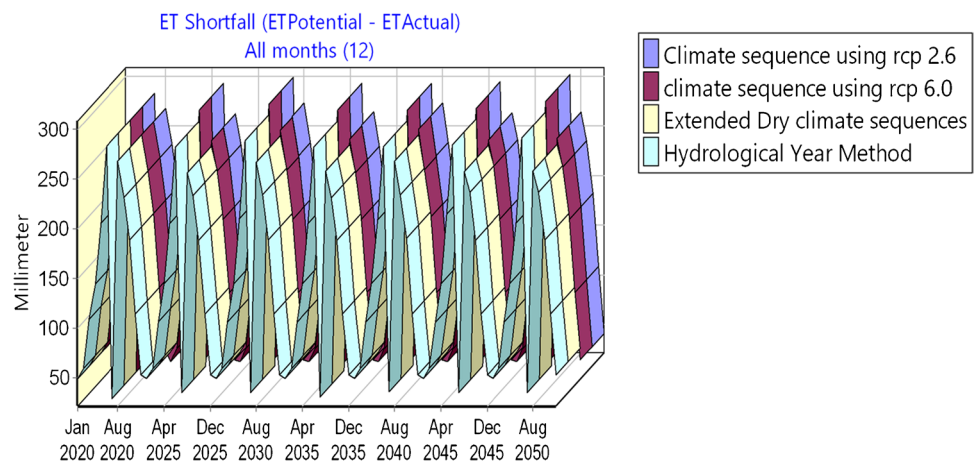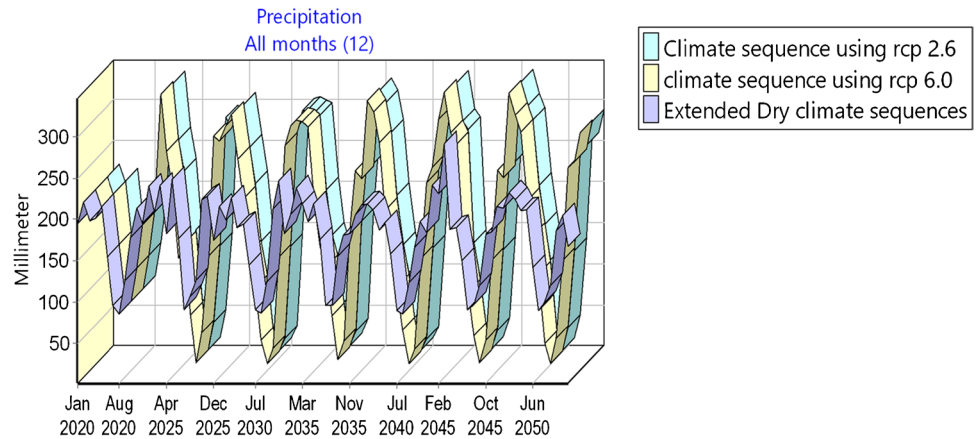
Fig. 6 Evolution of precipitation in the period of 2020 to 2050

Precipitation is particularly vulnerable. The variability of different regions and crops was shown from the analysis in their sensitivity to different future climate scenarios. Some regions and crops might be strongly affected, while others are less so. Water demand for irrigation sector is expected to increase in response to climate change, especially under the climate dry sequence scenarios. The results also show that there might be an increase in rainfall in January 2045 up to 242 mm. However, the increase in rainfall in the upper and middle areas of the basin may increase landslides and flood in the coming decades (Anand and Oinam 2019).

Surface water and vulnerability

The surface water in the basin is used largely for the agriculture, domestic, and industrial needs. Figure 7 shows a decrease in surface water resources between 2025 and 2040. However, there might be two periods of increase in July 2025 and July 2050.

The assessment shows a significant decrease under the climate change sequence scenarios, Fig. 8. According to

Kerim et al. (2016), climate change has a significant effect on water availability up to 2031 since climate change increased irrigation demands and water loss through evapotranspiration. Moreover, other scholars have found that climate change and agriculture practices have impacted surface water quality in the MRB (Slimani et al. 2020; Ben Ayed et al. 2022).

The comparison between the inflow and outflow values for each month during all the period of 2020 to 2050 shows that there is enough water in the MRB under the three climate change scenarios (dry climate sequence, RCP 2.6 and RCP 6.0) from October to April of each year.

Water demands

Water demands are projected to increase under all scenarios. In 2020, water demand was 218 Mm^3, and in 2050, the future water demand will increase to 509 Mm^3, 367 Mm^3 and 458 Mm^3 for the for the climate sequence, RCP 2.6 and RCP 6.0 scenarios, respectively. Some scholars found that MRB faces real water scarcity in the future due to climate change and development practices (Rajosoa et al. 2021).
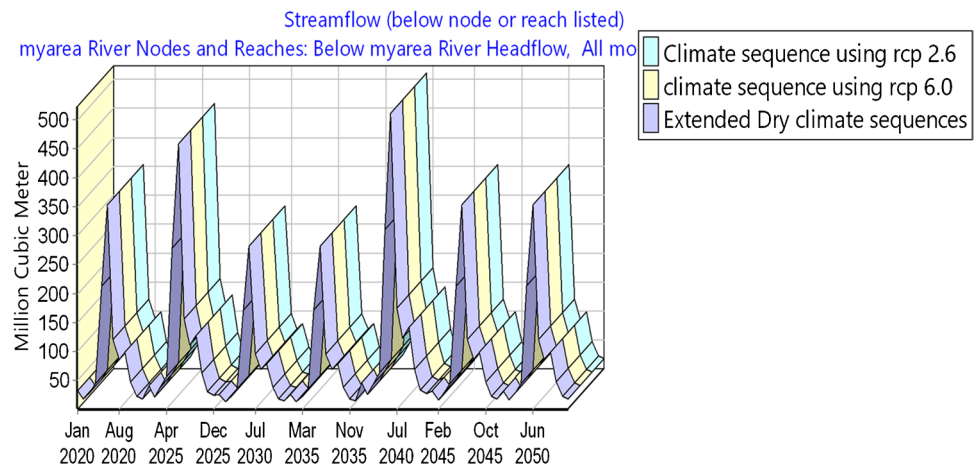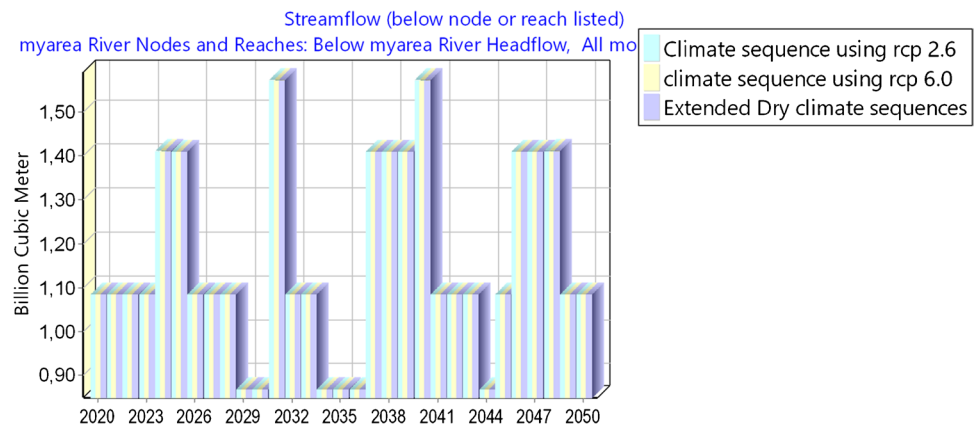
Fig. 7 Evolution of surface water flows

Fig. 8 The annual inflow under the climate change scenarios

Hamdi et al. (2016) found that water supply can be inadequate to meet water demand in the MRB.

Conclusions

The WEAP system was used to assess the impact of climate change on the MRB, shared between in Algeria and Tunisia, under RCP 2.6 and RCP 6.0 scenarios for future projection period (2020–2050). The results showed that climate change will negatively impact surface and groundwater resources at the MRB. Moreover, the combination of climate change and unsustainable agricultural practices has reduced water quality in the basin. Therefore, stakeholder involvement from both countries is needed to build an integrated water resource management strategy, by which water resource allocation and adaptation plans can be addressed and assessed in each sector taking the corresponding needs into account to achieve sustainability. The result showed that there will be a variety of changes in groundwater storage in the different sites. The storage of groundwater resources will have a big decrease between 2045 and 2050 for both climatic scenarios.

Last but not least, climate change impacts on the MRB and their associated uncertainties need further research work and assessment to improve our knowledge about the way that climate change can impact the hydrological cycle and assist water decision making process in Algeria and Tunisia, by which an integrated development plan with a better collaboration can be developed to synchronize human activities and choices related to the hydrological regimes using a holistic approach taking into account local and regional climate conditions.

Declarations

Conflict of interest The authors declare no competing interests.

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