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1D MODEL APPLICATION FOR INTEGRATED WATER RESOURCES PLANNING AND EVALUATION: CASE STUDY OF SOUSS RIVER BASIN, MOROCCO

MODÈLE D'APPLICATION 1D POUR LA PLANIFICATION ET L'ÉVALUATION INTÉGRÉES DES RESSOURCES EN EAU: ÉTUDE DE CAS DU BASSIN DE LA RIVIÈRE SOUSS AU MAROC

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ABSTRACT

The Souss basin is considered one of the most important Moroccan basins due mainly to its high value agricultural production, however, the intensive use of groundwater has led to a lowering of the piezometric level with an average of 2–3 m per years. This paper aims to develop a decision support system to model the water resources and their uses, assessing the balance-equilibrium resources needs and analyze the future situation of the water according to different scenarios. It is noted that the use of water is excessive especially at the level of agricultural use which results in overexploitation of the groundwater of the basin. On average groundwater abstraction exceeds recharge by an estimated 260 Mm^3 annually. Using water evaluation and planning system (WEAP), we built a model for managing water demand of Souss basin .three scenario of water demand were calculated by WEAP model over the period of 43 years (2007-2050), reference scenario, higher population growth scenario and demand side management scenario. The results confirmed that the proposed approach is valid to build a decision support system for Souss water resources management.

Keywords: WEAP, Water Resources, Water demand, Souss basin.

RÉSUMÉ

Le bassin versant de Souss est considérée parmi les plus importants bassins marocains due principalement à sa production agricole de grande valeur, mais L'utilisation intensive des eaux souterraines au niveau du basin a engendré une baise au du niveau nappe phréatique avec une moyen de 2 à 3m par année, cet article vise à développer un système d'aide à la décision pour modéliser les ressources en eau et les usages, évaluer l'équilibre de la balance besoins-ressources et analyser la situation future de l'eau selon différents scénarios. On constate que l'utilisation de l'eau est excessive surtout au niveau l'utilisation agricole ce qui se traduit par une surexploitation des eaux souterraines au niveau du bassin. En moyenne, le captage d'eau souterraine dépasse la recharge d'environ 260 Mm^3 par an. En utilisant le système d'évaluation et de planification de l'eau (WEAP), cet article vise à développer un modèle de gestion de la demande en eau du bassin du Souss, trois scénarios de la demande en eau sont élaborés par le modèle WEAP, trois scénarios de demande en eau ont été calculés par le modèle WEAP sur une période de 43 ans (2007-2050), le scénario de référence, le scénario de croissance démographique accrue et le scénario de gestion de la demande. Les résultats ont confirmé la validité de l'approche proposée pour la construction d'un système d'aide à la décision pour la gestion des ressources en eau du bassin du Souss.

Mots-clés : WEAP, ressources en eau, demandes en eau, bassin du Souss.

INTRODUCTION

In many basins around the world increasing water demand is leading to the overexploitation of limited water resources and more frequent and more pronounced periods of extreme water scarcity (Falkenmark and Molden, 2008). Arid and semi-arid areas are characterized by their high sensitivity to climatic hazards. Their water resources can hardly meet an increasing demand driven by irrigated agriculture, population growth, improved living conditions and economic development (Le Page *et al.*, 2012), Souss basin is one of the semi-arid areas that suffers from water scarcity due mainly to an increase in irrigated agriculture, tourism, and industry and in large part to irregular rainfall and its heterogeneous distribution. However, The Souss basin is Morocco's second most important economic basin due mainly to its high-value agricultural production, attracting tourism industry, and fishery development (Choukr-Allah *et al.*, 2017). Agriculture sector is the key driver of water demand in this region, the focus of the Souss plain in citrus production, amounting to 55% of the country's exports in these sectors (APEFEL, 2014). The Souss watershed is experiencing a depletion of its water resources. Pressure on available resources from excessive irrigation development, urban and industrial growth and the expansion of the tourism industry have led to the over-exploitation of its water table. The rate of decline of the water table is increasing at a worrying speed. Water scarcity alone caused the abandonment of at least 11,900 ha of merely cultivated land in the Souss valley, and particularly around the city of El-Guerdane, up to 2008. Wells dried out due to the sinking water table (Choukr-Allah *et al.*, 2017). The annual water deficit with regard to water use is estimated at 290 million cubic meters in the Souss valley (ABHSM, 2011).

Water resource management models are effective tools for addressing water shortages, this is because water supply and demand simulations can support decision processes for regional water resource planning (Kou *et al.*, 2018). Many studies and applications of water management models that have been used for previous research include the AQUATOOL, MODSIM, and WEAP (Zahidul, 2011). The Water Evaluation and Planning System (WEAP) software developed by the Stockholm Environment Institute has shown to be useful for the simulation of possible demand and supply-based changes in water resources systems (Zaoui *et al.*, 2010). In the last decade WEAP has been widely used to examine complex water systems in the water resource planning sector all around the world (Purkey *et al.*, 2007). Recently several WEAP models were applied to basins in the arid and semi-arid areas of Morocco, WEAP proved to be helpful in showing the various interactions of water supply and demand (Johannsen *et al.*, 2016). The water resources system in WEAP is represented by demand sites, supply sites, catchments, withdrawal points, transmission links, wastewater treatment, environmental needs, and the generation of pollution. Depending on the need and data availability, WEAP simulates several aspects such as sectoral water demands, water allocation rights and priorities, ground and surface water flows, reservoir operations, and the assessment of vulnerability and cost-benefit analysis, amongst others (Ojwang *et al.*, 2017).

The model is applied to evaluate and analyze the current and projected balance of water resource management by taking into account the various policies and the operational factors which can affect the demand until the year 2050.

MATERIALS AND METHODS

Study area

The Souss basin is located in the middle western of Morocco, occupying a total surface of 17186km^2, which is approximately between 9.6 and 7.47 degrees west longitude and between 29.70 and 31.11 degrees north latitude, the anti-atlas mountains in the south, the high atlas mountains in the north, the siroua massif in the east, and the atlantic ocean in the west are the natural limits of the the Souss basin (Fig. 1).

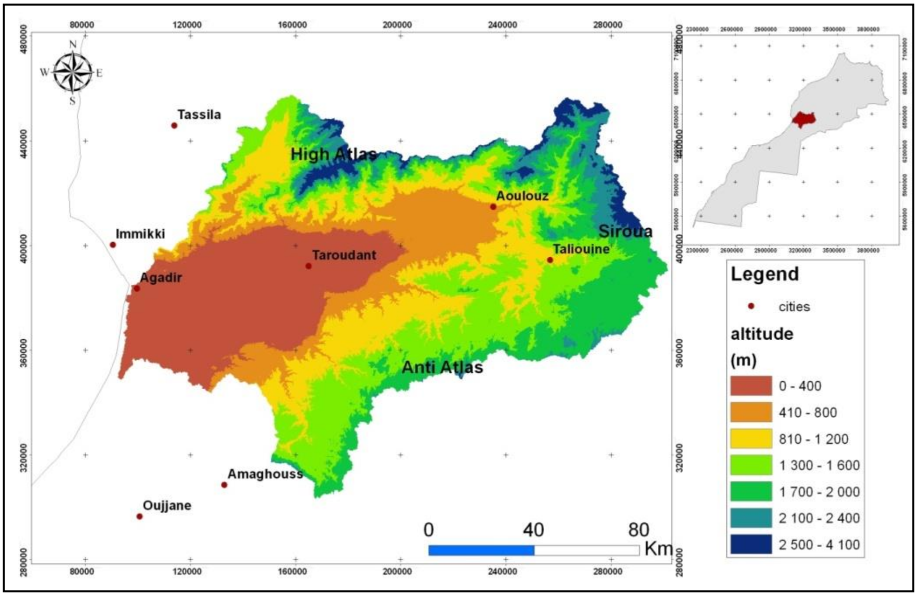

Figure 1 : Geographical situation of Souss River Basin

Methodology

The WEAP system was selected to model the Souss River Basin because it utilizes a scenarios-based approach that facilitates the exploration of a wide range of demand and supply options for balancing competing operational objectives. Additionally, WEAP allows for a reduced level of complexity to represent water systems, which, in combination with the graphical user interface, facilitates the testing of several scenario combinations independently by policy makers and other stakeholders (Hoff *et al.*, 2011). Most of the data entered into the Souss Basin WEAP model have been obtained from the Souss-Massa Hydraulic Basin Agency (ABHSM).

The geographical focus of the Souss basin WEAP model is the river basin and includes representations of the main water management features within the watershed, This includes all of the major tributaries, the Souss aquifer, the dams; the agricultural and domestic demands that are associated with these supply sources. The WEAP schematic (Figure 2) shows, how the main features of the Souss river water system have been aggregated and represented in WEAP as so-called supply and demand nodes, transmission links between these nodes and water allocation rules.

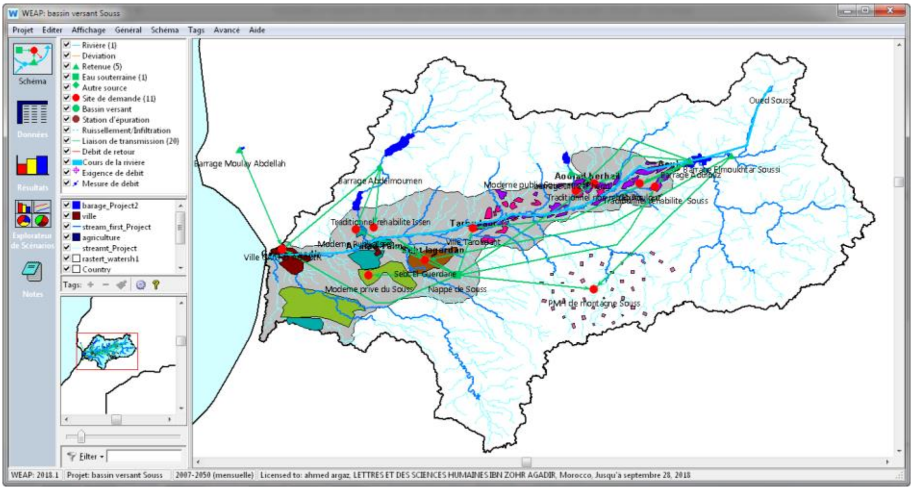

Figure 2 : Model schematic of the Souss basin water system in WEAP

Water supplies and demands

The Souss River Basin mobilizes around 831 millions meter cube of surface and groundwater, inducing a water deficit of 283 Mm^3. This negative balance between water supply and demand is covered by a groundwater mining and a lowering of the piezometric level with an average of 2–3 m per years (Choukr-Allah *et al.*, 2017). Most of available natural water is consumed for agricultural purposes (94%), and 6% as drinking and industrial water.

Surface water supplies

Based on data from the Souss-Massa Hydraulic Basin Agency (ABHSM) in 2007, The Souss River Basin is draining 278 Mm^3/year of surface water, through the High and Anti-Atlas tributaries. Surface water is collected and stored behind five dams (Abdelmoumen, Aoulouz, Imi El Kheng, Moulay Abdellah, and Mokhtar Soussi) that have a combined total useful capacity of 490 Mm^3 with an annual water mobilization of 310 Mm^3 (Table 1). These reservoirs regulate the downstream flow of the river, with the purpose of avoiding floods and artificial groundwater recharge and assuring the necessary flow for the main water concessions in the lower course of the Souss Basin. (Hssaisoune *et al.*, 2018).

Table 1 : Large and medium hydraulic structures of Souss River Basin (PDAIRE/ABHSM)

Dams	Service's date	Useful capacity (Mm^3)	Regulated volume (Mm^3)
Abdelmoumen	1981	210	54.9
Aoulouz	1991	108	173.8
Imi El Kheng	1993	12	5
Moulay Abdellah	2002	110	27
Mokhtar Soussi	2002	50	50
Total	-	490	310.7

Groundwater

Groundwater in the Souss bassin is heavily influenced, with dry season contributions. Groundwater tables are affected by annual rainfall and soil permeability. Groundwater is extremely important for drinking, industrial, and irrigation water supply (which is of excellent quality in most cases) (Hssaisoune *et al.*, 2018). Groundwater resources in the Souss River Basin area are developed from two aquifer systems, Deep Aquifers and Shallow Aquifer, but the Shallow Aquifer is considered the most important hydrogeological unit in the Souss bassin because, firstly, it is the easiest to use both extensively as intensively and, secondly, it contains most of the groundwater resources in the basin (Hssaisoune *et al.*, 2018). The potential renewable groundwater in 2007 is on average of 268 Mm^3/year. Groundwater exploitation in the region has increased dramatically during the last decades due mainly to an increase in irrigated agriculture, tourism, and industry (Choukr-Allah *et al.*, 2017).

Agricultural water demands

The hydro-agricultural development experienced since the area 1970 was also reflected in a significant increase in water demand for irrigation (Hssaisoune *et al.*, 2018). Irrigated agriculture uses more than 94% of water resources mobilized in the basin. The volume of water allocated to agriculture amounts to almost 781million m^3 for irrigation of over 1004,505 ha, of which 70% comes from ground water (ABHSM, 2008).

Drinking and industrial water

The volume of water allocated to the drinking and industrial water in 2007 is around 50.4 million m^3, provided from groundwater (about 40%) and Surface Water (about 60%). The urban centers are supplied with as follows: The greater Agadir is supplied from surface water (Abdelmoumen and Moulay Abdellah dams) and groundwater (Souss shallow aquifer), Taroudant province is supplied from Souss shallow aquifer. The evolution of drinking and industrial water requirement is based on the evolution of the population that reaches to 1,980,537 inhabitants in 2014. According to the Hydraulic Agency of Souss-Massa-Draa Basin (ABHSMD) the drinking and industrial water is growth to 70 Mm^3 in 2020 (Hssaisoune *et al.*, 2018).

Model calibration and validation

The Souss Basin WEAP model was calibrated with streamflow data from the Souss-Massa Hydraulic Basin Agency (ABHSM). Calibration is performed by comparing observed and modeled inflows to Souss Basin. The range of resulting values from the calibration process is shown in figure 3. In this figure we present results for the calibration period corresponding to the 2007–2009 period. The figure shows good agreement between calculated and measured inflows to Souss Basin.

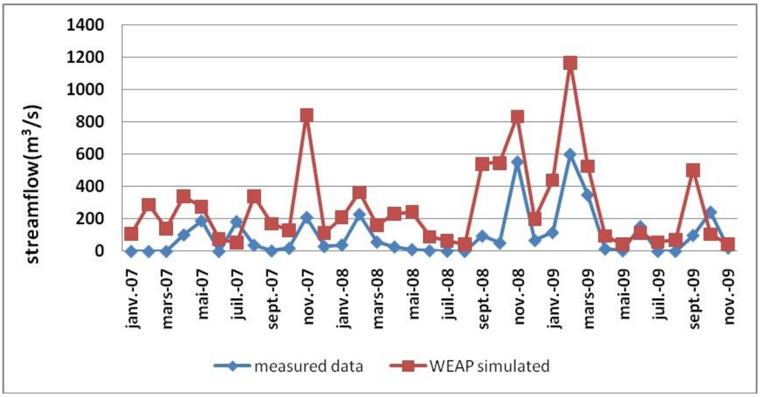

Figure 3 : Observed and WEAP simulated streamflow time series at Souss Basin

Scenario analysis with Weap

In order to assess the capability of water supply in meeting the demand for treated water in Souss Basin, three types of future projections were investigated: population growth, demand side management and supply side management. The key results investigated were water supplied and demand coverage.

Scenario 1: Reference.

The Current Accounts is the dataset from which the scenarios are built. Scenarios explore possible changes to the system on future years after the Current Accounts year (Hamlat *et al.*, 2013). A default scenario, the “reference” carries forward the Current Accounts data into the entire project period specified and serves as a point of comparison for the other scenarios in which changes are made to the system data (SEI 2007). The current situation (2007) is extended to the future (2008–2050). No major changes are imposed in this scenario. Figure 4 presents the "water demand" for current accounts of the year 2007 for all sites in The Souss Basin.

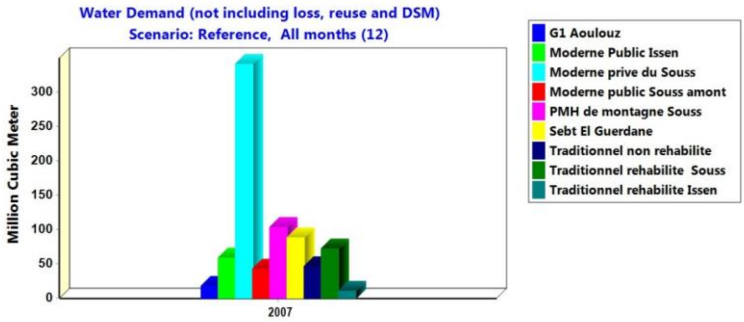

Figure 4 : Water demand for all sites (Year of current accounts 2007)

Scenario 2: Higher population growth

This scenario assumes a higher population growth rate of 3 % in the greater Agadir and 2.5% in Taroudant province, this scenario use to evaluate the impact of population growth towards the water supply and demand of Souss Basin in the future.

Scenario 3: Demand side management

Using this demand-side management scenario, the water conservation techniques were applied in the Souss Basin model. The water conservation strategies, Sprinkler (reduces 25% agricultural water consumption), Drip (reduces 35% agricultural water consumption), are introduced into the WEAP model. The basis of these conservation strategies is to improve the performance of the system and to examine the impact on the reliability separately.

RESULTS AND DISCUSSIONS

Reference Scenario

In reference scenario, drinking and industrial water demand would steadily rise as a result of population increasing at 1.4 % annually in the greater Agadir and Taroudant province, in 2004 the population of greater Agadir increasing from 907,568 to reach the capacity of 1,650,103 in 2050,while in Taroudant province, in 2004 the population increasing from 780661 to reach the capacity of 1,419,366 in 2050,The accompanying projected Drinking and industrial water demand rises to 161.7 Mm^3 compared to the existing demand is 48.9 Mm^3 (Figure 5), which is tripled of the demand of current situation.

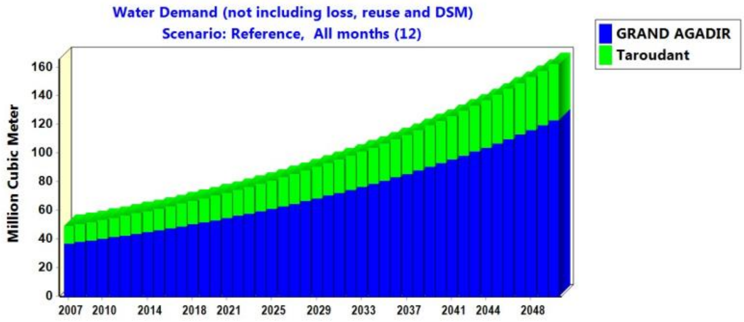

Figure 5 : Annual total water demand of reference scenarios

The accompanying projected irrigation water demand in reference scenario rises to 869 Mm^3 compared to the existing demand is 781 Mm^3 in 2007 (Figure 6).

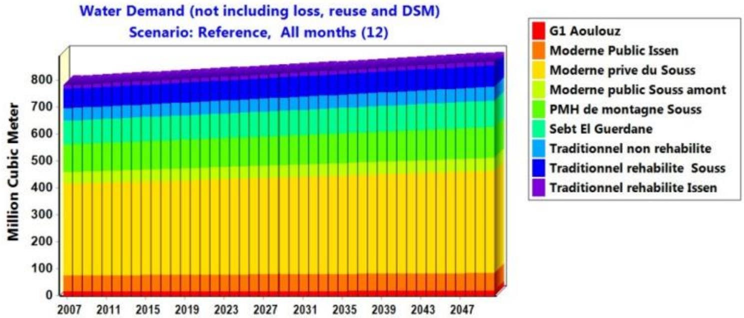

Figure 6 : Annual total irrigation water demand of reference scenarios

Scenario 2: Higher population growth

This scenario assumes population growing at a higher rate to forecast the impact of population growth towards the drinking water demand of water for the period of 2007 to 2050 in Souss basin area with the current system of water usage and supply maintain. The accompanying projected water demand raises to a maximum of 570 Mm^3 instead of 161.7 Mm^3 under the reference scenario (Figure7). This mean that population growth rate shown significant effect on the demand of drinking water and suppose the need to develop new cooperation, new technologies, or better water management plans to offset this anticipated shortfall.

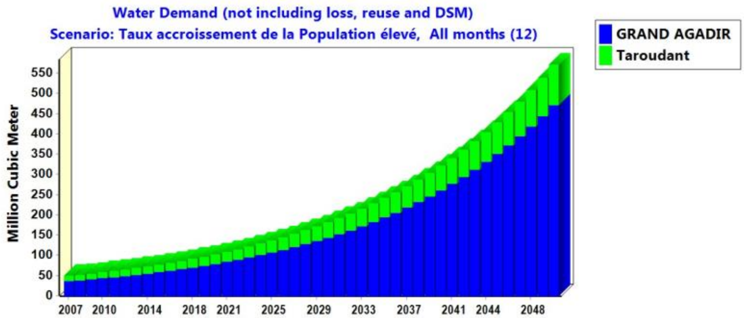

Figure 7 : Annual total water demand population growth scenarios

Scenario 3: Demand side management

In demand side management scenario ,assuming that there will be a decrease of the consumption of irrigation water following the training of farmers to new economic irrigation techniques, the proper use of Agricultural Water. We observe a reduction in Agricultural water demand from 781 Mm^3 in 2007, to 632 Mm^3 in 2050. So, we have a saving of 149 Mm^3 in 43 years (Figure8).

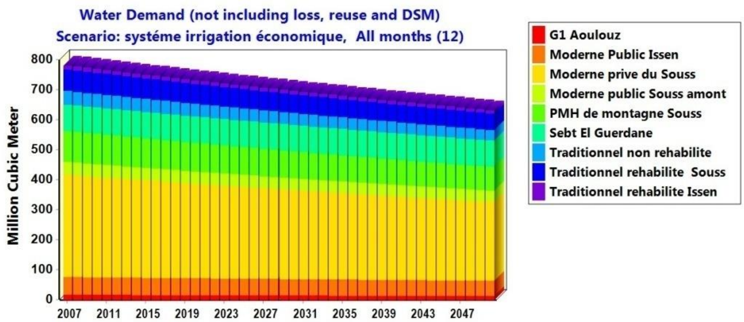

Figure 8 : Reduction of the consumption of irrigation water scenario

CONCLUSION

Being able to assess the ability of river basin to satisfy potential water demands is crucial to planning and wise decision making about water use and distribution. In this study, a scenario analysis approach was performed using the Water Evaluation and Planning (WEAP) model, to assess the impacts of possible water demands on the water resources of the Souss Basin in the year

2050. The model was calibrated and validated for the 2007–2009 period. The WEAP results show if the present growth rates continue, in 2050 the drinking water demand will be increased to 161.7 Mm^3 and irrigation water demand will be increased to 869 Mm^3(Reference Scenario). In higher population growth scenario, we observe an elevation in drinking water demand from 161.7 Mm^3 under the reference scenario to 570 Mm^3 in 2050. in demand side management scenario, we have a saving of 149 Mm^3 because the training of farmers to new economic irrigation techniques and the proper use of agricultural water.

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