

INTEGRATED RIVER BASIN PLANNING AND MANAGEMENT: A CASE STUDY OF THE SOUSS MASSA RIVER BASIN, MOROCCO

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ABSTRACT

River basins are inherently complex systems with many interdependent components (streams, aquifers, reservoirs, cities, irrigation districts, etc.). The sustainability of future economic growth and environmental health in a basin depends on the rational allocation of water among the basin riparians and sectors. Efficient and comprehensive decision support systems have an important role to implement integrated water resources management and lead to sustainable water use strategies. The aim of this study is to present an implementation of integrated water resources management and evaluate alternative water resource development in Souss Massa basin in Morocco. The capacity of the water resource system to satisfy the water requirements of urban and agriculture uses is assessed over different horizons. Scenario analysis was carried out with the decision support system for integrated water resource planning and management RIBASIM. Sustainability criteria were defined.

The balance of Maximum Resources - Peak Needs showed that the resources allocated to the drinking water of Agadir city would be unable to cover future needs. Measures have to be undertaken to fill the deficits. The outputs showed serious deficits and therefore a strategy is proposed to overcome these impacts by the horizons 2030, 2040 and 2050. The result of decision making for the future was tested under climate change impacts. The selected planning strategy included the construction of a new dam (Tamri Dam) and the use of non-conventional water (desalination). Hydraulic simulations were carried out to determine optimal reservoir capacity and assess the hydraulic performances of the dam. The first scenario showed that conventional water resources will reach their full utilization by 2030.

This situation would become more critical if water resources are affected by climate change. A second scenario including climate change impacts were analyzed. It showed that the reservoirs system will go through several critical periods during which the average supply of water can decrease to -6.37Mm by 2050 and the reliability and resilience indexes of the system will decrease drastically. In order to alleviate the future deficits, the third scenario including sea water desalination plant is analyzed. Results showed that the use of non-conventional water resources will address the indexes to meet fully the drinking water and agricultural water needs of the Souss-Massa basin until 2050.

Keywords: Decision making, scenario analysis, basin simulation, climate change, Drinking water, deficit, reliability, resilience, vulnerability, RIBASIM, performance criteria, desalination, Souss Massa basin, Morocco.

1. INTRODUCTION

The Souss Massa basin is currently facing major issues around increasing water scarcity. In fact, Souss Massa has experienced in recent decades, a quantitative and qualitative degradation of its water capital whether surface or underground. Surface

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water is increasingly becoming insufficient to meet the growing water demand, and the use of groundwater has always been a secular practice in this area. This scarcity is reflected today in user conflicts that could pose significant threats to drinking water supply up to the urban pole of Agadir in the long term. Agadir is a strong urban node characterized by dynamic development process.

Integrated Water Resources Management (IWRM) is a process that promotes the coordinated development and management of water, land and related resources, in order to equitably maximizing economic and social well-being, without compromising the sustainability of vital ecosystems (GWP, 2000). Various management methods have been proposed to respond to the physical, environmental and social, legal or institutional conditions of the basin. In all cases, managing water in a sustainable manner implies taking into account several multidisciplinary and multi-criteria aspects. One of the reasons for the use of decision support systems in integrated water resources management is that their use is an effective way to analyze and identify trade-offs between multiple objectives or targets under different scenarios (Teodosiu et al. 2003). At the same time to promote shareholder participation and group decision taken at different spatial and temporal scales (Carpenter & Georgakakos, 2004).

The present work focuses on a water resources management and planning model for securing the urban pole of Agadir in the short and long term, based on various options for diversifying its conventional and unconventional water resources.

2. METHODS

The main objective of this study is to develop a general framework and a complete simulation model of the Souss Massa basin to define and evaluate water resource management policies for the sustainable development of this basin. This assessment allows interested managers and decision-makers to identify and implement actions to minimize water shortages and secure the supply of drinking water and irrigation. The approach includes scenario development, river basin simulation, stakeholder participation and climate change assessment (figure 1).

Water resources planning for the Souss Massa basin is developed using the decision support tool "RIBASIM". It has been used in more than 20 countries to support the water resources planning process. Van der Krogt and Verhaeghe (2001) used the RIBASIM model to describe the effects of changes in the farming system on the regional water balance of three watersheds.

2.1 Description of the Model

RIBASIM is a model that develops a hydraulic balance in each step of time in two phases. The first definition phase involves the determination of all water demands, resulting in catchment targets in surface water reservoirs, aquifers, and bypass flows at spillways and pumping stations. In the second phase of water allocation, users' water supply is based on objectives of water availability and allocation rules (Van der Krogt, 2008).

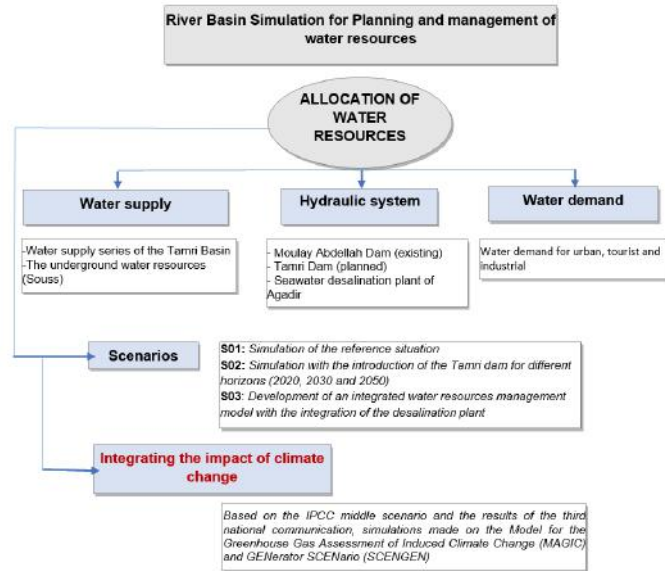


Figure 1. Water Resources Management and Planning Framework.

2.2 Study Area

The study area concerns the Tamri coastal basin, located northwest of the Souss-Massa basins in southern Morocco (figure 2). The defined area of the Souss Massa basin covers 27 800 km² and is limited to the north by the Tensift basin, to the east and south by the Draa basin and to the west by its Atlantic facade 200 km long. This is an important region because of the existence of industrial development projects, tourism and water supply of one of the great agglomerations of the kingdom, urban pole of Agadir.

Population growth and the uncontrollable development of the irrigation, industry, and tourism sectors are putting strong pressure on the region's water resources. To increase the resilience of the system to face this increase in water demand, the Souss Massa basin requires a water resource management plan that will solve the problem of water scarcity. The application of integrated water resources management in this basin is proposed as a way to address these challenges.

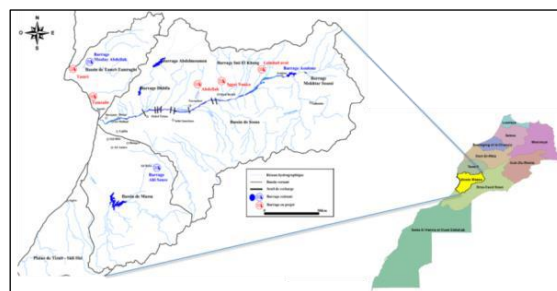


Figure 2. Delimitation of the Souss Massa basin, Morocco.

The Tamri Basin has a surface water resource mobilization structure, the Prince Moulay Abdellah dam, which controls a 1258 km² watershed of Ouggarriver, Tamri's main tributary, which was commissioned in 2002. The characteristics of that dam are presented in the table 1 below:

Table 1: Table of the main features of the Moulay Abdellah Dam

| Characteristics | Inflow (Mm ³) | Capacity (Mm ³) (2002) | Capacity (Mm ³) (2016) | Capacity lost (Mm ³) | Annual siltation (Mm ³ /year) | objectives of the dam |
|--------------------|---------------------------|------------------------------------|------------------------------------|----------------------------------|--|-------------------------------|
| MOULAY ABDELAH Dam | 53 | 110 | 85 | 25 | 1,7 | Drinking water and irrigation |

2.3 Simulation Scenarios on RIBASIM

The scenarios of this study were defined according to the existing problems in the management of the Souss Massa basin. The major problem is that of securing the drinking water supply of Agadir. Water supply is currently provided by Groundwater resources (the Souss aquifer), and Surface water resources (Moulay Abdellah Dam and Abdelmoumen Dam).

The proposed development plan is essentially based on a supply development policy with the aim of finding the best solution for strengthening the drinking water supply of Agadir:

- The construction of the Tamri dam (downstream of the Moulay Abdellah dam), this dam will come to improve the mobilization of all water resources in the Tamri basin and reduce losses at sea, and compensate for the rapid siltation of the retention of the Moulay Abdellah dam in the long term;
- The construction of the Agadir desalination plant to improve resilience to climate change.

Given the importance of these proposals for water managers and the distribution of water shortages between different user sectors, the work was done through three scenarios that are consistent with the views of policy makers and experts and report on the feasibility of implementation:

A. Scenario 01 « Situations without any hydraulic management realized »

- Reference situation: Simulation of the current situation (2018) with the current water demand to evaluate the performance of the water system of the Tamri Basin;
- Future situation (2030-2040-2050): Simulation of the Moulay Abdellah dam with the state of trend siltation and future water demand, to visualize in which year the shortage will appear if no solution for mobilization of water resources is taken.

B. Scenario 02 « Realization of the Tamri dam »

- Situation with the Tamri dam (2025): Realization of a regulation study to choose the size of the dam;
- Future situation with the Tamri dam for the three horizons (2030, 2040 and 2050) to visualize in which year the shortage will appear with the construction of the Tamri dam;
- Future situation (2030-2040-2050) integration of the impact of climate change.

C. Scenario 03 « Realization of the desalination plant »

- Integrated management with the Tamri Dam and the desalination plant to secure the drinking water supply and minimize operating costs.

2.4 Hypotheses of The Simulations

Two main assumptions were taken into account in the hydraulic simulations:

- (1) Regularized volumes from surface water resources are fixed, assuming actions on basin management for the fight against siltation in these dams will be undertaken to maintain these allocations;
- (2) The current water supply mobilized from groundwater (250 l / s) for the supply of drinking water to the Agadir cluster will remain constant; assuming that the dams projected in the Souss-Massa region will maintain the level of the groundwater with a significant artificial recharge.

According to the services concerned by the estimation of the current and future drinking water needs of the populations of the Agadir Urban Pole (ONEE: National Office of Water and Electricity), The demand estimates are presented in table 2:

Table 2. Water demand forecasts between 2018 and 2050 (ONEE)

| Horizon | 2018 | 2025 | 2030 | 2040 | 2050 |
|---|-------|-------|-------|-------|--------|
| peak needs (Mm ³) | 61,47 | 71,59 | 77,26 | 88,90 | 101,86 |
| Guaranteed water demand by the Abdelmoumen dam and groundwater (Mm ³) | 33,11 | 33,11 | 33,11 | 33,11 | 33,11 |
| Demand to be guaranteed by future water resources (Mm ³) | 28 | 38,47 | 44,15 | 55,79 | 68,75 |

2.5 Criteria for Guaranteeing Supplies

The potential of the resource, expressed in the volume of regulated water, depends not only on the hydraulic contributions and the physical possibilities of its regularization through the hydraulic structures but also on the guarantee conditions that are required when the resource is requested.

The threshold of tolerance of a shortage in front of a resource that cannot be constant is a determining factor that depends fundamentally on the flexibility of the consumer. The criteria of guarantee of the supplies to be respected during the simulation by sector are shown in table 3.

Table 3. Supplies Guarantee Criteria Table

| Criteria for guaranteeing supplies | Drinking water | Irrigation |
|------------------------------------|--|--|
| Deficit year | any year whose annual deficit exceeds 0% | any year whose annual deficit exceeds 15 % |
| max deficit | 0% | 50% |
| Frequency of failure | 0% | 20% |

2.6 Impact of Climate Change on The Souss - Massa Basin

The methodology adopted makes it possible to carry out climate change simulations and impacts on vulnerable sectors of Morocco (Souss - Massa case) using the 1MAGICC / SCENGEN climate model.

The method that has been adopted is to determine transfer functions calculated between large area and/or large-scale elevation data and local surface climates. Altitude data are derived from data assimilation or re-analysis of the National Center for Environmental Prediction (NCEP) developed for the present case (Souss Massa Region) using the climate model HADCM3.

Based on the results of the Third National Communication (TNC, 2016), the adopted methodology enables simulations of climate change and impacts on vulnerable sectors of Morocco (Souss-Massa case) using the climate model 1MAGICC / SCENGEN.

Knowing that the Tamri subbasin is the area of our study, the objective of this work is to estimate the projections of the climatic changes corresponding to this zone in order to use them in the simulations carried out on RIBASIM.

At the level of the simulations carried out on RIBASIM, we have identified the state of the water resources on the three horizons: 2030, 2040 and 2050. Based on these years and the forecasts established for 2020 and 2050, we estimated projections of climate change in the 2030 and 2040 horizon by simple linear interpolation. Table 4 shows the estimated results for the three horizons 2030, 2040 and 2050 at the Tamri sub-basin.

Table 4. Climate Change Forecasts for Tamri basin for 2030 2040 and 2050 (SCN, 2010)

| Watershed of Tamri | Range of variation of $\Delta Q/Q$ (%) | |
|--------------------|--|-----------------|
| | Lower limit (%) | Upper limit (%) |
| 2030 | -15,38 | -9,92 |
| 2040 | -19,59 | -12,4 |
| 2050 | -23,81 | -14,88 |

Knowing that our hydrological series used consists of 77 years (1939 - 2016), it is essential to use a constant rate of decrease of contributions, since a difference of 10 years (2030 to 2040 or 2040 to 2050) is significant by compared to our simulation period (77 years).

Based on the results in Table 4, it was noted that a rate of -15% belongs to the annual input variation intervals for the three horizons 2030, 2040 and 2050. On the basis of this assumption, we have set our choice on this rate (-15%) to be able to compare the functioning of our hydraulic system to the different horizons while fixing the factor of climatic changes

3. RESULTS AND DISCUSSION

3.1 Summary of Simulation Results

To study the performance of presented scenarios, the RIBASIM was run for five horizons; table 5 summarizes all the results obtained in the hydraulic simulations carried out, the blue color means that the system is balanced or exceeds, the yellow color indicates that the system is in deficit.

Table5. Summary table of the main results of the RIBASIM simulations

| Scenario 01 | 2018 (Actual) | 2025 | 2030 | 2040 | 2050 |
|---|------------------|------|-------|--------|--------|
| Demand for drinking water (Mm ³) | 28 | - | 44,15 | 55,79 | 68,75 |
| Drinking water Supply (Mm ³) | 28 | - | 37,14 | 38,15 | 37,33 |
| Frequency of failure (%) | 0 | - | 50,64 | 77,92 | 89,61 |
| Number of deficit years | 0 | - | 39 | 60 | 69 |
| Maximum of shortage (%) | 0 | - | 87,53 | 91,55 | 84,89 |
| Balance sheet (Mm ³) | 0 | - | -7 | -17,64 | -31,42 |
| Scenario 02 | 2018 | 2025 | 2030 | 2040 | 2050 |
| Demand for drinking water (Mm ³) | 28 | 31 | 44,15 | 55,79 | 68,75 |
| Drinking water Supply (Mm ³) | - | 38,5 | 43,44 | 51,45 | 56,23 |
| Frequency of failure (%) | - | 38,5 | 10,39 | 27,27 | 100 |
| Number of deficit years | - | 0 | 8 | 21 | 77 |
| Maximum of shortage (%) | - | 0 | 48,35 | 72,02 | 86,88 |
| Balance sheet (Mm ³) | - | 7,5 | -0,71 | -4,34 | -12,52 |
| Scenario 02* * Integration of climate change | 2018 | 2025 | 2030 | 2040 | 2050 |
| Demand for drinking water (Mm ³) | - | - | 44,15 | 55,79 | 68,75 |
| Drinking water Supply (Mm ³) | - | - | 41,87 | 47,81 | 50,22 |
| Frequency of failure (%) | - | - | 15,59 | 33 | 100 |
| Number of deficit years | - | - | 12 | 60 | 77 |
| Maximum of shortage (%) | - | - | 63,28 | 87,91 | 92,72 |
| Balance sheet (Mm ³) | - | - | -2,28 | -7,98 | -18,53 |
| Scenario 03 | 2018 | 2025 | 2030 | 2040 | 2050 |
| Demand for drinking water (Mm ³) | - | - | 44,15 | 55,79 | 68,75 |
| Drinking water Supply (Mm ³) | - | - | 44,15 | 55,79 | 68,75 |
| Frequency of failure (%) | - | - | 0 | 0 | 0 |
| Number of deficit years | - | - | 0 | 0 | 0 |
| Maximum of shortage (%) | - | - | 0 | 0 | 0 |
| Balance sheet (Mm ³) | - | - | 0 | 0 | 0 |

3.2 Discussion and Evaluation

The total payload capacity of 85 Mm³ of the corresponding Moulay Abdellah dam (2018) can satisfy the drinking water needs of Agadir (27.5Mm³) and the irrigation area of Tamri (1.26 Mm³) without ever exceeding the maximum limits of the allowable deficit criteria (Actual situation).

The mobilization of surface water from the Moulay Abdellah dam has reached a full use with which there are no significant opportunities for the regulation of additional water resources for 2030, 2040 and 2050 horizons. This is clearly shown in the first scenario, the shortage appears from 2030.

With a total useful capacity of 53.38 Mm³ for the Tamri dam, the Moulay Abdellah and Tamri hydraulic complex will be able to satisfy the needs of the drinking water of Agadir and the irrigation of Tamri by 2025. , from 2040, the shortage appears but less than the first scenario.

The integration of the climate change (CC) impact will create the risk of water scarcity as a result of climate change could lead to reduced inputs, and consequently dams failing due to lack of water during critical periods. The integration of the impact of climate change (Scenario 02 with CC) will accelerate the appearance of the shortage, the results show that the deficit will appear in 2030 instead of in 2040 (without CC).

Conventional water resources are vulnerable to the effects of climate change. The problem of saturation of conventional water resources was, however, a real obstacle to the sustainable development of the Souss-Massa region. However, the desalination project will eventually secure the water supply of Agadir and provide water for agriculture until 2050 as was shown at table 7. However, the use of non-conventional water resources is a relevant strategy to ensure 100% of water demands. With a volume of 70 Mm³, the desalination project makes it possible to resorb the shortage recorded from 2030 to 2050.

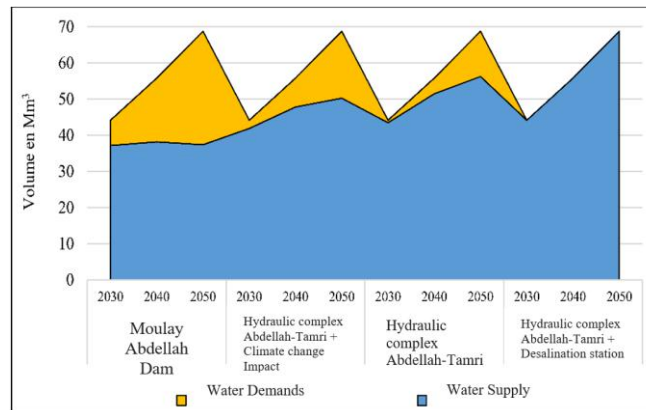


Figure 3. Evolution of the water supply and water demand

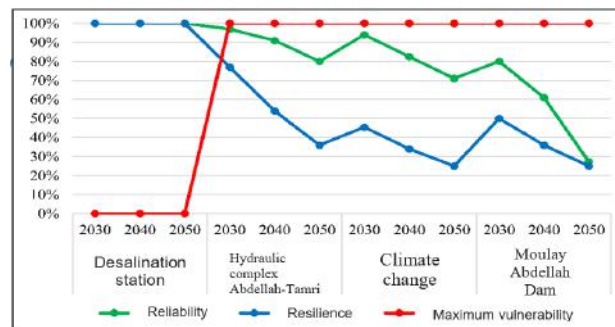


Figure 4. Indices of the performances of the hydraulic system according to the different scenarios

Figures 3 and 4 show that the more a new water resource is added, the more water needs are satisfied, the deficits decrease, the resilience and reliability of the hydraulic system increases. This is justified by the introduction of the Tamri dam, which can contribute to the satisfaction of 89.5% of the average drinking water demand in the urban pole of Agadir. However, this satisfaction rate can decrease by up to 83% due to climate change. The integration of the desalination plant will make it possible to fully securing the drinking water needs of the coastal zone.

Conventional water resources will not be sufficient in the long term to satisfy future water demands (2030, 2040, 2050), which is justified by a maximum vulnerability of 100%. The mobilization of non-conventional water resources by the desalination plant can give a reliable and resistant system with 0% vulnerability.

4. CONCLUSIONS

To sum up, the integrated water resources management approach applied in the Souss Massa basin is fundamental to help water planners and managers in decision-making. The best option to improve the sustainability of water resources is selected

by analyzing scenarios and using criteria that play an important role in sustainable basin management and through modeling and simulations, and effective scenario analysis and decision-making methods.

The results of this study show that, at present situation, the current water resource mobilization framework of the Souss Massa basin does not allow the satisfaction of future water needs, which highlights the vulnerability of the Agadir drinking water supply system. The reinforcement of the system with the Tamri dam does not make it possible to secure the demand for drinking water in the long term. The situation is much more difficult with the integration of the climate change impact. With the introduction of the desalination plant, the shortage could be reduced to secure all water demand of 2050, which shows that conventional water resources in the basin are not completely enough to build a reliable and resilient system to face the impact of climate change. The approach presented reflects the reality of the water resources management decision-making process in the Souss Massa Basin, taking into account the critical factors in developing an integrated model that has repositioned the decision-making framework for management options at the basin-wide level.

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