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Analysis of the Water Supply-demand Relationship in the Middle Draa Valley, Morocco, under Climate Change and Socio-economic Scenarios

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Authors' contributions

This work was carried out in collaboration between all authors. Author AK designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors II, AB, MM and MYK managed the literature searches, reviewed the first draft and provided valuable assistance. All authors read and approved the final manuscript.

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ABSTRACT

This article explores the water supply-demand relationship in the Middle Draa valley, under climate change and socio-economic scenarios; identifying some of the climate-hydrological variables that best express the vulnerability of hydrological resources at watershed level. The analysis utilizes the outputs of some general circulation models runs under different scenarios socio-economical and climate change (A2 and B2). We used the Statistical downscaling models (SDSM) that allow the observation of climate change at local level and the Water Evaluation and Planning System (WEAP), an integrated approach to simulate water systems and orient management policies. The results predict that under the scenario of climate change A2, the region will know more severe droughts than under B2 scenarios. The estimation of the water balance is made through WEAP model; which shows that the study area will know a lack in supply.

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Keywords: Water demand; climate change; WEAP; SDSM.

1. INTRODUCTION

Ecosystem services are the benefits provided to people, both directly and indirectly, by ecosystems and biodiversity [1]. In the Millennium Assessment, fresh water is a ''provisioning'' service as it refers to the human use of fresh water for domestic use, irrigation, power generation, and transportation. The fresh water and the hydrological cycle also sustain inland water ecosystems (rivers, lakes, and wetlands); providing cultural, regulating, and supporting services that contribute directly and indirectly to human well-being through recreation, scenic values, and maintenance of fisheries [2]. The climate change presents a risk for water resource in the developing countries in Africa, where agriculture is the main economic activity. In fact, Basins under water stress are located in North Africa in the Mediterranean region [3]. The Draa basin in the south of the High Atlas Mountains (Morocco) knows this crisis situation in terms of water resource. The Middle Draa Valley is the middle part of this basin. This valley is characterized by oasean agriculture. The studies that has been done on the environmental vulnerability index in arid valley of Middle Draa [4], Tafilalt Valley [5] and in semi arid area especially in Rheraya of the Marrakech El-houz region [6] showed that the category of indicators related to water resources has the highest vulnerability in the face the other categories (climate, biodiversity, agriculture and fisheries, human health and exposure to natural disasters); from where the importance of analyzing the vulnerability of the ecosystem service of water. The man was guided to the installation of oases, by the availability of water resources [7]. In Morocco, oases occupy an important place; they represent 15% of the country and contribute to economic and social development [8]. Resource sustainability is a major concern of oases zones. Demographic and economic pressures and the effects of climate change activities on water resources have altered the ecosystem quality [9]. Oasis in Middle Draa Valley (MDV) extends over a length of about 200 km and is a valuable heritage through the role it plays in economic and social life of the population of the region. Water is a supporting service, it is in the basis of other ecosystem services, and it provides a basis for the ecological balance and socio-economic development. In the last 30 years, under climate change and anthropogenic impact, water in the oases of MDV is more and more rare [4]. MDV is a part of the Biosphere Reserve of Southern Morocco Oases (BRSMO), which is constantly threatened by drought, salinity and sand advancement [4,5].

The paper analyzes the socio-economic impacts and potential climate change on water. The analysis is carried using two tools, the first is a climatic model called SDSM, used to draw future projections of two selected climate parameters (precipitation and temperature); and the second, WEAP is a hydrological model used for the management of water resources in the study area, using both scenarios developed by the SDSM, and other socio-economic scenarios developed in this paper.

2. MATERIALS AND METHODS

2.1 Study Area

The Middle Draa Valley (MDV) is a territory of 15000 km^2; 200 km long, it is located in the west of Upper Draa Valley and forms the border with Algeria. Fig. 1 shows the Location of the MDV. The topography is characterized by a great variation in elevations ranging between 1020 m and 375 m above sea level. Is fed by Draa Wadi, the longest Wadi in Morocco and formed by the confluence of its main headwater tributaries, Dadès and Ouarzazate Rivers.

Surface water resources in MDV consist of the Draa Wadi, which is became a temporary river since the construction of Mansour Eddahbi Dam in upstream of MDV [10]. This Wadi is used as a source of surface water and allows feed the groundwater resources. Topography and climate affected the distribution of cultivated areas, urbanization, road construction and other uses. According to the classification of Koeppen [11] & [12], MDV is marked with its hot and arid climate. This is also affected by its geographical position south; and experiences few but sometimes heavy rainfall occasions, typical of desert and steppe climates [13]. In the MDV, the oases occupy about 26,000 ha distributed into six palm groves, and are characterized by a vegetation management in stratum dominated by the date palm that promotes micro-hot and humid climate conducive to diversified agricultural production [4]. Since the construction of Mansour Eddahbi Dam in 1972, the number of motor pumps has increased steadily. It is estimated that in 1977, the six oases had about 2000 pumps, and in

1985, this number had doubled (Fig. 2). In 2005, the number of motor pumps has increased to nearly 7,000 for the whole MDV and more than 10.000 in 2011.

In the MDV, reduced surface water supplies caused increased groundwater pumping; consequently, the power generations by the Mansour Eddahbi Dam are anticipated to decrease under climate change due to the expected reduction in water “Lachers”.

In addition to the risk of overexploitation, we recorded an increase in the saline groundwater in most oases of the biosphere reserve in the south, mainly in the oasis of Tafilalet [14], and in the Middle Draa valley, especially in the downstream part [15]. At this valley, the river system is fed by releases from the Mansour Eddahbi Dam. In parallel with the impact of drought, this dam is subjected to the phenomenon of siltation. Indeed, the capacity of the dam was reduced by approximately 25% in 1998 [16]. Still in the Biosphere Reserve of Moroccan oases, Hassan Eddakhil Dam in the Ziz Valley also suffered the same problem of siltation. Messouli [17] argued that if the siltation rate continues at its current rhythm, the dam will not be operational for irrigation in 2030. What aggravates the situation is the orientation of farmers to more profitable crops but harmful in the long run, especially the cultivation of watermelons which dramatizes the demand for water [4]. In fact, from 2012 to 2013 (Fig. 3) the area is almost doubled (670 in 2012 to 1130 in 2013 and 2430 in 2014).

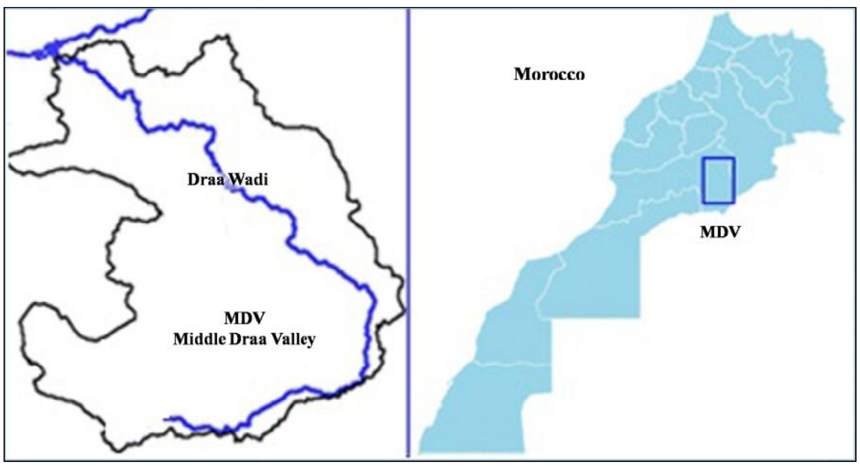

Fig. 1. Location of the Middle Draa valley (MDV) in south east of Morocco, (MDV map modified from The Digital Atlas Impetus)

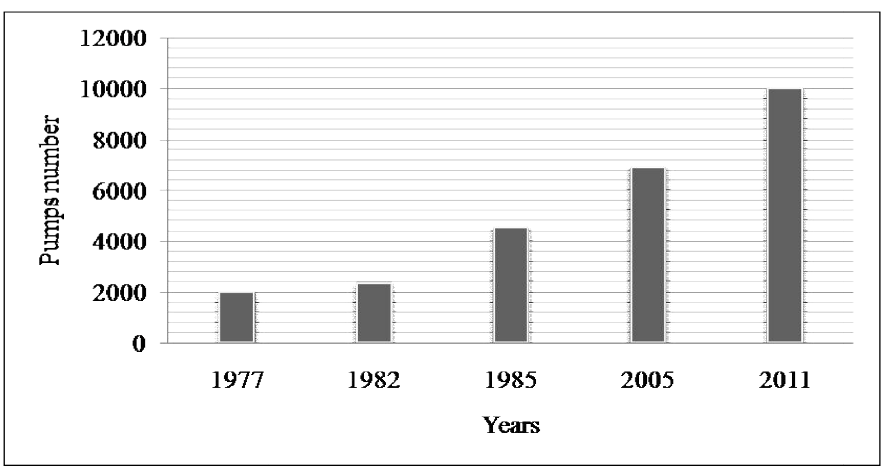

Fig. 2. Pumps number in 1977, 1982, 1985 and 2005 [18] and 2011 [19] in the MDV

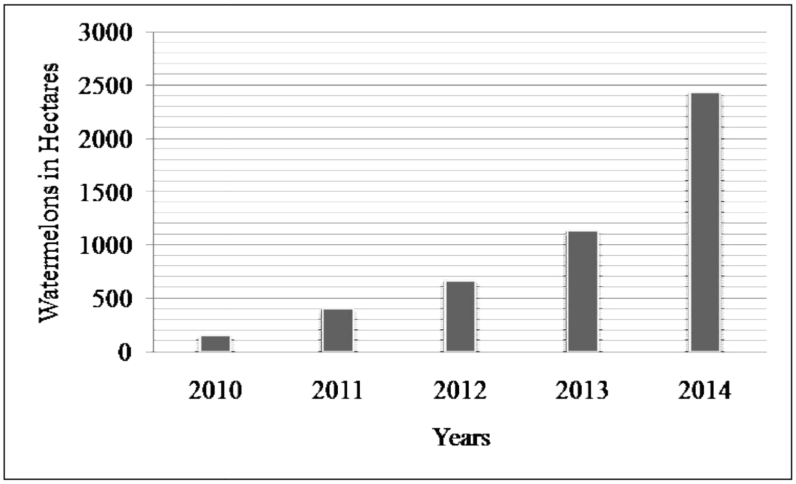

Fig. 3. Watermelons production rates in the MDV. Source of data: [20]

The total irrigated area in the Middle Draa valley is about 26,000 hectares, dominated by palm trees, wheat, alfalfa, and in the last decade the development of the culture of watermelons. For the distribution of water resources in the different users (sectors), and from the total amount of exploitable water resources; 96.66% is used for agriculture, 2.70% for domestic, 0.28% for tourism, and 0.36% for economic activities [21]. This shows that the agricultural sector is the biggest consumer of water resources.

2.2 Methodology

The methodology for the study of the hydrological vulnerability is based on two elements:

- The use of SDSM model to develop climate scenarios at local scale. To meet this objective, an analysis of how increases in temperature and runoff would affect the hydrologic characteristics.
- The use of the WEAP model to assess the options for managing water resources for the Middle Draa Valley.

It was necessary to collect data from a variety of sources, including documents, government ministries, and other environmental organizations. The anthropogenic data and general characteristics were obtained primarily from the High Commission for Planning and ONEE (Office national d'Electricité et d'Eau potable). Meteorological Data were obtained from the ORMVAO (Office Régionale de Mise en Valeur Agricole d'Ouarzazate) and the ABHO (Agence du Basin Hydraulique d'Ouarzazate).

2.2.1 Elaborations of climate change scenarios A2 and B2 at local scale

The Model of statistical downscaling (SDSM) is a tool for decision support, developed by Robert Wilby and Christian Dawson to assess the impact of local climate change through a robust technique statistical downscaling [22]. It is a hybrid between a stochastic weather generator and a multiple linear regression method which facilitates the rapid development of multiple scenarios in one site for daily weather variables under conditions of current climate forcing and future [23].

The Re-analyzes (data per grid point which are the output of a system to assimilate observations) large-scale NCEP on Morocco were used. For the future climate, we have used the climate change scenarios at low resolution from the English model HadCM3 in the period 1961-2099. HadCM3 systematically cover a period of 360 days (days modeled by the Model), divided into 12 months of each 30 days [24].

The modeling process generated these vulnerability scenarios using the parameters of rainfall and main temperatures in the two climate change scenarios A2 and B2. Table 1 gives a comparison of the evolution of climate and socio-economic parameters in both scenarios used in this study A2 & B2.

Table 1. Overview of A2 and B2 scenarios parameters (Cited by [25])

Storylines	A2 scenario	B2 scenario
Regionalization (heterogeneous world)	Regionally oriented economic development	local environmental sustainability
Population growth	high	medium
GDP growth	medium	medium
Energy use	high	medium
Land-use changes	medium/high	medium
Resource availability	low	medium
Pace and direction of technological	slow	medium
Change favoring	regional	“dynamics as usual”

2.2.2 Elaboration of socio-economic scenarios for the WEAP Model ‘water evaluation and planning system’

WEAP or « Water Evaluation and planning System » is created by Stockholm Environment Institue (SEI) by Jack Seiber, Chris Swartz, and Annette Huber. This Model helps to identify water resource management options under different scenarios. Also we will test WEAP capabilities as management tool. How a future system might evolve over time in a particular socio-economic setting [26] and under climate change conditions? Using WEAP, scenarios can be built and then compared to assess their impacts; all scenarios start from a common year, for which the model Current Accounts data are established [26]. We used a principal scenario, which is the Reference scenario that represents the changes to occur in the future, in absence of any new policy measure. Base case scenario is with population growth at a rate of 3 in urban area [27]. The Reference scenario is the scenario in which the current situation (2010)[1] is extended to the future (2011-2080). No major changes are imposed in this scenario. Only the cropping pattern slightly changes over the years.

3. RESULTS

3.1 Elaboration of Climate Change Scenarios in the Draa Valley

To develop the climate change scenario, we have used the SDSM software. This model predicts the mean temperature and precipitation for the period of 2010 to 2099 basing on climatic data of the period 1961-2000. The annual precipitation, leads to classify hydrologic years in 5 categories, that we attributed the number 1 to 5, were 1 indicates very wet, 2: wet, 3: normal, 4: dry, and 5: Very dry, using “Poissonnet” method which was followed by [25]. Our climate change model showed increases dry years. Fig. 4 summarizes the annual changes in water year studied for the period 2010-2099 under scenarios of climate change A2 and B2. The result predicts also that under the scenario of climate change A2 will be more severe droughts than under B2 scenarios.

3.2 Water Model in the Middle Draa Valley

The contribution of the present study is an analysis of the water supply-demand relationship in the MDV. All the information concerning water use and users (the demand sites like the agricultural sites mentioned in Table 2) in Draa basin was compiled, and was subsequently incorporated into the WEAP model, 6 irrigation districts (Mezguita, Tinzouline, Ternata, Fezouata, Ktaoua and M’Hamid), and seven sites of supply (groundwater and water surface).

Fig. 5 shows the water demand in the 6 palm groves of Middle Draa Valley under three scenarios, the results predict an increase of water demand 3 times on horizon of 2030 under A2, 2.5 times under B2 and 1.75 under reference scenario; the situation will be aggravated on 2050 and plus.

4. DISCUSSION

It is well recognized that water scarcity problem is especially alarming in the biosphere reserve oases of southern Morocco, where water resource is the main asset of rural populations. The results of both SDSM and WEAP models allow demonstrating that the situation of water in MDV is in crisis. In fact, water resources are becoming scarce due to precipitation decrease and temperature increase. Surface-water

[1] *We set the current situation at 2010 due to the fact that no data were available for 2011, 2012, 2013 (a complete set of data is only available for 2010)*

resources originating from the Draa Wadi are currently fully exploited, because the annual average of mobilized water is 276 Mm^3 which 190 million m^3 from the dam, 30 million m^3 of floods and 56 million m^3 of groundwater. The need for water irrigation in middle Draa valley in 2004, is estimated at 302.6 Mm^3, which corresponds to a coverage rate of 91%. In 2014, the needs will be in the range of 368.86 and coverage in 2014 becomes 74%. Draa is facing increasing water needs, demanded by rapidly growing population, and increased urbanization.

In this Valley, water demands are met by both surface water and groundwater supplies. For agricultural and urban areas with access to these two resources, demand is supplied by groundwater pumping. However, the areas without surface water access, all demands are met by groundwater pumping.

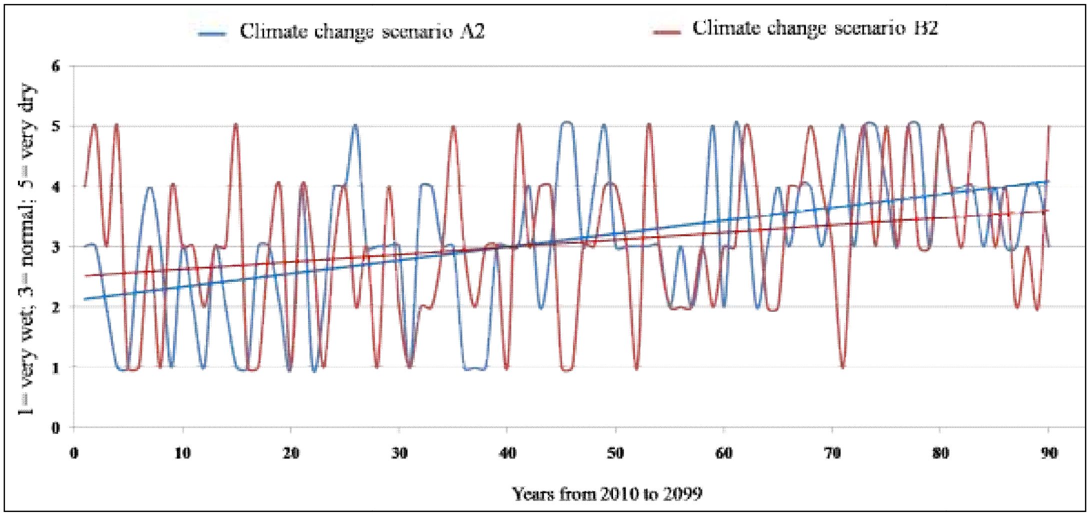

Fig. 4. Sequence of wet and dry years for A2 and B2scenarios (2010-2099)
Water year type: 1 = very Wet, 2 = Wet, 3 = Normal, 4 = Dry, 5 = Very Dry

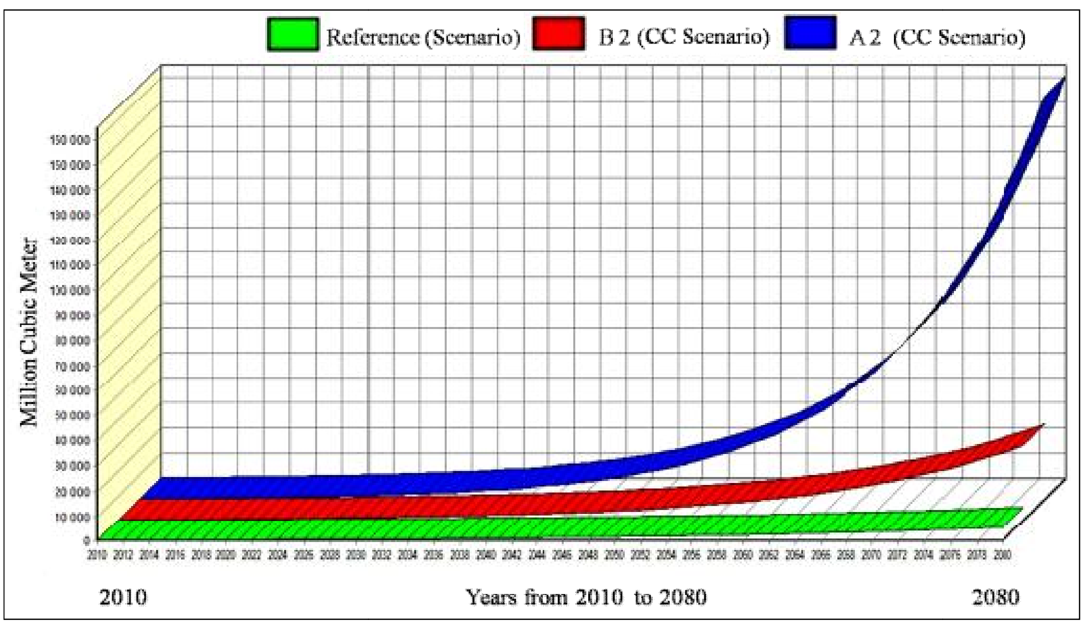

Fig. 5. Comparison of water demand between tree scenarios (reference, CCA2 & CCB2) for the 6 palm groves (Mezguita, Tinzouline, Ternata, Fezouata, Ktaoua and M'Hamid) in the period 2010-2080

Table 2. Demand sites of MDV

Demand sites	Sites of supply	
Agricultural sites	**Groundwater**	**Water surface**
Mezguita	Mezguita	Draa Wadi
Tinzouline	Tinzouline	Mansour Eddahbi
Ternata	Ternata	Dam
Fezouata	Fezouata	
Ktaoua and M'hamid	Ktaoua and M'hamid	

The problem of water resources is expressed in terms of availability that is attributable to the effect obviously of the repeated droughts and recently unsustainable farming practices (e.g. watermelon). At the level of the biosphere reserve oases of southern Morocco, crops that consume a lot of water spread everywhere. At Tafilalt, Bensalem [14] reported that some farmers have introduced varieties unsustainable cultures that consumes a lot of water and also cause genetic erosion. In the Middle Draa Valley, the culture of henna, this consumes a lot of water during the summer period, although it is a cultural heritage. In the last decade, we have experienced the expansion of the cultivation of watermelons as we mentioned in the study area section, which doubles from one year to another, and requires a lot of water in full summer. It is widely encouraged by the Agricultural Policy called "Plan Maroc vert", which also subsidizes its irrigation, 100% for areas less than 5 ha and 80% for areas greater than 5ha (according ORMVAO: Office régionale de mise en valeur agricole d'Ouarzazate). More than 5% of the crops used to feed animals or left in the fields. These cultures aggravate the water crisis that knows the area. The choice of these cultures no longer responds to climatic criteria as before, but to purely economic criteria. The choice of crops in arid regions is a mismanagement of water resources already in short supply. Thousands of pumps spew huge amounts of water to irrigate watermelon at this time. Knowing that the groundwater level decline [28], and only a few kilometers, villages may suffer from lack of water. In summer 2014, the situation of water availability was very critical as the population of the town of Bani Zouli had access to drinking water for a period of 30 minutes per 24 hours. After our field observation, in the Zagora city, the situation is much more serious, because for the past 3 years, plus recurring cuts, water is considered as very saline.

In the scientific literature, overexploitation of groundwater is clearly identified. The pressure of a growing population on groundwater resources is exacerbated by the impact of climate change in drylands, at Tafilalt [17], in Ziz Valley [14], In Middle Draa Valley ([19,4]) and even in semi-arid area like in Tansift [29]. The climate change scenarios developed by IMPETUS Project forced by the SRES A1B greenhouse gas scenario, developed produce warmer and, less significantly, dryer conditions in the Draa region. The results of regional climate modeling in IMPETUS project [13] might be understood as a warning: the probability that water stress in the region will increase in the future is considerably higher than we may be comfortable with. After the results of this paper, the hydrologic model predicted that in this situation the demand will increase greatly and available water will decrease due to dry years predicted in this paper both under A2&B2. During this extreme water shortage, water supply priority will be given to satisfy the domestic uses, and the remainder of available water will be directed to the agricultural sector [30,31]. The response must be advanced by government departments, to challenge the regulation of anarchy pumping. The government should offer farmers a premium per hectare to replace the culture of watermelon by other plants such as dried vegetables and oilseeds. This is expected to save several million cubic meters of water each year (15 Mm^3/year). 6000 m^3 per 1ha uses the technique drop by drop [32]; this amount is tripled or more during submersion irrigation. 4 months 15Mm^3 day and night, this is the amount needed to provide water to 5 villages or more. For example we can reduce evaporation by planting trees around crops and / or adopt an irrigation system "drip".

A number of measures can be taken:

- *Changing lifestyles and consumption*
- *Use of modern irrigation systems;*
- *Night irrigation:* since it reduces evaporation losses;
- *Introduction of short-age varieties*;
- *Launching public awareness campaigns;*

- *Reuse of drainage water and treated wastewater and;*
- *Desalination.*

5. CONCLUSION

Many of the provisioning, regulatory, and cultural services can be enhanced through development of water resources [2]. In Draa, the acceleration of economic and demographic development, with rapid urbanization, and growing agriculture (mainly the unsustainable crops like watermelon), has pressures on the region's water resources. This situation is alarming as Draa is an arid area that depends on a single source of water which is the Draa River. Water resources in Draa are limited to the Mansour Eddahbi Dam. This paper presents an assessment of the impacts of climate change induced water availability in the MDV. The WEAP was used to describe the vulnerability of the water resources in the case study river basin, taking into account the effects that climate change can have on water availability in the agricultural sector.

The results of WEAP showed that water demand varies significantly according to the three scenarios (climate change A2, B2, and Reference scenario), and underlined the importance role of water management aspects. Also the results revealed that an additional amount (more than 2 to 3 times in the horizon of 2030) is needed to satisfy water needs and development, otherwise the gap between demand and supply will grow dramatically if current supply conditions continued. The results confirmed that WEAP can be applied as a decision support at this local scale. The results indicate that climate change scenarios have the most negative impact on water availability. Projected increases in temperature and changes in precipitation could modify the volume and timing of water flow in the Draa Wadi (temporary River), and change the groundwater recharge and consequently the agricultural water demands.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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