The Handbook of Environmental Chemistry 53
Series Editors: Damià Barceló · Andrey G. Kostianoy

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The Souss-Massa River Basin, Morocco

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The Handbook of Environmental Chemistry

Founded by Otto Hutzinger

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Volume 53

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The Souss-Massa River Basin, Morocco

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Aims and Scope

Since 1980, *The Handbook of Environmental Chemistry* has provided sound and solid knowledge about environmental topics from a chemical perspective. Presenting a wide spectrum of viewpoints and approaches, the series now covers topics such as local and global changes of natural environment and climate; anthropogenic impact on the environment; water, air and soil pollution; remediation and waste characterization; environmental contaminants; biogeochemistry; geo-ecology; chemical reactions and processes; chemical and biological transformations as well as physical transport of chemicals in the environment; or environmental modeling. A particular focus of the series lies on methodological advances in environmental analytical chemistry.

Series Preface

With remarkable vision, Prof. Otto Hutzinger initiated *The Handbook of Environmental Chemistry* in 1980 and became the founding Editor-in-Chief. At that time, environmental chemistry was an emerging field, aiming at a complete description of the Earth's environment, encompassing the physical, chemical, biological, and geological transformations of chemical substances occurring on a local as well as a global scale. Environmental chemistry was intended to provide an account of the impact of man's activities on the natural environment by describing observed changes.

While a considerable amount of knowledge has been accumulated over the last three decades, as reflected in the more than 70 volumes of *The Handbook of Environmental Chemistry,* there are still many scientific and policy challenges ahead due to the complexity and interdisciplinary nature of the field. The series will therefore continue to provide compilations of current knowledge. Contributions are written by leading experts with practical experience in their fields. *The Handbook of Environmental Chemistry* grows with the increases in our scientific understanding, and provides a valuable source not only for scientists but also for environmental managers and decision-makers. Today, the series covers a broad range of environmental topics from a chemical perspective, including methodological advances in environmental analytical chemistry.

In recent years, there has been a growing tendency to include subject matter of societal relevance in the broad view of environmental chemistry. Topics include life cycle analysis, environmental management, sustainable development, and socio-economic, legal and even political problems, among others. While these topics are of great importance for the development and acceptance of *The Handbook of Environmental Chemistry,* the publisher and Editors-in-Chief have decided to keep the handbook essentially a source of information on "hard sciences" with a particular emphasis on chemistry, but also covering biology, geology, hydrology and engineering as applied to environmental sciences.

The volumes of the series are written at an advanced level, addressing the needs of both researchers and graduate students, as well as of people outside the field of "pure" chemistry, including those in industry, business, government, research establishments, and public interest groups. It would be very satisfying to see these volumes used as a basis for graduate courses in environmental chemistry. With its high standards of scientific quality and clarity, *The Handbook of Environmental Chemistry* provides a solid basis from which scientists can share their knowledge on the different aspects of environmental problems, presenting a wide spectrum of viewpoints and approaches.

The Handbook of Environmental Chemistry is available both in print and online via www.springerlink.com/content/110354/. Articles are published online as soon as they have been approved for publication. Authors, Volume Editors and Editors-in-Chief are rewarded by the broad acceptance of *The Handbook of Environmental Chemistry* by the scientific community, from whom suggestions for new topics to the Editors-in-Chief are always very welcome.

Damià Barceló
Andrey G. Kostianoy
Editors-in-Chief

Volume Preface

The Souss-Massa plain in southwestern Morocco suffers from a severe water deficit as the water demand exceeds the water supply. Irrigated agriculture and associated agro-industry, urbanization and tourism compete for the limited water resources. This book gives a comprehensive analysis of the available water resources in the basin and provides novel water management approaches to narrow the gap between supply and demand for water. The conventional water resources, surface water and groundwater, are evaluated. Rainfall harvesting into dams along the Souss and Massa wadis has been discussed. In addition, the geology of the aquifer is studied and the risk of over-exploitation is addressed. The options to use alternative water resources, such as desalinated seawater and domestic treated waste water, are considered. Management approaches including data development analysis and the SALTMED model are discussed. The book is focused also on connecting the scientific research to practical research cases and demands of river basin stakeholders. Implementation of the findings of the research presented in this book will contribute towards a sustainable water management in the Souss-Massa region.

The book on the Souss-Massa river basin is carried out as part of the collaboration between the IAV Hassan II, University Ibn Zohr, AABHSMD and other regional organizations operating in the field of water resources. The book summarizes the scientific results developed within the framework of GLOBAQUA project and several national and international projects (CNRST, IAEA, NATO, UNESCO).

R. Choukr-Allah
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Contents

Water Resources Master Plan for Sustainable Development of the Souss-Massa River Basin

R. Choukr-Allah, A. Nghira, A. Hirich, and L. Bouchaou

Abstract The Souss-Massa River Basin, which is bounded on the north by the High Atlas Mountains and on the south and east by the Anti-Atlas Mountains, covers approximately 27,000 km^2. With a year-round growing season, irrigated agriculture in the river basin produces more than half of Morocco's exported citrus and 85% of exported vegetables.

Surface water is collected and stored behind seven dams that have a combined total capacity of approximately 797 million cubic meters. Groundwater is obtained primarily from the Souss and Massa Valleys alluvial aquifer. The reported recharge rate is approximately 425 million cubic meters annually, an amount that varies significantly in response to rainfall.

The driving forces for a holistic water management with the basin are strong population growth and urbanization, tourism and industrialization, globalization, and climate variability and change leading to decreasing precipitation and increasing the frequency of droughts. Faced to the water deficit within the region, effective and efficient water management has to be based on long-term management master plan, prepared and implemented by the Souss-Massa Hydraulic Basin Agency. It was based on three scenarios including the no action plan which will lead to a

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disastrous social and economic situation and a moderate scenario to stabilize the piezometric level of the groundwater.

This chapter describes the vision of the river basin agency in developing a sustainable water supply system that meets current and future domestic and agricultural water demands and at the same time preserves the water resources for future generations and for the environment.

Keywords Master plan, Souss-Massa, Sustainable development, Water deficit, Water resource management

Contents

1 Introduction

The Souss-Massa Basin (SMB) is Morocco's second most important economic province due mainly to its high-value agricultural production, attracting tourism industry, and fishery development. Agriculture sector is the key driver of water demand in this region. Indeed, the focus of the Massa perimeter is in producing out season vegetable crops and the Souss plain in citrus production, amounting to 85%

and 55%, respectively, of the country's exports in these sectors [1]. 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, often leaving entire villages without drinking water. The annual water deficit with regard to water use is estimated at 290 million cubic meters in the Souss valley alone [2]. The irrigated areas are still extending despite the water crises affecting the region. Meeting the challenge of water scarcity requires both a supply management strategy, involving highly selective development, and exploitation of new water supplies (conventional and nonconventional) coupled with a vigorous demand management involving comprehensive reforms and actions to optimize the use of existing supplies. The water master plan developed by the Souss-Massa Hydraulic Basin Agency responds to the framework directive of the integrated water resource management in Morocco. The driving forces are strong population growth and urbanization, tourism and industrialization, globalization, and climate variability and change leading to decreasing precipitation and increasing the frequency of droughts.

2 Overall Objective of the Master Plan for Sustainable Development in Souss-Massa

Faced to the water deficit within the region, effective and efficient water management has to be based on long-term management plans, prepared and implemented by the Souss-Massa Hydraulic Basin Agency. It was based on three scenarios including the no action plan which will lead to a disastrous social and economic situation and a moderate scenario to stabilize the piezometric level of the groundwater [3].

The Souss-Massa water master plans have defined the medium- and long-term strategy and the objectives to be achieved within the basin, according to the priority issues identified through an initial status analysis related to water quality, water quantity, various uses and activities impacting water resources in quantity and/or quality, and the forecasting of all elements affecting water resources such as population growth rate, urbanization development, land uses, industrialization, deforestation, etc.

All the stakeholders and the end users' parties were invited to cooperate, invest, and help secure funding, in support of the governance, and implementation of the proposed interventions for the sustainable development of the Souss-Massa.

This master plan provides a baseline status of the basin in terms of land use, natural water resources, the population growth, the different economic sectors and related water demands, and the current governance of the basin. The master plan then delivers a projection of population and economic figures for the year 2030 and related land and water requirements, and it identifies the major challenges to be addressed.

3 Strategic Planning Objectives

The key challenge for sustainable development in the Souss-Massa is to strike the right developmental balance between a healthy economic developmental path for the basin and its people on the one hand and its water resources with sufficient environmental availability to sustain a healthy ecosystem on the other hand. A key condition for meeting this challenge is reducing the water deficit that reached 290 million m^3 in the Souss valley and 60 million m^3 in the Massa perimeter. In terms of sustainable water management, the key challenge clearly is to overcome the water scarcity-related problems facing the whole basin of Souss-Massa [4]. This means creating a sustainable water supply system that meets current and future domestic and agricultural water demands and at the same time preserves the water resources for future generations and for the environment.

The main objectives of the water master plan are:

- Meeting the water needs and securing the water supply according to the requirements of each sector and based on the predefined rules of priority, including the priority of drinking water over other uses
- Restoring reserves of the overexploited aquifers and their protection as a strategic reserve
- Establishing an upstream-downstream solidarity, interregional and intergenerations
- Safeguarding hydraulic and agricultural heritage in a sustainable vision
- Preserving the environment (oasis, wetlands, valleys, lakes, etc.)

The strategic agricultural objective for the Souss-Massa Hydraulic Basin Agency (ABHSM) is improving water use and irrigation efficiencies and economic outputs per unit of water used. The institutional challenge for this strategy will be to strengthen the cooperation among the main concerned authorities [5], including ABHSMD, ORMVA/SM, ONEE, RAMSA, municipalities, ONGs, farmers associations, and other related ministries and authorities, in their role as authority over and regulator of Souss-Massa region to restore the good ecological status of the basin and the role of all the existing water resources and the socioeconomic development of the region.

4 Population and Agriculture

The Souss-Massa region is located in central-west of Morocco (Fig. 1), and it is considered as one of the most dynamic and wealthy regions in Morocco. The region of Souss-Massa cover a surface area of 27,000 km^2 (2/3 Montagne areas and the rest are three main valleys), and according to the 2014 census, the population in these provinces and prefectures is 2.56 million people (55% in rural areas), with an annual growth rate of 1.4% [6].

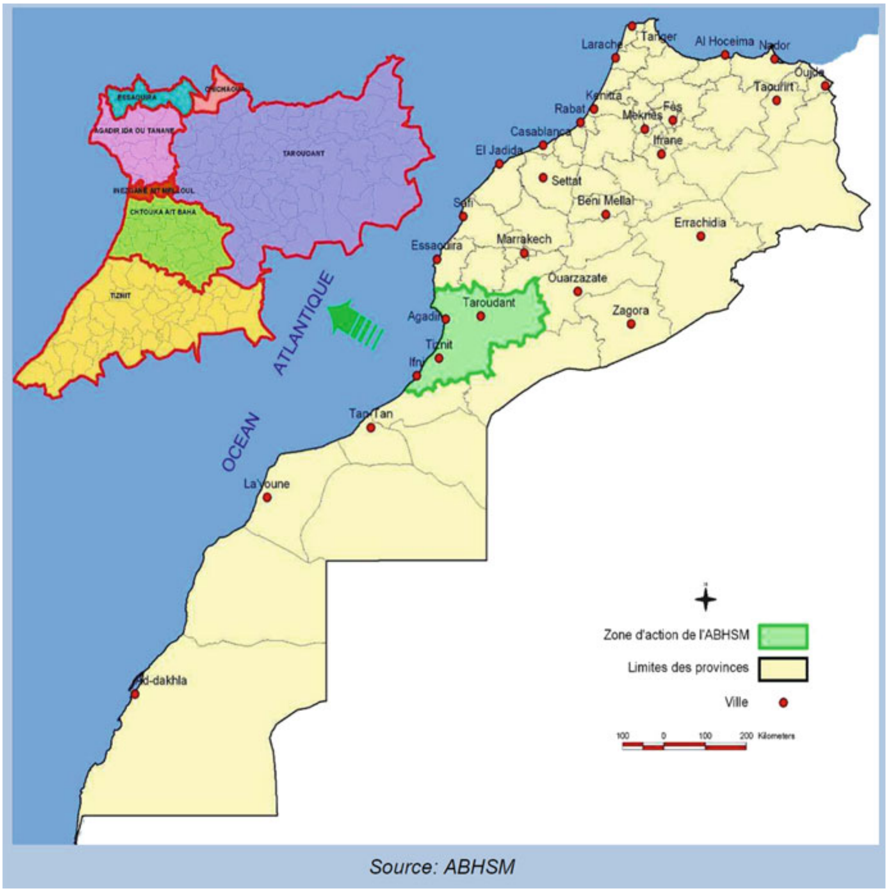

Fig. 1 Geographic situation of the Souss-Massa watershed

About 44% of cultivated land is irrigated. Cereals, citrus, banana, tomato, and other vegetables are the main crops cultivated in the region. About 80% of farms are smaller than 5 ha (covering 80% of cultivated land), and only 2% are bigger than 20 ha. Citrus and early vegetable represent, respectively, 55 and 85% of the national export. About one fourth of the regional citrus plantations is located in the El-Guerdane district (10,000 ha), and the remaining land of the district are annual crops. The El-Guerdane citrus production represents over 50% of the Moroccan citrus production [7].

The most used irrigation system in the SMB region is still flood irrigation, followed by sprinkler and drip irrigation. Actually, all citrus plantations in the El-Guerdane district are drip irrigated.

The cultivated agricultural area in the Souss-Massa covers around 160,410 ha of which 78,224 ha are irrigated lands and 82,186 ha represent rain-fed land. We distinguish nine irrigated areas [8].

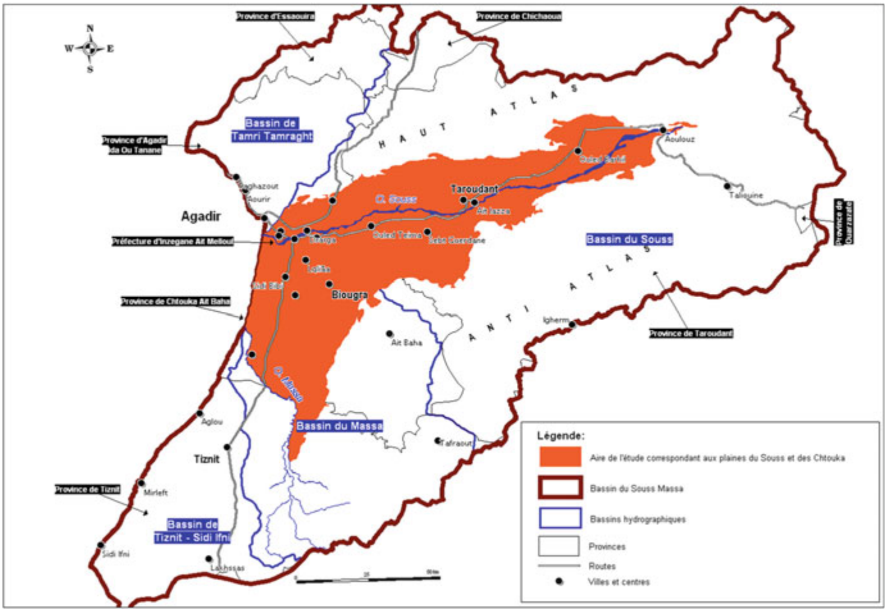

Fig. 2 The localization of the different basins with the Souss-Massa watershed

The Souss-Massa plain is characterized by a semiarid climate with an average rainfall rarely exceeding 200 mm/year and evapotranspiration close to 2,000 mm/year. Annual rainfall is highly variable from year to year, and the annual average values range from 600 mm in the north, on the peaks of the High Atlas, to 150 mm in the south, on the eastern Anti-Atlas. The river Souss supplies most of the available water of the basin. In total, available water in the basin is about 1,093 Mm^3 of which 61% is surface water and the remaining is groundwater [9]. Surface water is ensured through seven main dams regulating a volume of 364 Mm^3/year (Fig. 2) and three water transfers, two for drinking water and one for irrigation (viz., the El-Guerdane transfer). Withdrawals throughout water springs are about 112 Mm^3/year and essentially provide irrigation source in the mountain areas.

5 Current Situation of Water Resources in Souss-Massa Basin

The Souss-Massa River Basin, which is bounded on the north by the High Atlas Mountains and on the south and east by the Anti-Atlas Mountains, covers approximately 27,000 km^2. The Souss-Massa region is characterized by an arid climate with low precipitations (<200 mm/year). The annual rainfall is very variable; precipitations of the humid year sometimes reach 3 times of the average year and 15 times of the dry year. Surface water is collected and stored behind seven dams that have a combined total capacity of approximately 800 Mm^3 [10]. The total water use in the basin is approximately 1034 Mm^3/year, 36% from surface water and 64% from aquifers, 95% of this quantity is used mainly in agriculture and 5% as drinking and industrial water [11]. Overall, demand for water exceeds the sustainable supply, with the deficit being made up by groundwater overexploitation. Overpumping of the alluvial aquifer exceeds an average of 284 Mm^3/year in Souss aquifer and 58 Mm^3/year in Chtouka aquifer (Table 1), which has resulted in water-level declines ranging from 0.5 to 2.5 m per year during the past three decades. According to ABHSMD [12], the piezometric level analysis in the Souss-Massa aquifers between 1968 and 2003 shows a reduction in water table level of about 15 m in the Souss upstream, more than 30 m in the middle Souss and 20 m in the Souss downstream. While in the Chtouka aquifer, the piezometric level was reduced by more than 20 m.

The deterioration of water quality is observed in many zones marked by an increase of TDS and nitrate contents. The interannual monitoring shows that, Souss downstream groundwater present a low quality while in medium and Souss upstream, the quality is generally good as well as in Chtouka where the water quality is mainly suitable. Recently, several hydrochemical and isotopic studies were carried out in order to assess the recharge and the quality of groundwater, to define the sources of groundwater salinization, and to find out the impacts of agricultural activities as irrigation and fertilization on groundwater quality [13–16]. Therefore, the overall quality of groundwater in the Souss-Massa aquifers shows a deterioration from east to west in Souss plain and from north to south in

Table 1 Water balance in Souss and Chtouka aquifer

Aquifer recharge (Mm^3)	Souss aquifer	Chtouka aquifer
Rainfall water infiltration	31	3.5
River and flooding water infiltration	160	2
Return of irrigation water (surface water)	4.5	15.7
Artificial recharge	9	–
Upward drainage from deep aquifers	3	10
Flows from next aquifers	60	1.7
Total input	268	33
Water withdrawal (Mm^3)		
Underground flow to the sea	4	3
Drainage to drains and rivers	0	2.2
Irrigation water uptake	521	78
Drinking and industrial water uptake	26	7.2
Total output	551	90
Balance	−284	−58

Chtouka plain. According to Tagma et al. [16], the Souss and Chtouka aquifer are the most contaminated aquifers in the regions; 36% of wells exceed the regulatory threshold of drinking water which is equal to 50 mg/l of nitrates. In the Souss region, it is relatively less affected; 7% of wells presented nitrate concentration more than 50 mg/l with an average of 22 mg/l. The irrigated areas seem to be the most affected by nitrate pollution. The overall degradation of Souss and Chtouka aquifers is mainly due to geological origin (evaporates) and anthropogenic activities (fertilizers and wastewater).

6 Water Resources Management Constraints

Several factors are affecting the water resources management within the Souss-Massa watershed, including the aridity of the climate and an increasing demand of all sectors (agriculture, urban areas, industry, and tourism). The main constraints could be summarized as follows:

- Adverse climatic conditions due to Arid climatic conditions and climatic changes
- A large variability of surface water potential from year to year (Fig. 3)
- A limited groundwater potential
- A high vulnerability to pollution resulting from intensive use of fertilizers and pesticides in agriculture and urban wastewater discharge
- A high water demand caused by rapid population growth and conflicting demand between all sectors (Fig. 4)
- Vulnerability of the coastal zone to salinization and degradation of several wetlands
- A significant increase in the irrigated land
- Inadequate irrigation of water efficiency

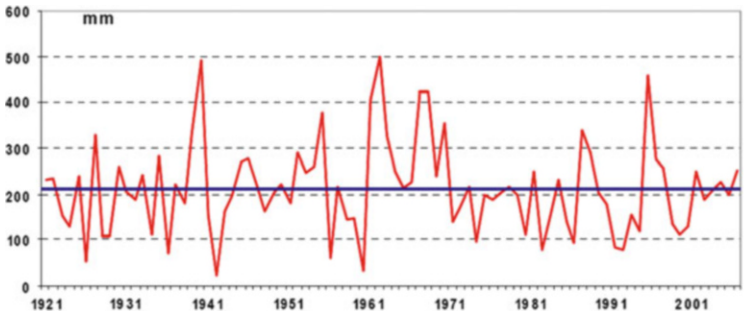

Fig. 3 Variability of the rainfall in the Souss-Massa

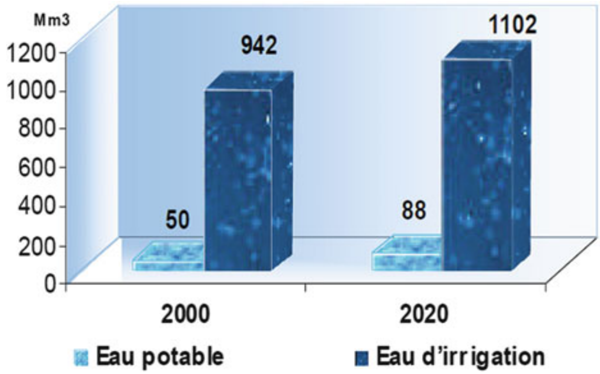

Fig. 4 Evolution of water demand

7 The Water Demands and Supply in the Souss-Massa Region

The region mobilizes around 1 billion meter cube of surface and groundwater, inducing a water deficit of 290 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. Most of available natural water is consumed for agricultural purposes (86%), and the other 12.5% is consumed by the industry and potable water.

The Souss-Massa Basin is draining 686 Mm^3/year of surface water (Fig. 5) through the High and Anti-Atlas tributaries [17]. Surface water is collected and stored behind eight dams that have a combined total useful capacity of 788 Mm^3 with an annual water mobilization of 345 Mm^3 (Table 2).

On the other hand, the hydraulic assessments prepared within the framework of the planning studies, carried out at the level of the entire hydrologic basin, have proved that this basin is showing a shortfall. In addition, the quality of the water resources has undergone a considerable degradation during the last decades due to the different sources of pollution (domestic, industrial, agricultural wastewaters, etc.).

The gap between water supply and demand is expected to increase next decades due to population increase and per capita consumption and irrigated agriculture extension along with decline in water availability. Water availability is decreasing due to overpumping from groundwater along with significant decline in natural aquifer recharge due to low rainfalls and intense urbanization processes. Water gaps are due to a series of factors that include inefficient agricultural consumption (only 42% of the surface area use drip irrigation), urban and industrial development, and low rainfalls. This shortage of water did lead to the loss of over 4,000 ha of citrus orchards in the Guerdane area.

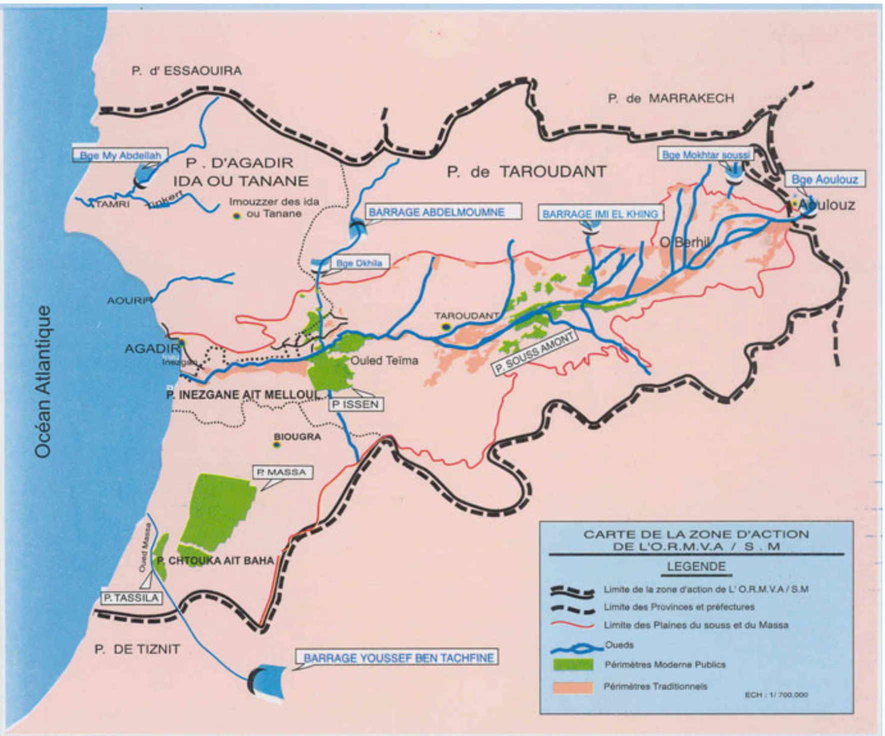

Fig. 5 The Souss-Massa surface water resources

Table 2 Large and medium hydraulic structures and their main features (PDAIRE/ABHSM)

Dams	Service's date	Useful capacity (Mm^3)	Regulated volume (Mm^3)
Youssef Ben Tachfine	1972	302	81.8
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	–
Ahl Souss	2004	5	2.6
Total	–	797	345

The potential renewable groundwater is on average of 425 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. Thus, many groundwater resources are at risk of being exhausted through overpumping. With withdrawal exceeding the internally renewable water resources, the resulting groundwater scarcity is rapidly becoming a major concern in certain coastal part of the region, as salt intrusion is threatening the deterioration of the groundwater. The pressures on natural groundwater resources are higher in the summer period, when natural supply is minimal, while water demands are maximum (irrigation, tourism).

The typical arid conditions of the region are reflected in limited availability of water. Efforts are continuously in progress to solve the chronic water shortage in this region. Water supply is mainly based on two major sources that include the groundwater aquifer and the surface water. Current major efforts to create more waters are based on intensive use of reclaimed wastewater and seawater desalination.

The assessment of the natural surface water resources in the Souss-Massa watershed provided an overall contribution of 668 million m^3. Despite significant policy mobilizing surface resources (seven big dams with a capacity regularization between 345 and 364 Mm^3) and the possibility of reusing unconventional resources (desalination, wastewater reuse), water supply remains limited. The aquifer's capacity of Souss and Massa for sustainable exploitation does not exceed an average of 318 to 41 Mm^3, respectively. This results in a water imbalance between supply and demand resulting in overexploitation of groundwater resources and an annual destocking of groundwater between 100 and 350 Mm^3/year in the case of Souss and nearly 60 million m^3 for Chtouka [2].

The current water demand requires about 1038 Mm^3/year (Fig. 6), of which 374 Mm^3/year (36%) of surface water and 664 Mm^3/year of groundwater (64%). The total equipped area is estimated at 148,640 ha. Irrigation actually use a gross volume of about 892 Mm^3/year (86%), and urban and industrial use consume

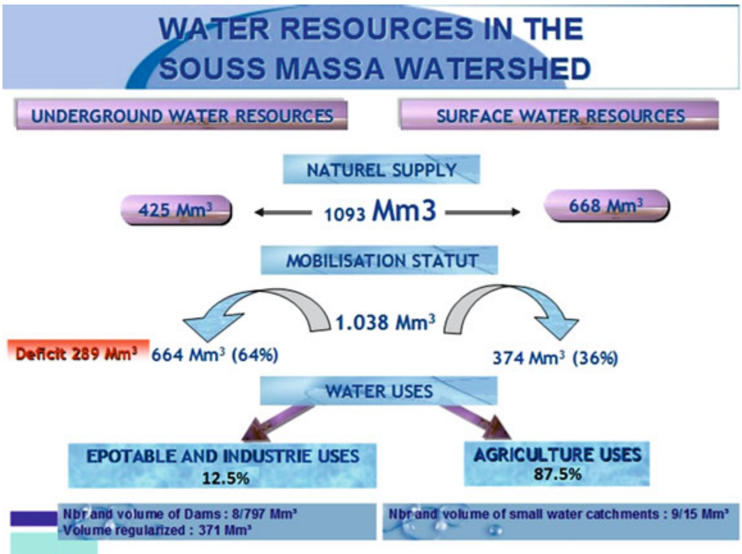

Fig. 6 Water resources in the Souss-Massa watershed

130 Mm^3/year (12.5% of the water demand), and the rest is used for landscaping, golf courses, and environment needs.

The demand for drinking and industrial water will rise to 197 Mm^3/year in 2030, and the greater part of the demand for urban drinking and industrial water is expressed by the great Agadir urban area whose needs in 2030 will reach 90 Mm^3/year. Water demand expressed in rural areas will increase to 35 Mm^3/year in the horizon (IWRM-DP). The expected water needs for the tourism sector will experience the largest increase to reach about 32 Mm^3/year in the horizon 2030. This water demand is dominated by golf courses and landscaping (14 Mm^3/year) and touristic areas North of Agadir (Taghazout, 5 Mm^3/year) and south of Agadir (Aglou Mirleft, 5 Mm^3/year).

The remaining potential that can be mobilized throughout extra-large and medium dams will not exceed 30 Mm^3/year. Also, a total of 29 hillside dams are also foreseen in the program. These structures are intended to protect against flooding; serve as drinking water supply, irrigation, livestock watering, and recharge of groundwater; and contribute to a volume of 5 Mm^3/year. Small dams could contribute up to 5 million m^3/year.

Several units of desalination (Tifnit, Cap Ghir, Tiznit) will be built within the watershed. The Tifnit unit will be mainly used for agriculture to support the water deficit with the Massa plain and will reach a capacity of production of 100 Mm^3/year by the 2030. The Cap Ghir is strictly for drinking water to support the need of the great Agadir and will have a production capacity of 100 Mm^3/year by the 2030. The 5 Mm^3/year unit in the region of Tiznit will be used for drinking water.

The reuse of treated wastewater presents a potential of 50 Mm^3/year in 2030, and it does concern mainly the great Agadir to 40 million m^3/year, while 10 million m^3/year will be generated by eight major cities (Biougra, Massa, Ouled Teima, Taroudant, Ouled Berhil, Ait Iâazza, Sebt El-Guerdane, and Tiznit).

Several actions on the water demand management are planned including the introduction of drip irrigation, good water management at the farm level, and saving with the drinking water will allow a saving of 162 Mm^3/year by the end of the projected Plan 2030. This will save 15% of the total water demand for drinking water and 89% of the total water demand in the irrigation sector (144 Mm^3/year).

8 Water Balance and Water Demand in Souss-Massa Basin

A survey is carried out by the Souss-Massa Hydraulic Basin Agency [18], the Office of Agricultural Development of Souss-Massa [19], the Office of Drinking Water (ONEP), and associations of water users (AUEA). The obtained results indicated that the water withdrawal in the region was equal to 738 Mm^3 of which 12.5% is used for drinking and industrial water and 86% for irrigation. The existing dams in the Souss-Massa Basin allowed a water storage of 797 Mm^3/year to irrigate more than 50,000 ha, 12 Mm^3 for drinking water and 162 Mm^3 for the artificial recharge of aquifers. The reduction in piezometric level of water table of Souss and Chtouka

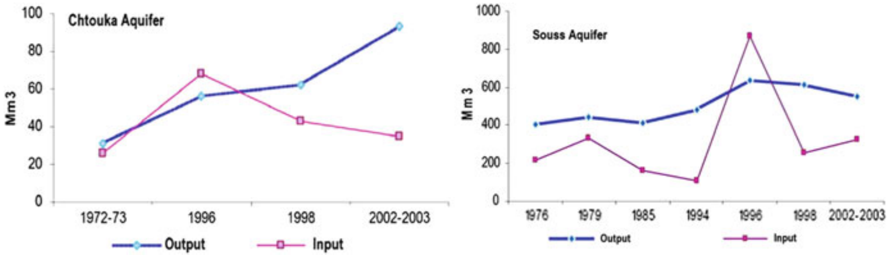

Fig. 7 Water balance of Souss and Chtouka aquifers

aquifers due to overpumping and drought exhibited by a decreasing of water deficit varies from 100 to 370 Mm^3/year for Souss aquifer and 60 Mm^3 for Chtouka aquifer [20]. Figure 7 shows the water balance for both aquifers [13].

9 Water Management Gaps and Predicted Scenarios

Despite all efforts carried out by the water management authorities at technical or political level as the generalization of drip irrigation, development of new alternative water resources (treated wastewater, desalinated water), extension services and the aquifer contract, and the water balance in the Souss-Massa continues to be negative as a result of the increased agricultural activities especially cultivating large water consumer crops as banana and forage crops. As water became scarcer, the various strategies diverged. Disinterest in farming (resilience or abandonment of crop land) or the modification of cropping patterns (reduction of irrigated surface area and changes in production systems) occurred, and alternative water resources were sought, leading to massive overscaled investment in a race to pump water from the aquifer or to shift land tenure.

The scenario to be achieved by the ABHSMD Integrated Water Resources Management and Development Plan (IWRM-DP) is based on restoring the balance between the supply and demand, mainly by increasing water availabilities, whether from underground, surface, or nonconventional sources. This strategy confirms that on the one hand the same conceptual framework is sustained despite the problems encountered and the failure of previous IWRM-DP strategy to restore the balance and, on the other hand, that emphasis is being placed on the offer without really controlling the demand.

In order to assess the global change impacts on groundwater in the Souss-Massa watershed, the hydraulic basin of the region has developed several scenarios taking in consideration all the stressors and their implications as well as the main interactions between them.

Change in the agricultural production trends following the market conditions and water availability is considered one of the stressors and at the same time

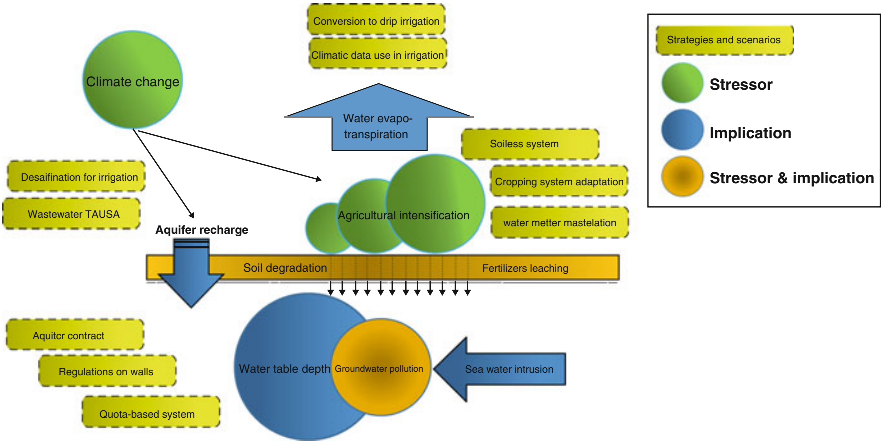

Fig. 8 Groundwater management model

implication, stressor because the increase in agricultural activities leads to more water extraction and implication because it depends to water availability. The cropping system scenarios are corresponding to change in production pattern especially adopting the soilless system and new crops and varieties.

The political interventions and strategies which the government has implemented and willing to set up as the public-private partnership projects (the project of using desalination for irrigation in Chtouka zone, modern irrigation district in El-Guerdane zone, aquifer contract) in order to reduce the global change impacts are also developed as political scenarios. Scenarios related to irrigation strategies especially at field scale which are conversion of surface to drip irrigation, using weather stations network in irrigation scheduling, reusing wastewater, and installing water meters in pumping stations were taken in consideration in this assessment. The baseline scenario of IWRM-DP which favors a return to equilibrium between demand and supply is mainly based on increasing the supply of water, whether from groundwater, surface, or even unconventional waters.

Thus, by the year 2030, the water supply will be increased by almost 20% from 901 Mm^3/year to 1,171 Mm^3/year. This increase in supply should lead to a return to balance the aquifer and satisfaction of growing demand. The balance of the baseline scenario is even surplus to the extent that it allows a surplus of 100 Mm^3/year. It will be possible to consider a restitution plan volume to the water table.

Figure 8 shows the groundwater management model.

Models are useful tools used to simulate and predict the effect of factors on receptors, and they can give a quite clear vision about the current or future situation. The MODFLOW model is used to simulate those changes and generate many outputs as the water table piezometric level, drawdown, water table depth, recharge, concentration, etc., in order to predict the impacts of all scenarios on quantitative and qualitative parameters of the aquifers.

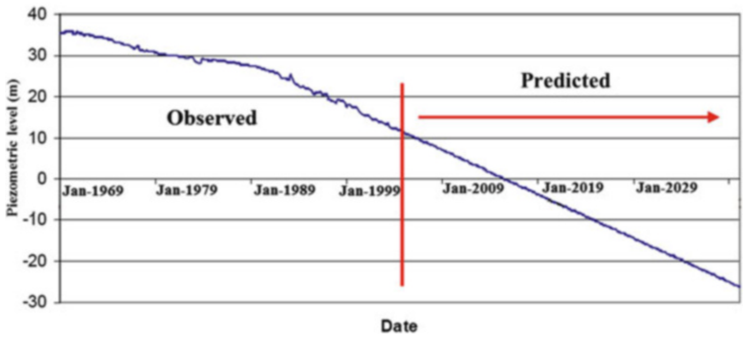

Fig. 9 Piezometric level evolution in the Chtouka aquifer

The scenario to be achieved by the ABHSM Integrated Water Resources Management and Development Plan (IWRM-DP) is based on restoring the balance between the supply and demand in combination with controlling the demand [21].

This strategy confirms that on the one hand the same conceptual framework is sustained despite the problems encountered and the failure of previous IWRM-DP strategy to restore the balance (Fig. 9) and, on the other hand, that emphasis is being placed on the offer with controlling the demand.

9.1 Catastrophe Scenario

This scenario is characterized by an overexploitation of water resources without any measures to be taken by water users and decision makers. Prediction results of the groundwater level in Chtouka aquifer are presented in Fig. 9.

Figure 1 shows clearly that during the last decades, groundwater level decreased by more than 30 m. This reduction will result in a second-time salt accumulation in the soil and groundwater quality degradation due to misuse of fertilizers and seawater intrusion. Consequently, this increase in salinity may lead to the installation of desalination individual units in larger farms. In 2010, some farmers have already installed this technology. However, this advanced technique would only be a step in the tragedy since brines issued from desalination will be discharged directly into the aquifer which leads certainly to groundwater salinity increase.

Losses associated with this scenario can be summarized as follows:

- Capital losses on all greenhouses, borehole, wells, and associated packaging houses. It is clear that the value of a borehole or well after saline intrusion is zero due to the fact that these installations cannot be moved.
- Loss in value of the total production using groundwater from Chtouka aquifer.
- Job losses for labor used in production and packaging.
- Job losses in inputs and services suppliers related to agricultural sector.

Table 3 Total losses of the catastrophe scenario in the horizon of 2035 [22]

Updated value of capital losses (million DH)	3,065
Updated value of added value losses (million DH)	8,903
Permanent job losses (equivalent)	2,834

The economic impact of the catastrophe scenario was estimated using a model based on representative farm samples associated with a packaging station. This representative model defines the added value per hectare, the number of agricultural jobs, packaging, and the capital invested per hectare. Table 3 summarizes the results obtained according to the nature of the losses.

9.2 Safeguarding Scenario

Water managers in the Souss-Massa region propose a preservation scenario to limit the imbalances in water resources by an active policy of mobilizing additional resources. This scenario is based on a political offer engaging all water users and stakeholders and aims to increase water offer to cope with existing water deficit. Several preservation measures are adopted in this scenario, some of them have already taken place, and others are planned in the future.

9.2.1 Water Supply Management Strategies

- Construction of dams planned in the PDAIRE (Master Plan of Integrated Development of Water Resources)
- Rainwater harvesting
- Seawater desalination
- Wastewater reuse
- Artificial recharge
- Water transfer from north basins
- Interconnection of hydraulic systems
- Saline water demineralization
- Use of saline water

9.2.2 Water Demand Management Strategies

- Adaptation of less water consumer crops.
- Infrastructure rehabilitation.
- Cropping adaptation technique to save water (hydroponics).

- Conversion to drip irrigation (facilitation of procedures for water users associations and small farmers, extension services): already 30,000 ha have been converted.
- Control of water withdrawal and pumping.

9.2.3 Transversal Actions

- Revision of water pricing
- Water governance (groundwater contract, implementation and strengthening of water users associations)
- Public-private partnership
- Encourage scientific research
- Capacity building
- Improve groundwater monitoring
- Improve hydrological monitoring
- Improve water withdrawal monitoring (remote sensing)
- Monitoring and evaluation of projects
- Encourage transnational cooperation
- Encourage the data exchange between stakeholders

In the horizon of 2030, water supply will be increased by almost 20%, from 901 Mm^3/year to 1171 Mm^3/year if the safeguarding scenario is occurred (Fig. 10). This increase in supply should lead to a return to the groundwater balance and satisfaction of growing demand. The safeguarding scenario balance even exceeds the water demand and allows a surplus of 100 Mm^3/year.

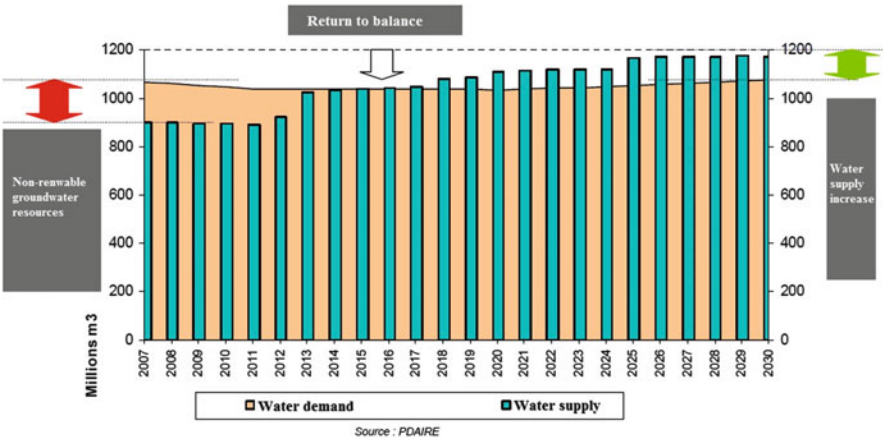

Fig. 10 Evolution of water balance under the safeguarding scenario toward 2030 [22]

10 Meeting the Planning Objectives

10.1 Water Saving in Agriculture

In Morocco, the "Plan Maroc Vert" adopted in 2008 includes a National Irrigation Water Saving Program with the objective to convert almost 500,000 ha to localized irrigation by 2020, which will make it possible to save 1 billion m^3 per year by 2020 [23]. National policies have recently led to the introduction of incentives to install advanced technology drip irrigation in all new and/or replanted orchards. All farmers eligible for a credit can receive subsidies of 60% when installing drip irrigation, provided they have legal titles for their land.

The limiting factor at the farm level is finding resources for technological modernization of farm irrigation systems. Small farmers and tenants have difficulty to afford efficient irrigation technology. In general, state or regional subsidies have been used to a different extent to support farmers' purchase of irrigation equipment (particularly drip irrigation) over time. In Morocco the state is still investing substantially for the conversion of large areas of the territory to drip irrigation, but subsidies are insufficient and the administrative bureaucracy does encourage small farmers to integrate in the system of conversion to drip equipment [24]. Several farmers argue that not only the purchase of drip irrigation equipment but also the design and installation of the irrigation system are expensive and require professional advice. However, most of the times, subsidies do not cover these expenses; thus, farmers who cannot afford the additional costs cannot take advantage of the subsidies to modernize their irrigation systems. Furthermore, new irrigation technology often does not come with training on how to use it properly, thus often leading to misuse and waste of water. Because of these limitations, a number of actions have been recommended changing the subsidy system by modulating subsidies so that to ensure a more balanced distribution of resources over design and installation, equipment purchase, and training [25].

At the regional level, the water master plan suggested several solutions to reduce the water deficit including actions at the demand and supply side.

10.2 Transfer of Knowledge

In the SMD region, an organization that could take this role is Agrotech. As illustrated in the previous sections, Agrotech is a young (2007) center for research in agro-technology promoting collaboration among private companies, public institutions, training organizations, and research organizations in the agriculture and agro-food sector for the diffusion of innovation and technology. Agrotech is primarily involved in connecting existing research initiatives. It also conducts some applied research which has increased the visibility of the agency over the last 2 years (e.g., the development of a network of weather stations through which providing irrigation advice to farmers). However, Agrotech has not yet consolidated its role and reputation in the region, and its activity does not support policy-making. Given its inclusive institutional design with all relevant private and public organizations in the management board, Agrotech is in the position of picking up farmers' needs and promoting research projects to respond to those needs by, for example, connecting research institutes to potential investors, and it could also promote regulatory frameworks to enable such initiatives.

10.3 Irrigation Efficiency at the Farm Level

The use of PPPs in the water sector is gaining popularity since both the public and the private provision of water services have proved inefficient in many countries over the past decades. The El-Guerdane water transfer in Morocco is one of the few examples where a PPP is used in irrigation management [26]. The innovative aspect of this project lies on the fact that other policy instruments were included in the project, such as subsidies to farmers who entered the partnership for purchasing drip equipment, regulation by law of the water tariff applied by the contractor, and voluntary participation of farmers to the project. Although, some implementation problems exist, these are mostly related to the country's structural problem of violation of law and distrust of public agencies. Therefore, in principle this business model, in combination with other policy instruments, has the potential to be successfully adopted for the provision of irrigation services in the Souss-Massa as the terms of the agreement are carefully regulated so as to avoid inequalities in the distribution of the benefits.

10.4 Aggregation Business Model in Agriculture

The voluntary partnership between small farmers and commercial and/or industrial businesses which have management, financial, and technical expertise supports small farmers of a region to optimize the production process from the field to the commercialization. One of the key factors leading to the adoption of this model in the Souss-Massa was the capacity of farmer cooperatives to develop a network with potential interested parties and to connect this idea to the national political agenda. This experience shows that this model has more chances to be adopted in regions where formal and informal networks of farmer groups (cooperatives, associations, etc.), private businesses such as technology developers, and regional/local public organizations are already in place and are well connected with national policy circles, so that ideas and information can flow and trust on this project gradually develop across different actors.

10.5 Water Quality Monitoring

The Hydraulic Basin of Souss-Massa Drâa Agency [27] has implemented a monitoring network of groundwater quality since 1990. The measurements are carried out once per year [11]. The monitored parameters are electrical conductivity (EC), pH, N^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, SO_4^{2-}, NH_4^+, NO_2^-, NO_3^-, PO_4^{3-}, organic matter (OM), fecal coliforms, and total coliforms.

In general, the groundwater quality in the Chtouka aquifer degrades from north to south. This degradation is linked to agricultural activity within the perimeters of Massa and Tassila and movement of groundwater at shallow depth in the shale. According to Tagma et al. [16], the aquifer in Chtouka-Massa region is the most severely contaminated; 36% of wells exceed the regulatory threshold of potability of 50 mg/L nitrate.

In the Souss region, it is relatively less affected; 7% of wells crossed 50 mg/L with an average composition of 22 mg/L. The irrigated areas seem to be the most affected by nitrate pollution as the result of the excess of nitrogen fertilizers application.

Due to groundwater overexploitation, the coastal area of the Souss-Massa Basin tends to be affected by salinization problem led by the seawater intrusion. According to surveys carried out by the ABHSMD agency in the Souss-Massa Basin, the saline groundwater is located in Issen and in the south Agadir coastal zone of Souss aquifer; Sidi Bibi, Massa, Belfâa, and Aït Milk in the Chtouka aquifer; Tiznit aquifer; Ifni basin; the coastal zone of Tamraght basin; and at the center of Tamri aquifer [11].

10.6 How Can We Move Forward Now?

Striking a balance between water supply and demand involves drawing on new resources, along the following four lines: (1) improving agricultural as well as urban usage efficiency; (2) promoting integrated water management, achieving optimal allocation through consultation between uses; (3) drawing on nonconventional resources, reuse of wastewater and desalination; and (4) water transfers when the previous levers have proven their limits.

Progress made over the past 15 years or so regarding the inclusion of WDM in water policy has started to move down this path. They have adopted official national WDM strategies combining legislative and regulatory, technical, economic, and institutional instruments and mobilizing stakeholders or are intending to further develop these tools. A degree of devolution of water management to units such as catchment basins, increasing user participation, and the redefinition of the role of the state are all helping to drive the emergence of such strategies.

10.7 Promoting Private-Public Partnership (the Case of El-Guerdane District)

In this district water scarcity has led to the abandonment of citrus plantations and has forced the remaining farmers to invest into additional deep well drilling over the past decade. To protect the economy of this region and offset the over abstraction of groundwater, the Moroccan government decided to bring additional water from the Aoulouz dam located upstream the Souss River to the district through the construction of a water transfer. The project became operational in 2009. It included 90 km of underground conveyance pipeline and 300 km of irrigation network for pressurized water distribution.

The project was realized through a public-private partnership (PPP) covering the design, construction, operation, and maintenance of water infrastructure. The total cost amounted to about 90 M Euro. Financial resources were provided by the state (48%), the construction company Amensouss (44%), and the beneficiary farmers (8%). To join the project, farmers paid an entrance fee of about 700 Euro/ha and agreed to pay a service charge of 0.15 Euro/m^3. Furthermore, as part of the deal, the beneficiary farmers were obliged to convert to drip irrigation with the support of state subsidies. The water transfer satisfies 50% of the district crop needs, being additional water withdrawn from the Souss aquifer through private wells.

This district has shown capacity to improve irrigation efficiency over the years, thanks to the adoption of a mix of policy instruments including PPPs, voluntary agreements, subsidies, contracts along with development, and transfer of knowledge. However, this represents an exception more than the rule in Morocco where the SMD region and the El-Guerdane district are promoted as role models of modern, innovative, and technologically advanced agriculture. The functioning of the irrigation governance system and further improvements in the region are conditioned to the capacity of the governments to address a number of structural problems commonly found in emerging economies such as violation of law, lack of enforcement of regulation and control, isolation of small farmers, and insufficient public participation to decisions.

As for the El-Guerdane district, the major component is that there is a private company (Amensouss) managing the irrigation network delivering water to the district. According to the terms of the PPPs, Amensouss is entitled to apply a water tariff covering construction and maintenance cost and ensuring a profit (a cap is established by law). As previously noted, a number of interviewees point to the fact that the Amensouss' water tariff is one order of magnitude higher than that applied in the neighboring areas by ORMVA/SMD without these revenues generating an efficient service. Specifically, farmers lament that the irrigation network is not well maintained and that there are frequent interruptions of water delivery. Other interviewees, however, highlight the fact that because a number of farmers refuse to pay the water tariff, Amensouss does not collect sufficient resources to provide an adequate service. In addition, some argue that only big farmers or farmer cooperatives could benefit from the project as the entry fee to join the PPP was too high.

The example provided by El-Guerdane has shown capacity to improve irrigation efficiency over the years, thanks to the adoption of a mix of policy instruments including PPPs, voluntary agreements, subsidies, contracts along with development, and transfer of knowledge. However, this represents an exception more than the rule in Morocco where the SMD region and the El-Guerdane district are promoted as role models of modern, innovative, and technologically advanced agriculture. The functioning of the irrigation governance system and further improvements in the region are conditioned to the capacity of the governments to address a number of structural problems commonly found in emerging economies such as violation of law and lack of enforcement of regulation and control.

11 Stakeholders' Participation in the Water Resource Management

11.1 The Souss-Massa River Basin Agency

The Souss-Massa River Basin Agency is responsible for assessing, planning, managing, and protecting water resources and for issuing licenses and concessions concerning hydraulic public property in their area of action.

Article 20 of the Law 10-95 on water assigns the River Basin Agencies (RBA) to be the authority responsible in their own area of actions.

The Souss-Massa River Basin Agency water resources strategy focuses on three major components for the short-term period:

- Improvement of institutional, legal, and organizational structures in the water sector
- Capacity building of water management of the water sector of the local stakeholders
- Improvement of communication, information management, and dialogue between actors in the water sector

This program concentrates on four issues:

- Improving the monitoring and control systems in water management planning
- Protection of groundwater resources
- Promoting the reuse of wastewater and desalinated water
- Reinforcing the participation of the various actors to enhance water resources planning and management

The role of the RBA is to contribute to the development of participative policy to protect groundwater aquifers Souss and Chtouka for sustainable development, lead a participatory action plan negotiated and agreed in line with the recommendations

Table 4 List of the stakeholders

Stakeholders	Representing
Ministère de l'Aménagement du Territoire, de l'eau et de l'environnement	Ministry of environment
Ministère de l'Agriculture, du Développement Rural et des Pêches Maritimes	Ministry of agriculture
Ministère des Finances et de la Privatisation	Ministry of finance
Secrétariat d'Etat Chargé de l'Eau	Department of water
Wilaya de la Région Souss-Massa Drâa	Local authority
Conseil de la région du Souss-Massa Drâa	Region authority
Agence du Bassin Hydraulique du Souss-Massa	River basin agency
Office regional de la mise en valeur agricole du Souss Massa	Regional department of agriculture
Crédit Agricole du Maroc	Agriculture bank
Chambre d'Agriculture d'Agadir Chambre d'Agriculture de Taroudant Chambre d'Agriculture de Tiznit	Agriculture chamber
Association AGROTECH du Souss-Massa Drâa	Regional platform for technology transfer
APEFEL	Farmers vegetable and fruit association
ASPEM	Farmers vegetable association
ASPEM	Farmers citrus association

and provisions of the water master plan [28] for the protection and preservation of water resources of these aquifers, and to follow up and assist the commission groundwater contract.

The responsibilities of the RBA in this agreement related to the protection of water resources in the Souss-Massa Basin are (Table 4):

1. The involvement and commitment of all stakeholders that signed the agreement based on their responsibilities and make sure to arrange and to reserve the necessary funding to implement the actions of the agreement
2. The implementation of the water resources development strategy of the Souss-Massa Basin

11.2 Water Allocation and Pricing

Until 1995 in the SMD region, the regional offices of the Ministry of Agriculture (ORMVA/SMD) were responsible for issuing water concessions and collecting water charges. Then the responsibility passed on to the river basin authority (ABHSMD) with the exception of major irrigation water infrastructure (e.g., El-Guerdane transfer) for which ORMVA/SMD retained responsibility of issuing water permits.

As for water pricing, both ORMVA/SMD and ABHSMD apply water charges. The ABHSMD charges farmers 0.01 Euro/m^3 and use this levy for subsidizing small farmers to purchase drip equipment. The ORMVA/SMD charges water consumption 0.063 Euro/m^3. In the El-Guerdane district, Amensouss applies volumetric charges of 0.15 Euro/m^3.

12 Conclusion

The diagnosis has to recall that the agricultural dimension totally dominates the debate on demand management in the Souss-Massa region. With less than 7% of the volumes used for drinking water supply, reducing demand for potable water by 50% only saves 3.5% of volume, while a 10% discount on agricultural volumes saves the threefold.

The technical actions to be undertaken by the plan for sustainable development of the region must be supported by the adoption of all the implementing regulations of the Law 10-95 on water. It appears then that urgent steps must be taken:

- Stopping the extensions private modern perimeters
- Compulsory installation of water meters at all pumping point, especially large farmers
- Strengthening the capacity of exercising the water police and applying the corresponding sanctions to illegal water users
- Users' awareness on the need to respect the regulations in the interest of the conservation and protection of water resources to ensure sustainable development of the region
- More increased participation of the users in integrated water resources management and coordination of all the operators and economic agents to introduce the principle of lap contract that will encourage all stakeholders to commit to safeguarding the water heritage the region

In the regions of Souss-Massa, water scarcity has proven a driver of water policy change. However, water scarcity alone is not sufficient to ensure that this change goes in the direction of more efficient irrigation management. As explained in the previous sections, it is sometimes difficult to ensure that actors respect the decisions made in times of water scarcity once the water crisis is over (e.g., violation of terms of the groundwater agreement during the rainy year) or after they have achieved their needs (e.g., farmers obtaining water thanks to the construction of the El-Guerdane water transfer now refusing to pay the water bill to Amensouss). In addition, in terms of water scarcity, violation of law such as illegal water withdrawals for irrigation purposes is more common. Therefore, although water policy instruments (e.g., voluntary agreements, PPPs, contracts) and regulations are established in response to the water scarcity problem, structural institutional failures (e.g., violation of law, lack of enforcement) may hinder the achievement of the expected outcomes (e.g., improve replenishment of the aquifer).

The issue of enforcing the rules is fundamental to sit up and establish an environment in which the use of economic instruments of the management of the demand to be effective and can give a result. This issue is the low effectiveness observed at the legislation and regulatory levels and, consequently, not stopping the groundwater mining which could cause a major economic crisis for the region.

Direct measures include increased control over land rental, submitting to prior authorization from the citrus grove, and the possibility of sanction of non-authorized well drilling. These measures should prevent land transactions leading to a deepening demand. Indirect measures include drilling companies' controls (e.g., approvals), checking electrical connections, or a refund of agricultural subsidy policy.

To stop pumping trend is also a matter of monitoring the development of irrigated areas in the valley. The use of satellite data to identify and monitor irrigated areas, strengthening the water police, or the creation of local water resources management districts are all measures which remove the problems inherent in this.

This proposed reform cannot be conducted without the involvement of regional authorities that led to the development and conclusion of the "groundwater of agreement." This dialogue and the effective participation in decision gave legitimacy to the action of the authorities on the ground and without which nothing could be successful.

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Physical Geography, Geology, and Water Resource Availability of the Souss-Massa River Basin

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Abstract This chapter presents synthesis results of physical geography, geology, and water resource availability of the Souss-Massa River Basin. The geomorphology and geology are very complex in detail. The actual valleys of Souss and Massa are due to erosion processes caused by floods. The Souss-Massa plain is a narrow fainting zone with recent sedimentary deposits, embedded between the High Atlas in the north and the Anti-Atlas in the south. The calibration of electrical soundings with deep boreholes allowed understanding of the geometry and the structure of the aquifer of Souss-Massa plain.

The Souss-Massa area has a typical semiarid to arid climate with annual rainfall average ranging from 250 mm in the plain to 600 mm in the mountains.

Plio-Quaternary shallow aquifer and Turonian deep aquifer constitute the major groundwater resource in the basin. The water resource availability of Souss-Massa River Basin is scarce; this situation is getting worse as a consequence of rapid population growth, expanding urbanization, increased economic and agriculture development, and natural forces (climate change). The renewable surface water

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may vary a lot over the year or even between 1 year and another. It’s estimated at 667 million cubic meters. The construction of dams produces a number of economic and social benefits with a storage capacity reaching 639 million cubic meters.

The groundwater availability is often being overexploited and polluted. On average groundwater abstraction exceeds recharge by an estimated 260 million cubic meters annually. This overpumping has led to a decrease in the water levels in a range of 0.5–2.5 m/year in the past 4 decades.

Keywords Geology, Geometry, Physical geography, Souss-Massa River, Water resource availability

Contents

1 Introduction

Souss-Massa River Basin is one of the most productive agricultural areas in Morocco. Irrigated agriculture produces more than half of Morocco citrus and vegetables [1]. The principal water resource is provided by the groundwater of Souss-Massa aquifer and dams [2, 3].

The diverse geographic, geologic, and climatic characteristics of the Souss-Massa River Basin play an important role in water resource availability, which in turn affects a range of water resource-related activities. The Souss-Massa system is one of the best cases that illustrate the influence of topography, geology, and climate on surface and groundwater flows. Such a large basin area cannot be expected to have uniform climatic and rain patterns; the Souss-Massa shows typical ecosystem zones from Atlas Mountains toward Atlantic Ocean. A combination of human population growth, unsustained water resource use and development, and desertification threatens the Souss-Massa River's ability to supply crucially needed natural resources to the people of Souss-Massa region and its activities. The geological, structure, and soil characteristics in the basin greatly influence groundwater availability. Significant rainwater deficits and the variable duration of the rainy season result in hydrological shortage that is not necessarily reflected in a direct response of the base flow. This chapter reviews the basin's physical geography characteristics, the geology, and the water resource availability of the Souss-Massa Basin.

2 Physical Geography

2.1 Geography

The Souss-Massa Basin is located in the middle western of Morocco, occupying a total surface of 27,000 km^2 with about 21% of plain area (5,700 km^2) and 79% of mountain area (21,300 km^2). 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 Souss-Massa River Basin (Fig. 1).

Elevations in the basin range from 0 m (Atlantic Ocean) to 4,168 m (Toubkal summit in the High Atlas Mountains). The plain area lying between 0 and 700 m.a.

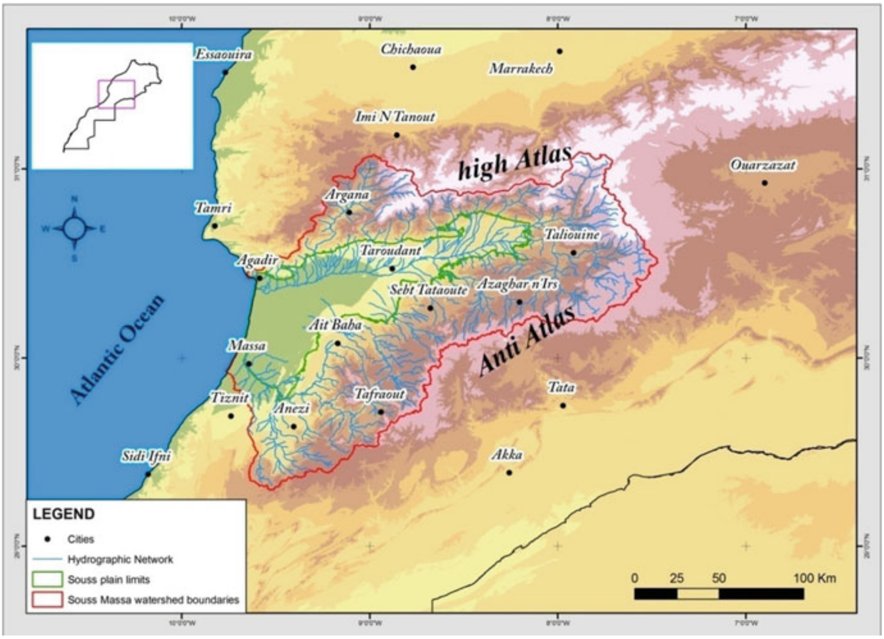

Fig. 1 Geographical situation of Souss-Massa River Basin

s.l. covers about 5,700 km^2 and contains the groundwater reservoir, while the remaining part is mountainous [4–12].

The Souss plain is covered by recent alluvial deposits deposed by Souss River and its tributaries and by Massa River and its tributaries in the Massa plain.

The two hydrographic regions of the Souss-Massa Basin are distinguished by their unique topographic and drainage characteristics. Several studies were carried out in this regard [4, 12–15]. Figure 1 illustrates the hydrographic regions, geographic settings, and characteristics.

The regions are as follows:

- The Souss River: The headwaters of the Souss Valley have an extensive network of tributaries originating from High Atlas Mountains in the right side and a very light network of tributaries originating from Anti-Atlas Mountains in the southern side. After its confluences with the High and Anti-Atlas tributaries, the Souss Valley flows into a large plain, extending east to west along 182 km toward Atlantic Ocean. The flow of the Souss River and its tributaries is seasonal with irregular and sometimes highly floods between October and February during rainy year. The discharge flow is regulated by four big dams (Mokhtar Soussi, Aoulouz, Imi El Kheng, and Abdelmoumen).

  To summarize the topographic description of the Souss River Basin, we can distinguish three main zones:

  (i) The upper part of the basin (Souss upstream) between the base of Siroua Mountains and the city of Taroudant where the plain is narrow (1,200 km^2).
  (ii) The middle Souss from the city of Taroudant to the city of Oulad Teima, which extends the central plain of Souss and is wider (1,500 km^2), more regular, and less corrugated.
  (iii) The lower part of the basin from the Oulad Teima to the sea where the cities of Agadir and Ait Melloul take place. The Souss downstream extends over an area of 1,700 km^2.

- The Massa River: It is the second valley that drains the Souss-Massa Basin. It is located 70 km south of the Agadir city, close to the south watershed basin. This fluvial system has only the headwaters from the Anti-Atlas Mountains, which is just the perennial flow to the sea of freshwater southern of Souss-Massa Basin. His course in plain is incised and forms a narrow valley over a distance of around 36 km before flowing into the Atlantic Ocean. The regime of this valley follows annual and interannual climatic irregularities and is characterized by brief flooding, sometimes violent and interrupted by long periods of dryness. The discharge flow is regulated by two dams (Ahl Souss and Youssef Ben Tachfine).

2.2 Geomorphology

As a geomorphological point of view, the Souss-Massa plain is shaped as a gutter at very small bending radius, adjusted to the mountainous foothills and in the axis of Souss River which traced its bed. Headed and branched off in the upstream portion, it is relatively cashed in the downstream part. From east to west, the slope is 1% to Aoulouz; it decreases to 0.5% near Taroudant and 0.3% in the downstream part of the plain. From Aoulouz to the Atlantic Ocean, the elevation of the plain is range from 700 to 0 m over a distance of 150 km [12].

The plain has no notable reliefs except some remains of a Cretaceous cuesta in the form of hills and buttes split and almost completely hidden in the Pliocene–Quaternary formations filling the plain [4, 7, 14, 16, 17].

The actual course of the Souss and Massa is due to erosion processes caused by floods [9, 17–20]. Floods in Souss-Massa are very scarce and occur irregularly: after 10 mm of rain, rill wash occurs over the area and concentrated flow begins in some valleys; when the flood is effective in the main valley, its effects, except for rill incision on the slopes, are mainly the construction of inner fans at the mouths of the tributaries, a widening of the braided channel reach, and a delivery of the suspended load to the ocean [15]. Consequently, occurrence of vertical and lateral channel erosion in the whole catchment, colluvial deposition on slopes, widening of the braided channels in the median zone, and silt deposition in the distal zone collectively characterize the predominant processes in present-day conditions. Two other noteworthy characteristics are the various types of calcareous indurations and links with eolian deposits.

2.3 Climate

The Souss-Massa area has a typical semiarid to arid climate. The variation of rainfall is very important in time and space showing a clear decrease from the mountains to the plains. The average rainfall is 250–300 mm/year in the plain (Fig. 2) and around 500–600 mm/year in the mountain [21].

The annual mean temperature ranges between 14 and 18°C in the High Atlas and Anti-Atlas. The average temperature in the plain is higher and can reach up to 20°C [22]. The rainfall period extends from November to March, and the dry season can extend up to 7 months (April to October). Although the potential evaporation is very high in the plain and can reach up 2,000 mm/year [12], the rainfall exceeds the evaporation during winter in the mountain areas that become the main recharge areas.

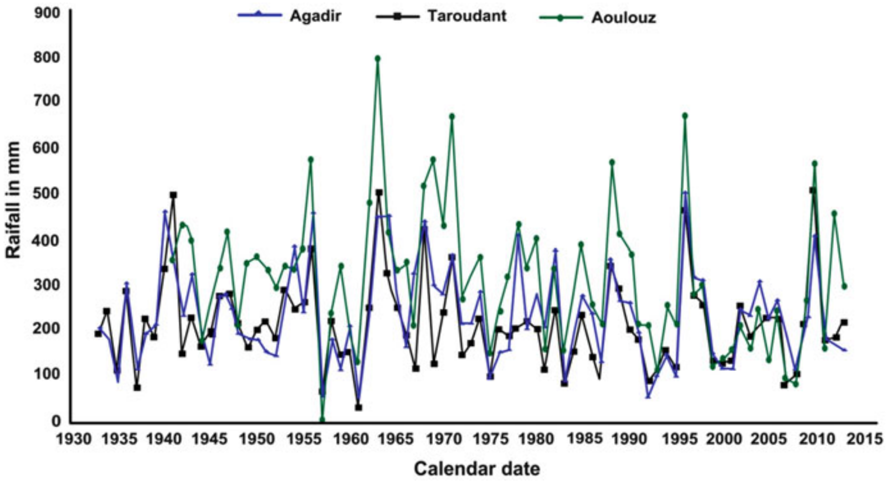

Fig. 2 Annual variation of precipitation in three main meteorological stations (Agadir, Taroudant, and Aoulouz) in the Souss-Massa Basin

3 Geology and Tectonic Setting

The Souss-Massa Basin (Fig. 3) is a part of the Pre-African trench. It is a narrow fainting zone with recent sedimentary deposits, embedded between the High Atlas in the north and the Anti-Atlas in the south. Both Atlasic domains are connected at depth beneath the Souss Valley in a complex manner and are covered with thick detritic formations and calcareous marls of Plio-Quaternary deposits. These overlie a Cretaceous–Eocene syncline [6, 7, 16]. The northern flank of this syncline largely, but only partly, outcrops the side of the High Atlas. The southern flank is seen as an alignment of hills in the middle of the valley.

3.1 Geological Formations

In addition to monumental works on the Souss Basin [16, 23–25], several studies were carried in this area [4–7, 9, 10, 12, 14, 26]. The age of the geological formations ranges from Paleozoic to Quaternary. The plain is composed of Plio-Quaternary sediments (sands, gravels, and lacustrine limestone), which covers a Cretaceous syncline in the north of the basin and a Paleozoic schistose basement in the south (Fig. 3).

The Plio-Quaternary strata in the plain are locally heterogeneous both in vertical and lateral directions (Fig. 13). The syncline axis is oriented on east–west direction (Fig. 4). Its northern flank outcrops vertically in the High Atlas and marks a vertical

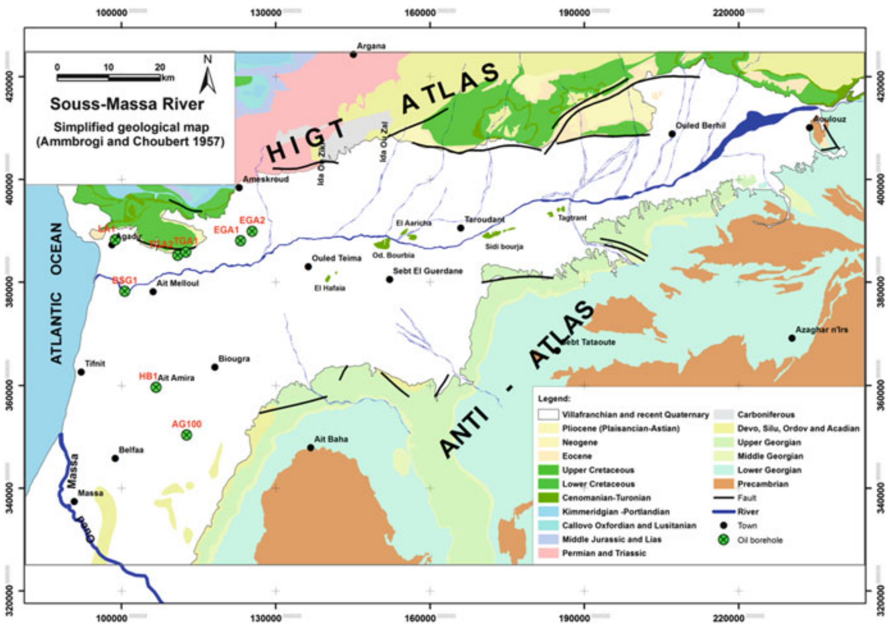

Fig. 3 Geological map of Souss-Massa Basin in [6] modified

fault, which is known as the South Atlas fault. Its southern short flank outcrops slightly in the center of the basin.

The High Atlas shows an alternation of permeable and impermeable Mesozoic formations. Some layers contain evaporate minerals (gypsum in Jurassic and Cretaceous and halite in Triassic formations).

The Cretaceous layers resulting from the major transgression in the area, underlain the plain (Fig. 4). This is confirmed by data revealed from boreholes that penetrated rocks from surface alluvium through Turonian-age rocks. The deep boreholes and geophysical measurements have shown a large variability in the substratum (Figs. 6, 7 and 8).

The Anti-Atlas Mountains are characterized by carbonate and crystalline formations [16, 24, 26].

3.2 Structural Evolution

Several authors [7, 14, 16, 28–31] describe the Souss Basin as a tertiary synclinorium structure including two depocenters located in the western and eastern parts of Souss Basin. The Souss plain, which acted as the High Atlas foreland basin during the Cenozoic, constitutes an E–W-oriented depression separated from the Ouarzazate Basin by the Siroua high plateau.

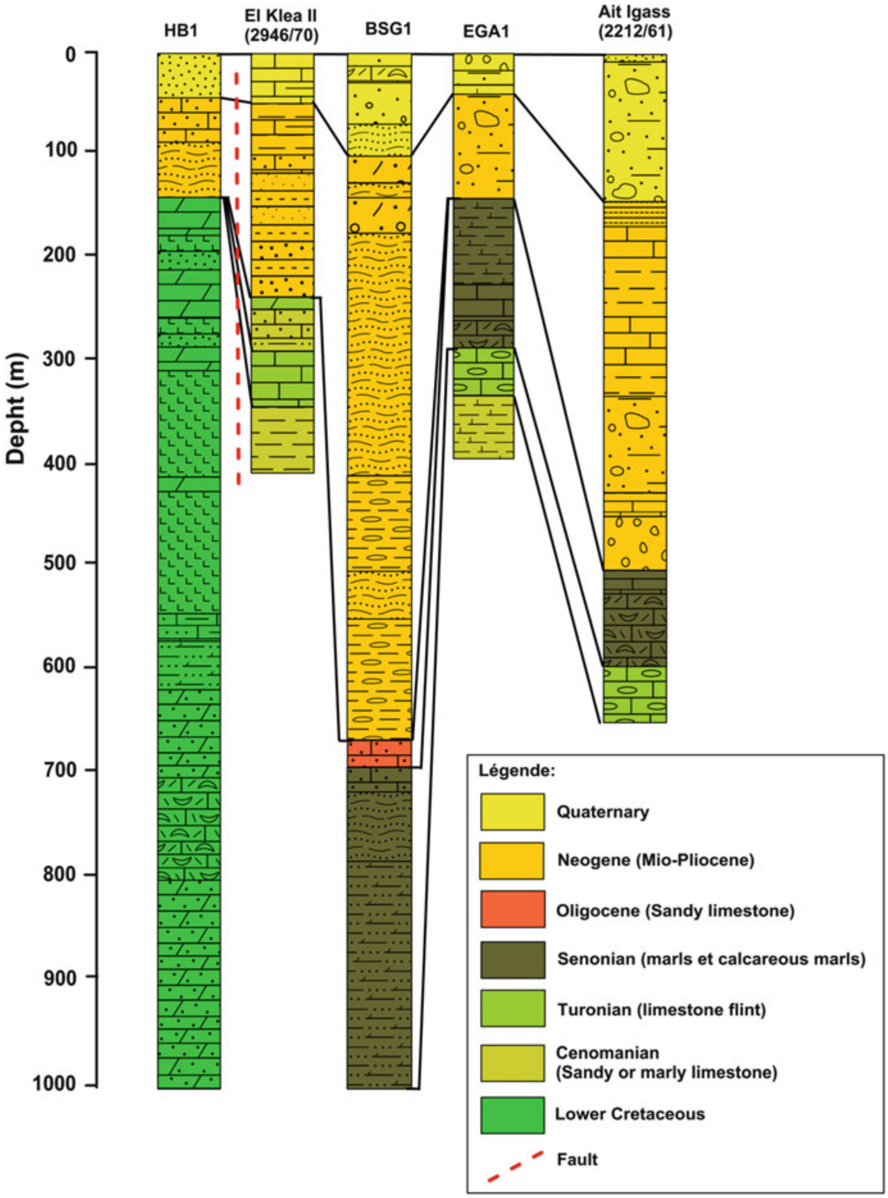

Fig. 4 Logs of deep oil and hydrogeologic boreholes showing the stratigraphy of the subsurface of Souss-Massa plain

Many studies have emphasized the role of the inversion tectonics in the evolution of High Atlas system and its foreland [29, 32–37].

Thrust and fold structures would have resulted from the reactivation (inversion), caused by the Cenozoic compressional events, of the preexisting extensional faults associated with the Triassic–Liassic Atlasic rifting.

The beginning of tectonic inversion is not synchronous; the western border has been lifted in the first, as suggested by the absence of Eocene deposits and unconformity of Aquitanian conglomerate on Maastrichtian levels [28].

The northern edge of Souss Basin is bounded by 150 km long in the South Atlas Front. This WSW–ENE striking fault zone is structurally formed from west to east by four main fault tracts [38]: the WNW striking, 30-km-long Agadir–Tagragra fault tract; the WSW striking, 3-km-long Oued Issen fault tract; the east–west striking, 45-km-long North Taroudant fault tract; and the E–W to WNW striking, 40-km-long Oulad Berhil fault tract.

The deformations visible within the basin are recent (Quaternary age); and, in the western part, Ambroggi [16] distinguished from surface observations, several folds, and flexures affecting quaternary levels. These structures are, from north to south, (1) the Mesguina syncline, with an axis east–west; (2) the Aknibiche anticline with an axis E–W to ENE–WSW; (3) El Klea and Chrarda flexures; (4) Haffaia–Ouled Bou Rbia anticline (NE–SW to E–W) which appears outcrops of Cretaceous layers.

3.3 Geometry and Structure of Subsurface

The exploration of the subsurface structure of the Souss-Massa plain is based on the determination of electrical discontinuities from the quantitative interpretation of electrical sounding and the correlation between the geoelectrical cross sections [27, 39]. These discontinuities probably correspond to faults or flexures affecting the basement of the plain; they are divided into three main families' directions: NE–SW, WSW–ENE, and N–S.

The first family is represented by the F1 discontinuity (F1a and F1b) traversing El Klea region, north of Oulad Teima, and El Gouna region, orientated NE–SW. It corresponds to the fault of El Klea [6, 7] initially described like a subsurface flexure by [16].

This fault has been identified in oil borehole El Klea II and HB1 (Fig. 4), and from the analysis of seismic profiles (Fig. 5), the fault of El Klea (F1) affects, with an average dip about 50–60° toward the NN, the Mesozoic and Paleozoic basement formations, defining a half-graben collapsed SSE with an approximate initial dip of 10 [35, 36, 40, 41]. It is extended to the ocean, separating the coastal area of Souss downstream of western plain of Chtouka and middle Souss, thereby defining the first compartment of Souss-Massa plain.

The second family oriented ENE–WSW is indicated by the F2 discontinuity passing at Biougra and the south of Cretaceous outcrops, and F3 discontinuity

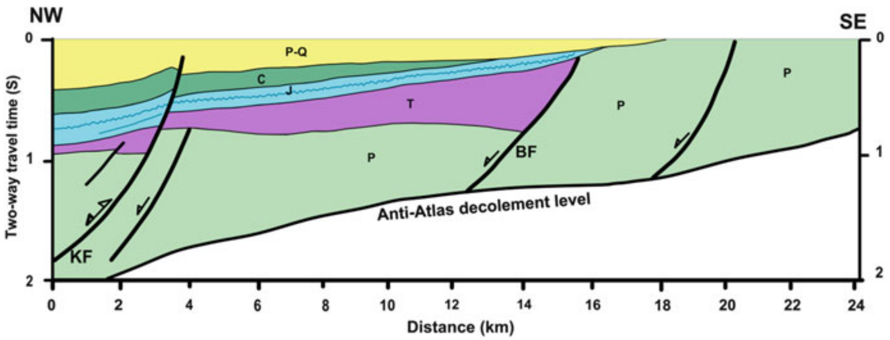

Fig. 5 The interpreted seismic reflection image across El Klea (KF) and Biougra (BF) faults. *P-Q* Plio-Quaternary, *C* Cretaceous, *J* Jurassic, *T* Triassic, *P* Precambrian and Paleozoic, in [36], modified

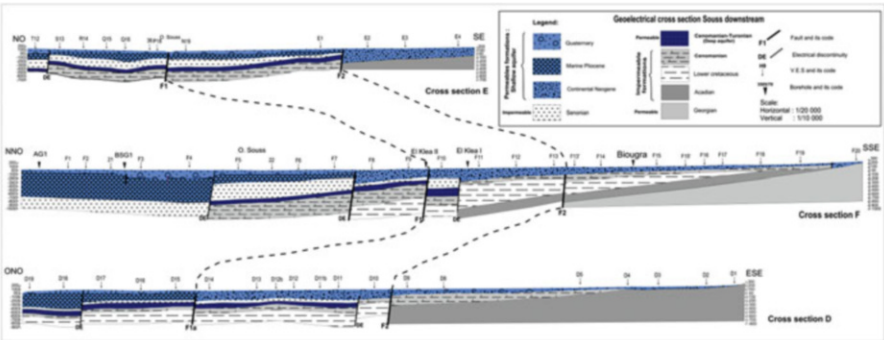

Fig. 6 Geoelectrical cross sections along three profiles *E*, *F*, and *D* realized in Souss downstream [27]

parallel to F2 appears on the eastern hill El Haffaia from the Cretaceous outcrops of Sidi Borja and Tagtrannt and then joined the F2 discontinuity at the Cretaceous El Madida hill. This discontinuity family divides between the second and the third compartment, the one located beyond the Cretaceous outcrops of the Souss Valley toward the Anti-Atlas and the other located beyond the Cretaceous outcrops toward the High Atlas.

The third family consists of the F5, F6, F8, and F11 discontinuities oriented N–S to NNE–SSW. The F5 and F11 discontinuities pass in the NW of Oulad Berhil. F6 discontinuity is located in NW of Arazan region. The F8 discontinuity is detected between Oulad Teima and Sebt El Guerdane towns.

The geoelectrical cross sections show a deepening of Cenomanian–Turonian resistive strata from the south toward the north and the interpretation of this structure as a horst and graben system (Figs. 6, 7, and 8).

The correlations made on these geoelectrical cross sections made it possible to highlight electrical discontinuities and to elaborate the structure map (Fig. 9).

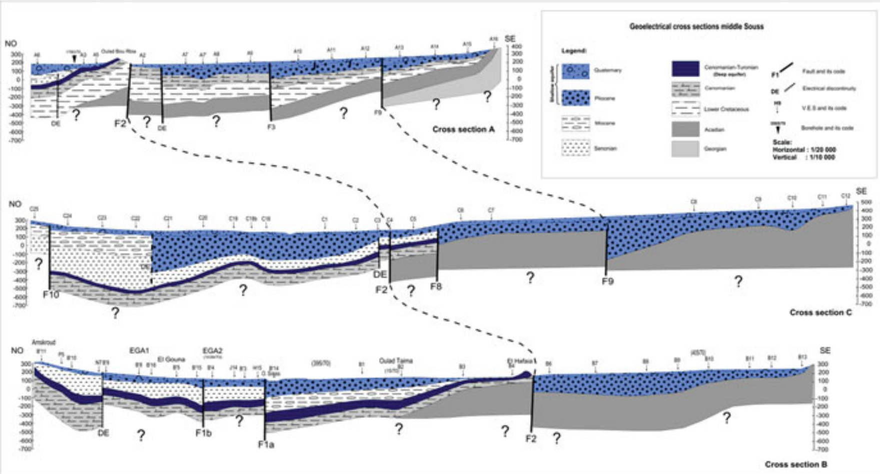

Fig. 7 Geoelectrical cross sections along three profiles *A*, *B*, and *C* realized in middle Souss [27]

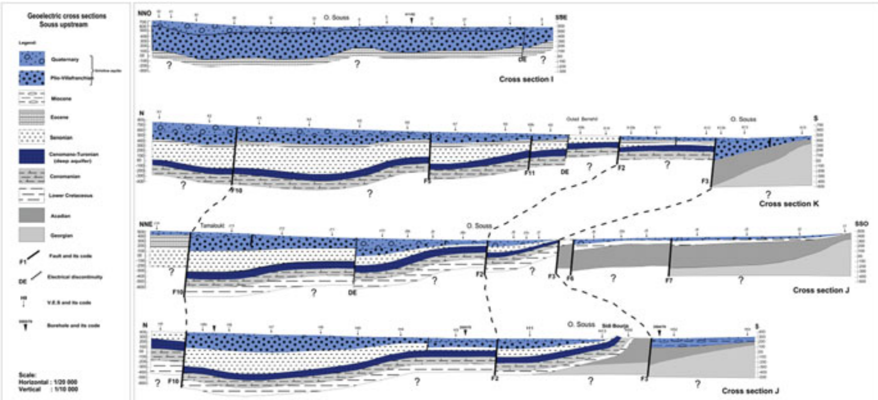

Fig. 8 Geoelectrical cross section along Souss upstream area [27]

The latter most likely corresponds to major faults, which affect the underground strata in the area.

The correlation of these faults, was carried out taking into account the structural directions already described in the region by [30, 31, 35–38, 40–45].

The faults have divided the Souss-Massa plain underground into four compartments (Fig. 7). The first compartment (I) corresponds to a collapsed area between the El Klea fault (F1) crossing and the Atlantic coast forming the coastal aquifer of Souss. The second compartment (II) corresponds to a depression, limited in the south by Cretaceous hills in the plain and to the north by the South Atlas foothills. The third compartment (III) is located between the Cretaceous outcrop in the center of the Souss Valley and Paleozoic outcrops of the Anti-Atlas. The fourth

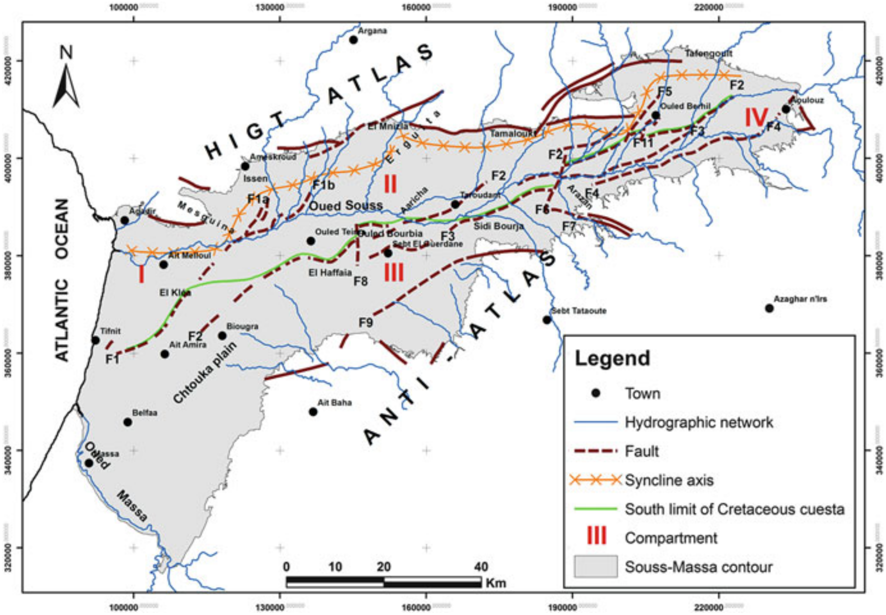

Fig. 9 Structural map of subsurface of Souss-Massa plain showing the syncline axis, faults, and compartments [27, 39]

compartment (IV) is located between Oulad Berhil and Aoulouz in the Souss upstream (Fig. 9).

4 Water Resource Availability

4.1 Surface Water Availability

The surface water availability may vary a lot over the year or even between 1 year and another and depend on climate change.

4.1.1 Renewable Surface Water

The renewable resources are estimated to be 131 and 418 million cubic meters in the Massa and Souss Basin, respectively (Table 1).

Table 1 Average monthly and annual renewable surface water in the Souss-Massa Basin on million cubic meters [46]

	Average monthly contributions												Annual contributions		
Basin	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun	July	Aug.	Moy.	Max.	Min.
Souss	20.2	40.0	57.0	67.6	59.6	48.0	46.5	29.9	15.5	11.3	10.9	12.6	418.9	2,030.1	90.4
Massa	5.2	10.7	17.4	23.1	20.1	16.3	15.0	10.6	4.5	2.8	2.6	3.2	131.4	633.2	26.4
Total	27.6	60.3	93.5	114.7	100.8	80.1	76.0	48.4	22.0	14.5	13.5	16.1	667.5	3,440.4	116.8

4.1.2 Drainage Network and Runoff

The Souss-Massa River Basin has a very dense hydrographical network, where the larger sides are the High Atlas range and the Anti-Atlas, the two converging in the east. In between, a depression, with a triangular shape, increases in width from the west to the east.

At the Souss River, the main tributaries coming from the High Atlas Mountains are larger and with higher discharge than the tributaries from the left margin (Fig. 11). The left margin tributaries are perpendicular to the main channel. The tributaries from the right margin are tangential to the main river and have a dendritic network in the mountains. The main tributaries from the east to west in the right margin are the Oued Lemdad, Oued Talkjount, Oued El Ouaar, Oued Mhannd, and Oued Issen, while those from the left margin are the Oued Tidnass, Assif n'Oulil, Oued Sdas, and Oued Merkh (Fig. 11).

The Souss headwaters collect waters from the High and the Anti-Atlas system and after crossing the Souss plain flow to the Atlantic Ocean in the Souss mouth at the Ait Melloul city.

The hydrological regime of the Souss and Massa Rivers is characterized by strong seasonal and interannual irregularity. The average discharge of Souss Basin is estimated to 394 million m^3/year. In Aoulouz at the dam, the average discharge is 170 million m^3/year, depending on water availability of water year. The Souss river bed is dry in Taroudant for 8 months per year on average, because the water discharge is diverted from the main channel to the irrigation channels and seeps into the groundwater. At its mouth in Ait Melloul, water discharge observed is about 200 million m^3/year that is lost at sea.

The rest is taken, seeped into groundwater, evapo-transpired by vegetation cover, or lost through evaporation.

The flows have high interannual irregularity and depend on precipitation [12] and regulated by dams. In the downstream of Aoulouz dam at the entrance to the Souss River in the plain, the annual average flow is 4.87 m^3/s with a maximum of 28.05 m^3/s and a minimum of 0.001 m^3/s. In the Taroudant station the annual average flow is 0.92 m^3/s with a maximum of 6 m^3/s and a minimum of 0.001 m^3/s. In the mouth of Souss River, the annual average flow is 4 m^3/s with a maximum of 25.4 m^3/s and a minimum of 0.002 m^3/s (Table 2 and Fig. 10).

The first conclusion we have drawn from these figures is that in Taroudant, the flows are much less abundant than Aoulouz despite the contributions of tributaries

Table 2 Interannual variation of average flows in the Souss Basin [22]

Station	Aoulouz (1954–2009)	Taroudant (1993–2009)	Ait Melloul (1972–2010)	Total (m^3/s)
Average annual flow (m^3/s)	4.87	0.92	4.009	9.799
Max	28.05	5.92	25.40	59.37
Min	0.001	0.001	0.002	0.004

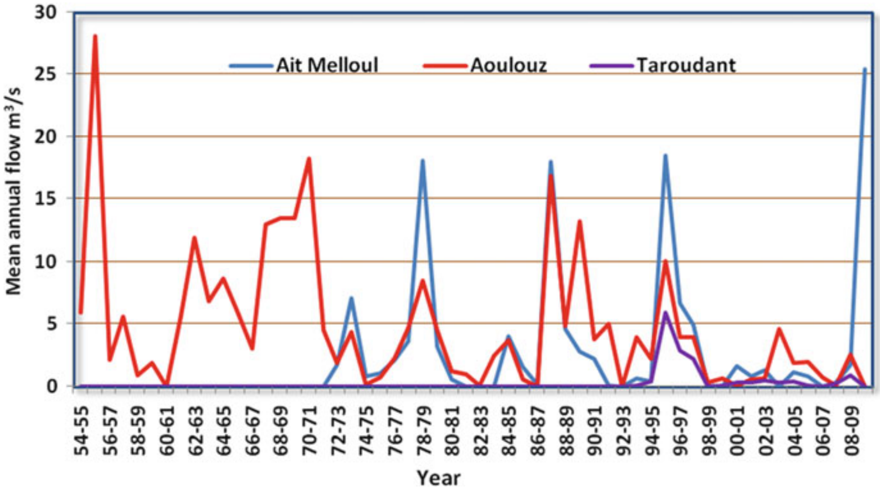

Fig. 10 Interannual average flows of Oued Souss in the three main stations from 1954 to 2010

Table 3 Interannual variation of average flows in the Massa Basin [46]

Station	Massa River	Massa remaining	Total (m^3/s)
Average annual flow (m^3/s)	3.91	0.25	4.16
Max	18.26	1.8	20.06
Min	0.83	0.00	0.83

between the two stations. We must therefore admit that a quantity of water at least equal to the difference of rates observed in Taroudant and in Aoulouz evaporated, diverted from the main channel to the irrigation channels by local residents to irrigate cultivated area and seeps into the groundwater. The volume of water, disappeared either to the atmosphere or to groundwater, can be of the order of 90 hm^3 per year, a continuous flow of 3 m^3/s (Table 2).

We also noticed the huge quantities of water lost in the ocean, highlighted by the flows observed in Aït Melloul. These volumes are estimated to average 240 hm^3 per year; these are very significant amounts that could be recovered, at least partially, if they were retained behind dams located on tributaries of the High Atlas and the upstream basin.

The Massa River has its headwaters only in the Anti-Atlas and flows to the northwest collecting waters from tributaries such as the Oued Assaka.

In the Massa Basin, the annual average flow is 4.16 m^3/s with a maximum of 20.06 m^3/s and a minimum of 0.83 m^3/s (Table 3).

4.1.3 Dams

The Souss and Massa Rivers are under the influence of the system of reservoirs of Mokhtar Soussi, Aoulouz, Imi El Kheng, Abdelmoumen, Dkhila, Ahl Souss, and Youssef Ben Tachfine with the total capacity of 639.99 mm^3 (Fig. 11). 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 and Massa: the drinking water concession and that of the channels for the irrigation of the Aoulouz area, Sebt El Guerdane area, and Massa plain. The characteristics of the reservoirs of Souss-Massa Basin are shown in Table 4.

The dam of Aoulouz is located in the Souss Valley, between the reservoir of Mokhtar Soussi and city of Aoulouz. The dam was commissioned in 1991. Its storage capacity is 89 mm^3; its main use is artificial recharge groundwater and irrigation. The reservoir of Aoulouz receives contributions of water from the reservoir of Mokhtar Soussi (overflow) and from the valleys Ouzioua, N'ait Oughelli, and Imirguene.

Youssef Ben Tachfine is a big dam with 298.2 mm^3 of storage capacity and is located in the Massa Valley. The dam is a nonrigid dam. It was finished in 1972. The main tributary of the reservoir is the Assif n'Assaka, Oued Boutergui, Assif n'Boukoura, and Oued Massa.

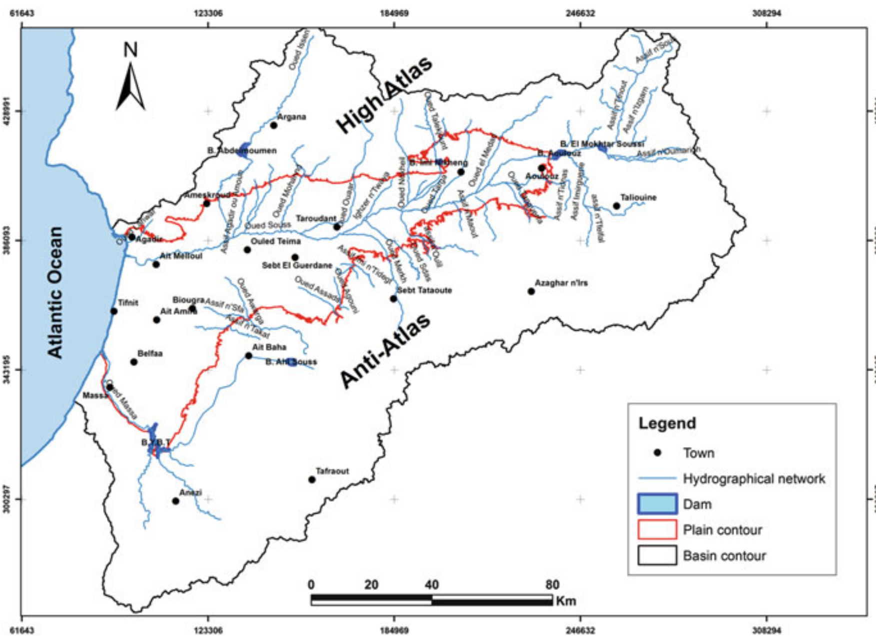

Fig. 11 Main tributaries of Souss-Massa River and location of dams in Souss-Massa Basin

Table 4 Capacity of the man dam of the Souss-Massa Basin (*Source*: ABHSMD 2015)

Dams	Valleys	Type of dam	Use	In commission	Storage capacity (mm^3)	Current volume (mm^3)	Filling rate (%)
Youssef Ben Tachfine	Massa	Nonrigid dam	Irrigation and drinking water	1972	298.2	73.673	24.70
Abdelmoumen	Issen	Rigid dam	Irrigation and drinking water	1981	198.4	54.997	27.70
Aoulouz	Souss upstream	Rigid dam	Irrigation and recharge	1991	89	62.838	70.60
Imi El Kheng	Talkjount	Rigid dam	Irrigation and recharge	1993	9.75	6.318	64.80
Mokhtar Soussi	Ouzioua	Rigid dam	Irrigation and drinking water	2002	39.75	28.003	70.40
Ahl Souss	Ait Baha	Rigid dam	Irrigation and drinking water	2004	4.6	3.443	74.80
Dkhila	Issen	Rigid dam	Regulation	1986	0.2	0.221	110.50
Total	–	–	–		639.99	229.493	35.85

The reservoir of Abdelmoumen is the second big dam, after Youssef Ben Tachfine, in the Souss-Massa Basin and is located 45 km northeast of Agadir in the Issen Valley; its storage capacity is around 198.4 mm^3. The main tributary of the reservoir is the Oued Issen.

Mean discharge at the Souss River is 400 m^3/s, with the tributaries from the right margin showing a higher discharge than those from the left margin.

4.2 Groundwater Availability

Groundwater availability in the Souss-Massa is heavily influenced, with dry season contributions. In general, 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) for both urban and rural settlements.

In order to understand the hydrological functioning of the aquifer system, several studies have been carried out during the last years [5, 6, 8–11, 21, 27, 39, 47–55] using different approaches and tools. The more pertinent information from these was used here in summarizing the groundwater resources of the area. According to these authors, groundwater resources in the Souss River Basin area are developed from two aquifer systems:

4.2.1 Deep Aquifers

Two types of deep groundwater have been recognized in the Souss-Massa Valley. They correspond to the Cenomanian–Turonian limestones and conglomerates of the continental Neogene. Both have provided conditions for drilling artesian at Oulad Teima, Ain Chaib, El Klea, El Gouna, and recently Ait Igas with low flow on the ground (13 l/s). In some places, Cenomanian–Turonian aquifer communicates closely with a shallow aquifer. Their deep aquifers have a similar facies; they are Ca-Mg-HCO_3.

The recharge area for the deep confined aquifer is in the northern part of the region, meaning come from lateral water flow from the water tables of border of High Atlas Mountains (outcrop areas). Some recharge also occurs from infiltration from the rivers in the foothills where deep and superficial layers are combined and vertical leakage [5, 7].

The deep limestone aquifer of the Cenomanian–Turonian is encountered at an average depth of about 250 m below ground surface (Fig. 12). It has an average thickness of 50 m and is composed chiefly of limestone flint and dolomite (karstified upstream). The Cenomanian–Turonian bed represents an available confined aquifer that can be important in water resource management in the Souss area.

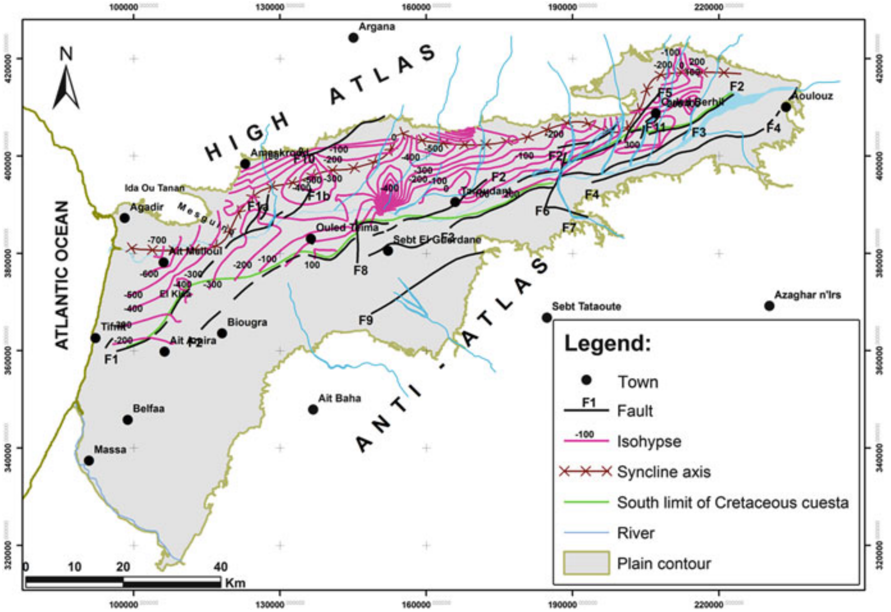

Fig. 12 Roof isohypse map of Turonian aquifer established after electric sounding and deep borehole data

4.2.2 Shallow Aquifer

Despite the interest shown by the deep aquifers, the shallow aquifer is considered the most important hydrogeological unit in the Souss-Massa Valley because, firstly, it is the easiest to use both extensively as intensively and, secondly, it contains most of the groundwater resources in the basin.

This groundwater flows through sedimentary rocks that accumulated during the Neogene and Quaternary orogenic phases. These sediments are recognized by drilling and sounding consisting of sandy marl and sandstone in the Gulf of Agadir; conglomerates, calcareous marl, limestone, sandstone, silt, and alluvium across the plain; and conglomeratic formations mainly from alluvial fans on the mountainous borders. Continental Neogene formed by powerful conglomerate deposits at the foot of the High Atlas mountains. Further to the south, it is fluviolacustrine formations mainly calcareous clay, clay, and sandstone interbedded with conglomerates. This is the famous formation of Souss [23] assigned to the Pliocene–Quaternary. Other older formations that are permeable, such as Cenomanian–Turonian limestone, are identified in the valley and are the islets of Haffaia, Ouled Bou Rbia, Aaricha, Sidi Borja, and Tagtrannt. The lithology of shallow aquifer is very complex in detail (Fig. 13).

However, it seems possible to distinguish four aquifers communicating with each other:

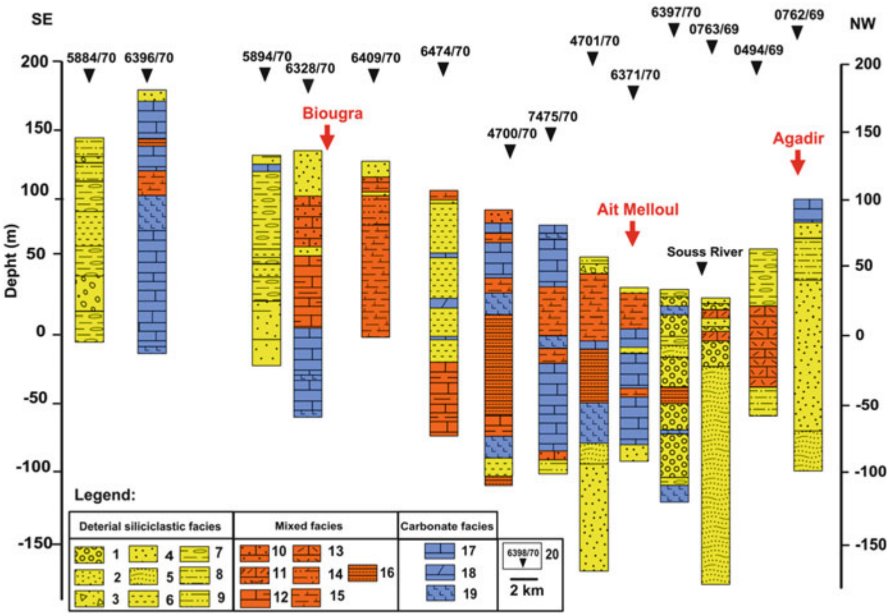

Fig. 13 Geological cross section established after hydrogeologic borehole data in the Souss downstream, showing the very complex lithology. (*1*) pebbles; (*2*) sand; (*3*), alluvium; (*4*) sandstone; (*5*) marls with pebbles; (*6*) clay; (*7*), clay and pebbles; (*8*) sandy clay; (*9*) clayey sand; (*10*) sandy limestone; (*11*) shelly limestone; (*12*) clayey limestone; (*13*) calcareous marls; (*14*) sandy marl; (*15*) alternance marl and calcareous marls; (*16*) clay and marl; (*17*) limestone, (*18*) dolomite, (*19*) marl, (*20*) borehole code

- **Souss formation:** the most widespread in the plain. Its lithology is very complex; we can distinguish, nevertheless, three predominant facies [7] (lacustrine, clayey limestone, and mainly calcareous marls) overlying a fluviolacustrine facies (sandy–sandstony and clayey) in its lower part. The third facies is formed by more or less solidified conglomerates which constitute the near total of the formation, at the foothills of the High Atlas and toward the eastern part of the plain. They appear as interbeddings reaching sometimes 10–15 m in calcareous marl and clayey sandstone series.

  The Souss formation is widely in the plain, with different characteristics; the center transmissivity *T* is good (in the order of $1.5 \cdot 0^{-2}$ m^2/s) and a coefficient of $3 \cdot 10^{-2}$ emmagasinement S whereas border, formation is poor aquifer except alluvial fans (*T* varies between $7 \cdot 10^{-3}$ and $8 \cdot 10^{-4}$ m^2/s). The thickness varies from 200 to 400 m zones [6, 7].
- **Fossil beds of the Souss Valley**: formed by sands, sandstones, and gravels from old alluvium dating from the Quaternary. The average transmissivity is in the range of $50 \cdot 10^{-2}$ m^2/s with a storage coefficient ranging between $5 \cdot 10^{-2}$ and $1 \cdot 10^{-1}$. The thickness of this formation is between 20 and 40 m and can reach more than 50 m upstream.

- **Sandstones and limestones:** it is about conglomerates and sandstony and shaly limestones from the Pliocene Agadir marine and sandstone and dunes in the south of Agadir. These sediments are often intercalated clay and a transmissivity of between $2 \cdot 10^{-3}$ and $20 \cdot 10^{-3}$ m^2/s.
- **Cretaceous outcrops in the plain**: in the middle of the plain, in the Southern flank, hills of the Cretaceous syncline, the Turonian outcrops or under a thin cover, communicates laterally with the Plio-Quaternary aquifer. This formation, karstified on the surface, is very transmissive, with T ranging between $5 \cdot 10^{-2}$ and $20 \cdot 10^{-2}$ m^2/s; deep karst is not developed and T is $2.5 \cdot 10^{-4}$ m^2/s. The power of this series range from 10 to 30 m thick.

4.3 Water Use

4.3.1 Water Resource Demands

During the 4 last decades (1970–2010), Souss region has had a significant socio-economic development. Therefore, the constant economy's growth and social development has produced increasing demands of both, surface and groundwater resources.

The volume of water used in the Souss-Massa amounts to about 1,100 million m^3, 68% of this volume is pumping from groundwater. Irrigated agriculture uses more than 95% water resources mobilized in the basin.

The volume of water allocated to the drinking and industrial water is around 50 million m^3 mainly provided from groundwater (about 76%). The major urban centers are supplied with as follows:

- The greater Agadir is supplied from surface water (Abdelmoumen–Dkhila and Moulay Abdellah dams) and groundwater (Souss–Chtouka water table).
- The water supply for the Biougra city is assured from Chtouka shallow aquifer.
- Taroudant province is supplied from Souss shallow aquifer.

The volume of water allocated to agriculture amounts to almost 1,050 million m^3 for irrigation of over 134,000 ha, of which 68% comes from ground water.

- Drinking and industrial water:
  The evolution of drinking and industrial water requirement is based on the evolution of the population that would reach close of 2,637,000 inhabitants in 2020. According to the Hydraulic Agency of Souss-Massa-Draa Basin (ABHSMD) the drinking and industrial water is growth from 52 mm^3 in 2005 to 70 mm^3 in 2020 (Table 4).
- Irrigation water:
  The hydro-agricultural development experienced since the area 1970 was also reflected in a significant increase in water demand irrigation currently valued at nearly 1,100 million $m^{3.}$ The irrigated area should evolve from 149,000 ha in

Table 5 Water requirement in the Souss-Massa region [46]

Use	Water requirement (mm^3)	
	2005	2020
Irrigation	1,100	1,030
Drinking and industrial water (mm^3)	52	70
Total	1,152	1,100

Table 6 History of groundwater exploitation for irrigation, drinking and industrial water in Souss-Massa [46]

Groundwater exploitation	1976	1979	1985	1996	1998	2003	2007
Irrigation (mm^3)	374.1	361.3	390.5	497.2	604.5	595	599
Drinking and industrial water (mm^3)	9.1	11	18.1	30.73	43.13	35.8	33.2
Total	383.2	372.3	408.6	527.93	647.63	630.8	6,322

2003 to nearly 150,000 ha in 2020. The water requirements are estimated at nearly 1,030 million m^3 (Table 5).

4.3.2 Wells and Groundwater Abstraction

As a consequence of decrease in precipitation and demographic pressures, groundwater pumping has been accelerated and the exploitation of the aquifers has intensified (Table 6).

A number of problems associated with increasing water scarcity and recurrent and extended droughts have been noticed in the Souss area particularly in the past few decades [21, 48, 54]. Manifestations of water scarcity include, among others, an alarming decline of both surface and groundwater resources, which resulted in the introduction of strict water control by the hydraulic agency (Fig. 14).

A large number of active boreholes (more than 25,000) have been drilled in the Souss area with depths varying from a few meters to 300 m (Fig. 15). Most of them penetrate the Plio-Quaternary sands and gravels of the Souss-Massa aquifer. Although some of the wells are used for industrial or drinking water, most of water up to 94%, is used for irrigation. Local authorities estimate the total water abstraction in 650 million cubic meters per year [46]. On average groundwater abstraction exceeds recharge by an estimated 260 million cubic meters annually [46]. This overpumping has led to a decrease in the water levels in a range of 0.5–2.5 m/year (Fig. 14) in the past 4 decades.

There are concerns that the recurrent droughts will further deplete the available water resources.

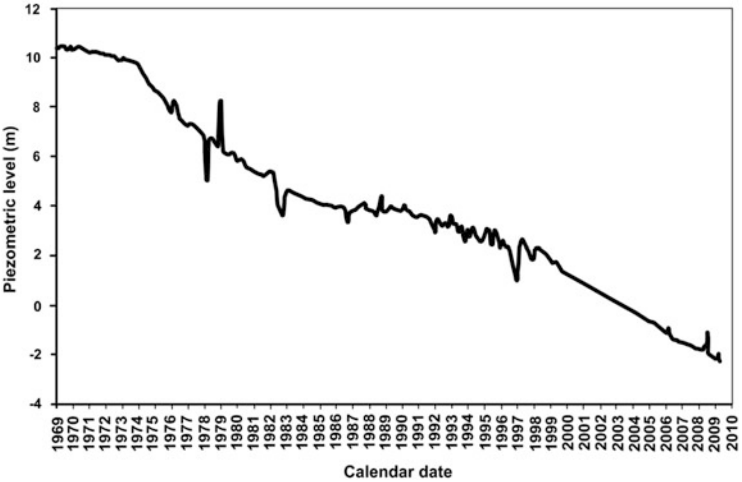

Fig. 14 Decrease in water table during the last 4 decades in [21]

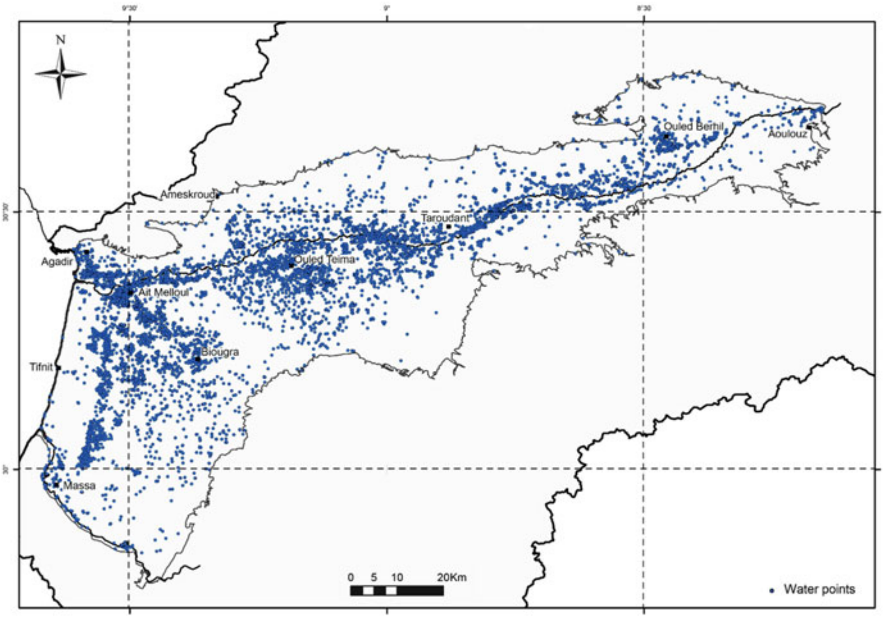

Fig. 15 Wells and boreholes pumping water in Souss-Massa plain aquifer [56]

4.4 *Water Balance and Water Level of Souss-Massa Aquifer*

4.4.1 Water Balance

The major trend indicates an overall decrease in water resources, due to the combination of the natural decreased recharge and human activities (pumping). The demand for water in the Souss-Massa Basin exceeds the sustainable supply and the deficit is made up by mining groundwater. A groundwater balance from 1972 to 2007 is presented in Tables 7 and 8.

4.4.2 Groundwater Level

The reduction in piezometric level of water table of Souss and Chtouka aquifer due to overpumping and drought exhibited by a decreasing of water deficit varies from 100 to 370 mm^3/year for Souss aquifer and 60 mm^3 for Chtouka aquifer [46].

The piezometric level analysis in the Souss-Massa aquifer between 1996 and 2010 (Fig. 16) shows a reduction in water table level of about 15 m in the Souss upstream, more than 30 m in the middle Souss, between 12 to 20 m in the Souss

Table 7 Water balance of the shallow aquifer of Souss (million cubic meters) [46]

Shallow aquifer	1976	1979	1985	1994	1996	1998	2003	2007
Recharge								
Infiltration from rain and surface runoff	66.2	62.8	57.8	31.3	105	29.7	39.6	31
Valley bank infiltration	88.7	208.5	50.2	17.3	490	31	199	160
Irrigation water return	14.3	13.7	8	10.2	80	17.4	15.8	4.5
Artificial recharge	–	–	–					9
Upward flow from deep groundwater	3	3	3	3	3	3	3	3
Contribution from exposed aquifers	48	48.8	43.7	46.2	192	174.9	65	60
Total recharge	220	337	163	108	870	256	323	268
Discharge								
Groundwater flow	22	19.9	15	19	142	16.4	4	4
Upward by Souss River	8.2	60.5	0	0	0	0	0	0
Pumping for irrigation by traditional farmers	116	73.7	11.1	65.4	33.8	67.6	519	521
Pumping for irrigation for public and private sectors	250	278.1	365.4	375	431	488		
Pumping for drinking and industrial water	8.1	9.8	16.6	18.6	30	41.9	28.7	26
Total discharge	405	442	408	478	637	614	551	555
Balance	−185	−105	−246	−370	233	−358	−228	−283

Table 8 Water balance of the shallow aquifer of Massa-Chtouka (million cubic meters) [46]

Shallow aquifer	1972	1996	1998	2003	2007
Recharge					
Infiltration from rain and surface runoff	8.2	45.0	13.5	7.7	3.5
Valley bank infiltration	0.3	2.0	2.2	3.0	2
Irrigation water return	6.1	6.0	12.7	6.8	15.7
Upward flow from deep groundwater	10.9	15.0	15.0	15.0	10.0
Contribution from exposed aquifers	–	–	–	2.6	17
Total recharge	26	68	43	35	33
Discharge					
Groundwater flow	14.3	16.0	12.5	5.7	3
Upward by Massa River	5.5	70		3.7	2.2
Pumping for irrigation	9.7	32.4	47.9	76.1	78
Pumping for drinking and industrial water	1.0	0.7	1.2	7.1	7.2
Total discharge	31	56	62	93	90.5
Balance	−5	12	−18	−58	−58

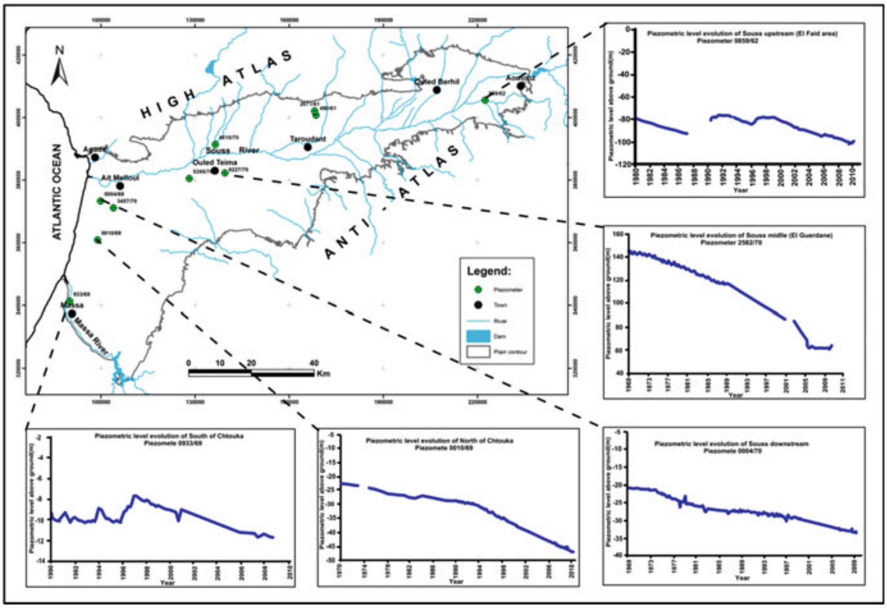

Fig. 16 Piezometric-level evolution of water table of Souss and Chtouka aquifer between 1996 and 2010

downstream, while in the Chtouka-Massa area, the piezometric level was reduced between 10 and 15 m.

We can see that the decline of the water table has a general trend in Souss-Massa Basin which is variable in time and space due to several factors as the quantity of

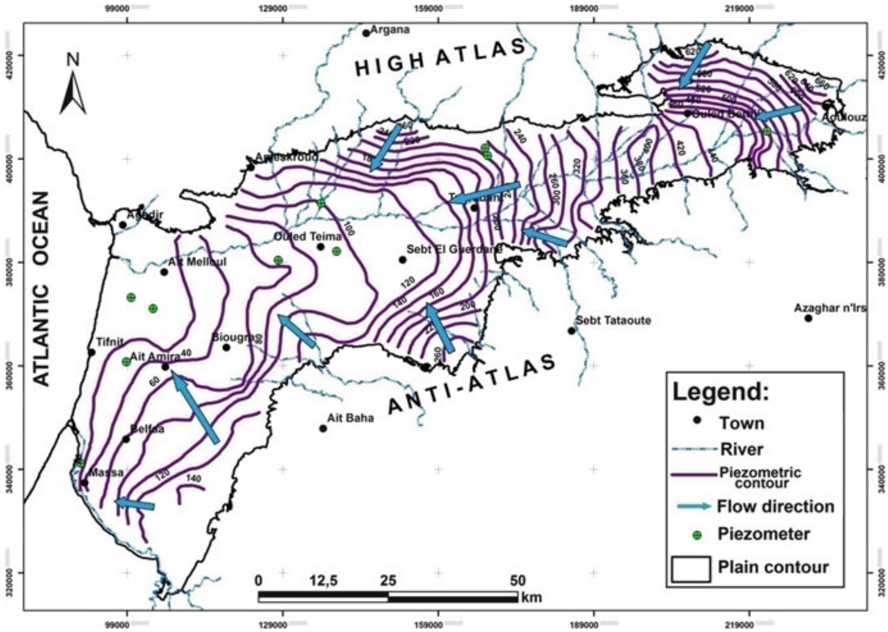

Fig. 17 Piezometric surface contour map of the Souss-Massa shallow aquifer [2]

recharge and inflow to the groundwater system, the amount of groundwater pumping, and the distribution and intensity of the operated wells.

In 2003 the Hydraulic Agency of Souss-Massa produced a piezometric map of Souss-Massa unconfined aquifer (Fig. 17). The shallow piezometric contours show a general eastern–western groundwater flow. The recharge is mainly coming from the Atlas Mountains.

4.5 Artificial Recharge

In some parts of Souss-Massa, due to over-exploitation of groundwater, decline in groundwater levels resulting in shortage of supply of water, and intrusion of saline water in coastal area have been observed. In such areas (e.g., Sebt El Guerdane and Oulad Teima), there is need for artificial recharge to improve the groundwater situation.

For the first time the artificial recharge of the groundwater was made by ABHSMD at 1991 until now, from the Aoulouz and Imi El Kheng dams, with an average released volume of 64 mm^3/year [56]. The artificial recharge scheme in Souss area makes use of the direct recharge technique which typically employs retention dykes (3–4 m of high of the wall), in the bed of Souss and Talkjount River, to enhance the natural percolation of water into the subsurface [56].

The use of artificial recharge from Aoulouz and Imi El Kheng dams in the upstream part of the basin is due to geological conditions, high permeability and good water quality in this part of the watershed. The aim is to strengthen a share of the natural recharge, and thus to cope with continuing declines in water level and the risk of sea intrusion, and secondly to give effect to the dilution, waters being more mineralized in the medium and in the downstream parts of the watershed. Generally the artificial recharge is low compared to the reservoir volume and can reach 30–40 m^3/m^2 for an average released flow of 70 m^3/s from dam, due to which the renewal rate is also low [3, 49].

5 Conclusion

This chapter has summarized the main synthesis results of physical geography, geology, and water resource availability of Souss-Massa River Basin.

From the geomorphology and geology point of view the Souss-Massa Basin is a southern foreland of the western High Atlas. The Souss-Massa plain occupies a depression between two major structural domains: the Anti-Atlas in the south and the High Atlas in the north. That depression is filled with Mesozoic to Quaternary sedimentary deposits overlying the Paleozoic basement.

Water resources for the area consist of surface water, dams and groundwater resources. The renewable surface resources are estimated at 131 and 418 million cubic meters in the Massa and Souss Basin, respectively. Seven reservoirs are installed in the basin with the total capacity of 639.99 million cubic meters, these reservoirs produces a number of economic and social benefits in the region. About 645 million cubic meters per year of groundwater (renewable and non-renewable aquifers) are currently used in the region. Most of the groundwater resources in the region are fully exploited (decrease in the water levels in a range of 0.5–2.5 m/year in the past 4 decades), and some aquifers are overexploited, particularly in Sebt El Guerdane area.

Therefore, the information provided in this synthesis would be useful for the subsequent elaboration of strategies for current and future water management in the region.

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Flood Hazard Mapping and Modeling Using GIS Applied to the Souss River Watershed

Z.E.A. El Morjani, M. Seif Ennasr, A. Elmouden, S. Idbraim, B. Bouaakaz, and A. Saad

Abstract This study describes a simple and cost-effective methodology and process to accurately delineate the flood hazard areas in the Souss River basin from the available database using a geographic information system (GIS).

The approach proposed to spatially distribute flood hazard combines the extent of past flood events with the spatial distribution of causal factors. This combination enables the calculation of a weighted score for each individual causal factor. The spatial distribution of the weighted scores are then aggregated to derive the distribution of the flood hazard index (FHI) before being reclassified to obtain the spatial distribution of the intensity level of flood hazard.

The high-resolution 30 m map resulting from this methodology has been assessed by Souss Massa Draa Hydraulic Basin Agency (ABHSMD) flooding sites information. The cross-validation indicates that the accuracy of the flood hazard distribution map is 85%.

In this context, this map provides actionable information to the decision-making process on development planning, emergency preparedness, and mitigation measures by helping to identify and prioritize areas with high probability of hazard occurrence or intensity in order to avoid any dramatic disaster.

In addition, this work should also be seen as a first step aiming at improving information management in the study area. An important amount of data and information have been compiled, homogenized, updated, and generated.

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Finally, this process could be transferred and implemented in other basins or regions of Morocco by using their own accurate and reliable information.

Keywords Disaster, Flood hazard, Geostatistics, GIS, Gumbel frequency analysis, Inundation, Mapping, Modeling, Morocco, Souss River, Stepwise regression

Contents

1 Introduction

In the last two decades, a number of significant natural disasters in Morocco and in the rest of the world resulted in many lives lost, livelihoods destroyed, and disability among the affected populations. In Morocco, floods, one of the most devastating natural hazards, caused more than 1,165 deaths, more than 232,896 affected population, and more than US$ 295 million in damage from 1995 to 2005 [1].

Douben [2] defined a flood as a temporary condition of surface water (river, lake, sea) in which the water level and/or discharge exceeds a certain value thereby escaping from its normal confines. The Souss River is not immune to this natural disaster. Indeed, its area is characterized by a very rugged terrain, steep slopes, high relief, variable climates, and a relatively degraded vegetation cover, which are favorable factors to the genesis of floods [3].

Although small floods are beneficial to the functioning of river Souss, short-term extreme floods could jeopardize agricultural lands, existing infrastructure (housing, roads, tracks, etc.), and sometimes people's lives in addition to the isolation of some villages. Many floods occurred between 1960 and 2014 at Taroudant (2005), Aït I'azza (1978), Sidi Moussa El Hamri (1992, 1995, 1996, and 1997), Machraa El Ain (1996), Agadir-Ida Ou Tanane (2007), and Aït Melloul (1987, 2010, and 2014); they should serve as a reminder that floods are a serious risk to those living and working in the area. Thereby, the Souss River basin is now calling for better disaster preparedness and mitigation programs to avert the adverse effects of floods.

In addition, the ability to determine flood risk for the Souss River basin and its resident populations will strengthen its flood management capacity by providing the information necessary to decision makers to: advocate for resources to improve emergency preparedness; support emergency response; and help to identify, plan, and prioritize areas for mitigation activities to minimize the effects of flood hazard.

Three components are needed to determine flood risk: flood hazard, vulnerability, and capacity.

In this context, the United Nations International Strategy for Disaster Reduction (UNISDR) [4] defines a hazard as "a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation," each hazard being characterized by its location, intensity, frequency, and probability.

It then defines vulnerability as "the conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards."

Whereas capacity is "the combination of all the strengths, attributes and resources available within a community, society or organization that can be used to achieve agreed goals. *It may* include infrastructure and physical means, institutions, societal coping abilities, and human knowledge, skills, and collective attributes such as social relationships, leadership, and management."

And finally, it defines risk as being "the probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions."

Based on mathematical calculations, risk as presented in the below formula is a function of the hazards to which a community is exposed and the vulnerability of that community, both from a population and infrastructures/services perspective, modified by its capacity to resist that hazard (notion also referred to as resilience).

$$\text{Risk}\ \alpha \frac{\text{Hazard} \times \text{Vulnerability}}{\text{Capacity}}$$

For this study, with the objective of reducing flood risk in the Souss River basin, we have concentrated especially on studying the first component flood hazard. The vulnerability, capacity, and indirect flood risk will be treated in the future research.

In this context, this work attempts to produce a flood hazard map of high resolution of the Souss River basin, 30 m, using a geographic information system (GIS) to improve disaster preparedness; aid emergency response measures; and assist in identifying, planning, and prioritizing areas for mitigation activities. The GIS provided, in this research, an ideal platform for the integration of the different spatial and temporal thematic data and information coming from disparate sources, their analysis, and, ultimately, the development of a flood hazard model.

The methodology proposed to spatially distribute flood hazard is based on two key documents that we have developed in the context of the second version of the WHO e-atlas of disaster risks [5, 6]. This approach combines the extent of past flood events with the spatial distribution of causal factors. This combination enables the calculation of a weighted score for each individual causal factor. The spatial distribution of the weighted scores are then aggregated to derive the distribution of the flood hazard index (FHI) before being reclassified to obtain the spatial distribution of the intensity level of a flood hazard.

The method and process presented in this study could be applied to other geographic areas provided that the analyses use geospatial data of similar or better quality and resolution.

2 Required Software and Hardware

The implementation of the methods and processes described in this study requires the following software under Windows NT 4 (Service Pack 5 or 6a), Windows 2000 (Service Pack 3 or 4), Windows XP (all versions), and all newer Windows versions:

- ArcGIS 10.0 and corresponding Spatial Analyst extension (Esri) for all the GIS data preparation work as well as the application of a flood hazard model
- The flood hazard toolbox developed to apply the flood hazard modeling protocol [6]
    - Matlab 6.0 (or higher) developed by MathWorks and Matlab to run the EatlasClimMod 1.0 application
    - The EatlasClimMod 1.0 application developed under Matlab 6.0 to calculate and estimate different climatic variables for a selected return period. The codes of this application and the instruction file are all available in a zip file named EatlasClimMod.zip located in the tools section of the WHO e-atlas of disaster risk [7]
        - S-Plus 6.0, developed by Insightful Corporation, to explore and identify statistically significant parameters and their relative contribution to the spatialization of the precipitations using a stepwise multiple regression

The minimum and recommended hardware requirements for running all the above software are as follows:

- Processor: Intel Pentium 3 and above
- 256 MB of RAM (512 MB or more is recommended)
- 600 MB of free hard drive space (1 GB is recommended)
- A color graphics card and monitor (SVGA is recommended)

3 Methodology

Over the past 30 years, a large amount of research has been conducted in order to identify techniques for the generation of flood hazard maps. These techniques, presented in this section, include hydrological frequency analysis, hydraulic modeling, hydrological modeling, and statistical methods.

1. Hydrologic frequency analysis uses historical flood data to calculate the probability and extent of future flood events for different intervals (10, 50, 100, and 500 years) [8–13].

This procedure requires adequate historical meteorological and stream flow data to allow statistical analysis to an accepted confidence level. Additionally, changes in stream and flood flows, caused by reservoir regulation, channel improvements (levees), or land use changes, limit the usefulness of historical data because the physical parameters that existed when the floods occurred no longer exist. Due to these two disadvantages, flood frequency analysis is not used in this protocol.

2. Hydraulic models convert discharge flow values into stream or flood depths. The Hydrologic Engineering Center's river analysis system (HEC-RAS) model developed by the Hydrologic Engineering Center (HEC) of the US Army Corps of Engineers (USACE) calculates and estimates the duration and extent of inundation, changes in water depth, and velocity through time at any location based on measurements of unsteady flows through a river network [14, 15].

The following data are needed to calculate viable inundation estimates using the HEC-RAS model: a high-resolution digital elevation model (DEM), a stream network model, detailed cross-sectional geometries of channels and adjacent flood plains, and flow length parameters. Although this model yields accurate and actionable results for small catchment areas, it is very difficult to apply this model to a large geographic area such as the Souss River watershed because of the robust input data requirements.

3. Hydrological models use mathematical calculations with known or assumed values for various components of the hydrologic cycle to analyze the behavior of stream flows and floods in a specific watershed. Hydrological models can be divided into deterministic models that are based on specific physical parameters and processes and stochastic models that allow for probabilistic variability in both parameters and processes [16–23].

These models require careful and accurate calibration to yield accurate estimates of flood-prone areas. Calibration of a hydrological model for this basin would be enormously time consuming and therefore hydrologic modeling was not used for this study.

4. Statistical methods combine historical flood frequency and distribution of flood causal factors in order to predict areas with a probability of floods across a geographic area. This method allows for the calculation of a flood hazard index (FHI) based on the weighted scores of the causal factors and the historical flood distributions [6, 24–26].

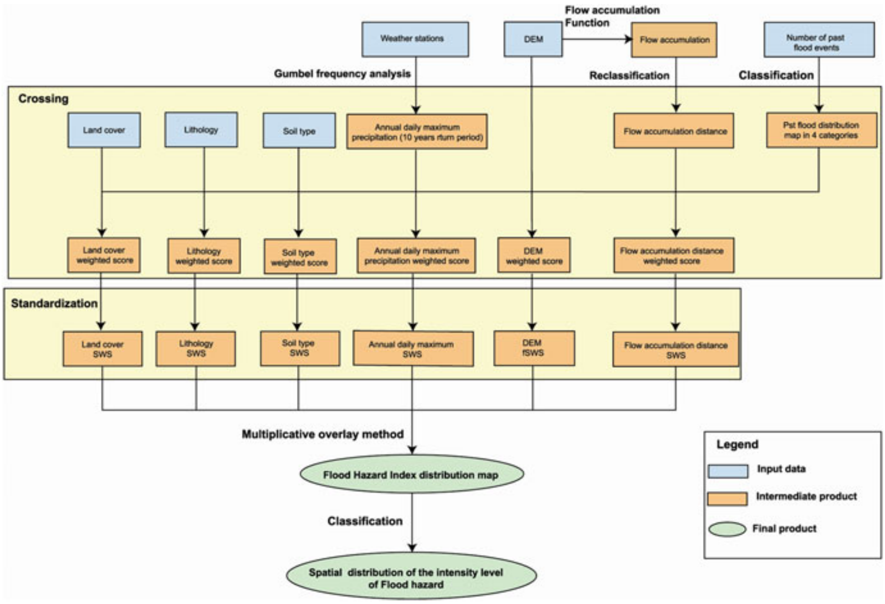


Fig. 1 Methodology for generating the spatial distribution of the intensity levels of flood hazard

The first three methods described here require resources and data far beyond the frame of the present study; therefore, it has been decided to use a statistical method for spatializing the distribution of the intensity level of flood hazard over the Souss River basin.

Among the statistical methods already developed, the one used by Islam and Sado [25, 26] in Bangladesh and the WHO e-atlas of disaster risk covering 100 countries [5, 6] have several advantages. First the method yields realistic estimates without using an empirical model; second the model requires historical flood distributions and causal factor data, which are readily available for the Souss River basin. The third advantage is that the method can be readily applied with the GIS technologies to generate the spatial distribution of the flood hazard. The final advantage is it considers both the susceptibility of each area to inundation and the factors related to flood emergency management.

The implementation of this method goes through the application of the following steps (Fig. 1):

1. Identification of the causal factors
2. Creation and classification of the past flood frequency distribution map
3. Estimation of the weighted score for each causal factor by crossing them with the reclassified flood frequency layer
4. Standardization of the weighted scores
5. Classification of the resulting map to obtain the spatial distribution of the intensity level of flood hazard

3.1 Identification of the Causal Factors

The methodology described in this study uses a composite flood hazard index based on six causal factors (elevation, land cover, soil type, lithology, flow accumulation volume, and precipitation). These factors, which are listed here, have been selected based on a review of different case studies reported in the literature and their relevance to the Souss River basin.

Before the description of the causal factors, it was decided at first to mention the following dataset specifications in order to ensure compatibility among the different sources of GIS data.

Projections:

- For data collection and representation, including maps in this study (unprojected):
  - Geographic coordinate system: WGS 1984
  - Angular unit: degree (0,0174532925199433299)
  - Prime meridian: Greenwich (0,000000000000000000)
  - Datum: D_WGS_1984
    - Spheroid: WGS 1984
    - Semimajor axis: 6378137,000000000000000000
    - Semiminor axis: 6356752,314245179300000000
    - Inverse flattening: 298,257223563000030000
- For analysis when a metric system was required:
  - Projection: Lambert conformal conic
  - False_easting: 500000
  - False_northing: 300000
  - Central_meridian: -5,4
  - Standard_parallel_1: 28,1063
  - Standard_parallel_2: 31,2933
  - Scale_factor: 1,00
  - Latitude_of_origin: 29,7
  - Linear unit: meter (1,00)
  - Geographic coordinate system: GCS_Merchich_Degree
  - Angular unit: degree (0,0174532925199433299)
  - Prime meridian: Greenwich (0,000000000000000000)
  - Datum: D_Merchich
    - Spheroid: Clarke_1880_IGN
    - Semimajor axis: 6378249,200000000200000000
    - Semiminor axis: 6356514,999904193900000000
    - Inverse flattening: 293,466020000000010000

Extent of the study area (decimal degrees):

The Souss River basin has been considered as the study area, derived from the digital elevation model (see Sect. 3.1.1).

- min long: −9.6321
- max long: −7.4666
- min lat: 29.6860
- max lat: 31.0903

Spatial resolution and scale of work:

- Scale of work: 1:100,000
- Spatial resolution: 30 m to respect the scale of work.

3.1.1 Digital Elevation Model (DEM), Slope, Aspect, and Watershed

The likelihood of a flood increases as the elevation of a location decreases, making it a reliable indicator for flood susceptibility [16, 19, 25–32].

The elevation parameter used in this study is derived from the Shuttle Radar Topography Mission (SRTM) global elevation data. The SRTM, flown in February 2000, is a joint project between the US National Aeronautics and Space Administration (NASA) and the Department of Defense's National Geospatial-Intelligence Agency (NGA, previously known as the National Imagery and Mapping Agency or NIMA), as well as the participation of the German and Italian space agencies, to generate a near-global digital elevation model (DEM) of the Earth using radar interferometry. There are three levels of SRTM DEM:

(1) SRTM30 with 30 arc-second spatial resolution (approx. 1,000 m on the equator),
(2) SRTM3 with 3 arc-second spatial resolution (approx. 90 m on the equator), and
(3) SRTM1 with 1 arc-second spatial resolution (approx. 30 m on the equator), released since September 24, 2014; previously the SRTM1 data at this high resolution have only been available for the USA and its territories.

This 1 arc-second resolution data has been used in the context of this study because it provides a major advance in the accessibility of high-quality elevation data. The SRTM1 is distributed by the US Geological Survey and downloaded from their website http://dds.cr.usgs.gov/srtm/version2_1 or http://earthexplorer.usgs.gov/in georeferenced tagged image file format (GeoTIFF).

Starting from this DEM, the processes described in Section 3.3.1.7 of the El Morjani, [33] publication have been used for automatically defining the Souss River watershed delineation (Fig. 2) through ArcGIS hydrology tools. This boundary has been considered as the study area.

Subsequently the downloaded unprojected DEM is extracted using the polygon delineating the study area created above to cover the Souss River watershed (Fig. 2). It is freely redistributable.

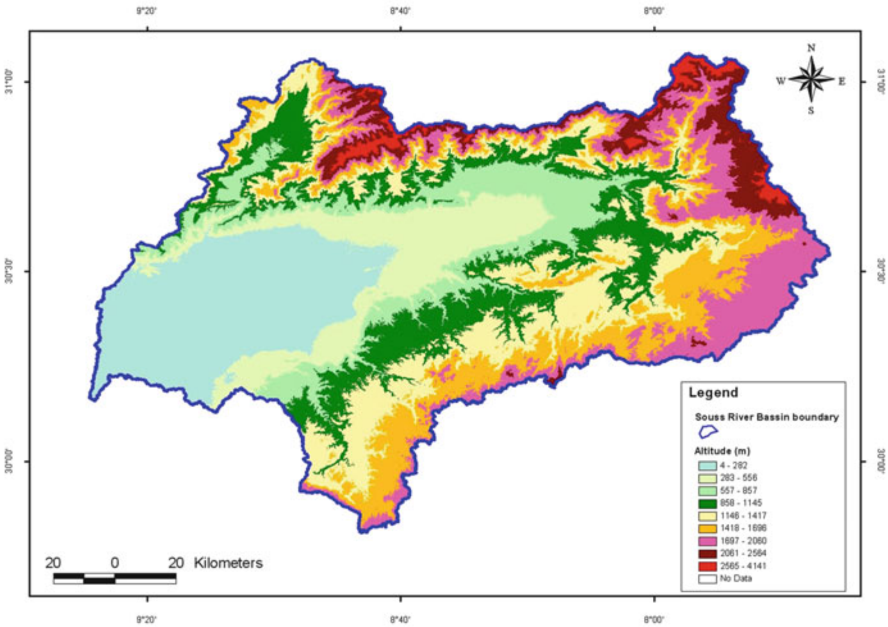


Fig. 2 Digital elevation model (DEM) of the Souss River watershed delineation

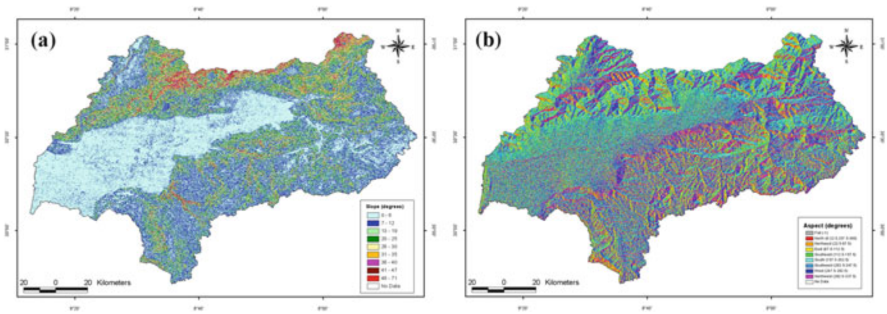


Fig. 3 Slope in degree (**a**) and aspect (**b**) derived from the DEM for the Souss River watershed

Finally, the slope and aspect distribution layers (Fig. 3) were derived from the resulting DEM for the Souss River basin, using sections 4.2 and 4.3 of the protocol for the preparation of the datasets for the second version of the WHO e-atlas of disaster risk [5]. These two layers, freely redistributable, have been employed to be used in the spatial interpolation of precipitation (see Sect. 3.1.6.4).

3.1.2 Land Cover

This factor describes the appearance of the landscape and is generally classified by the amount and type of vegetation, which is a reflection of its use, environment, cultivation, and seasonal phenology. Land cover has a direct influence on a number of parameters in the hydrologic cycle including interception, infiltration, concentration, and runoff behavior and therefore indirectly on flooding. Together these characteristics yield information about the hydrological response and the degree of flood hazard [5, 6, 13, 19, 25–27, 31].

The land cover data used in this study is called GlobeLand30 with a high spatial resolution of 30 m for the year 2010, produced by the National Geomatics Center of China [34].

The images utilized for the GlobeLand30 classification are multispectral images, including the TM5 and ETM+ of the US land resources satellite (Landsat) and the multispectral images of the Chinese environmental disaster alleviation satellite (HJ-1). Besides multispectral images, many auxiliary data are also used such as the existing land cover data (global and regional), MODIS NDVI, global geographic information, global DEM, thematic data (global mangrove forest, wetland and glacier, etc.), and also online resources (Google Earth, Bing Map, OpenStreetMap, and Map World). For more information please refer to the GlobeLand30 website at http://www.globallandcover.com/GLC30Download/index.aspx.

This dataset includes ten types of major land cover classes, namely: cultivated land, forest, grassland, shrubland, wetland, water bodies, tundra, artificial surfaces, bare land, and permanent snow and ice. Table 1 shows the illustration of each land cover type.

This raster data format set with GeoTIFF format has been downloaded from the website http://www.globallandcover.com, extracted for the Souss River basin, and projected by ArcGIS from the UTM projection to the Lambert conformal conic projection, and to a geographic coordinate system, in order to ensure compatibility projection among the different sources of GIS data.

The resulting land cover distribution layer for the Souss River basin is reported in Fig. 4.

This layer is free of charge for scientific research and the public welfare undertakings.

3.1.3 Lithology

The macroscopic nature of an area can influence its susceptibility to floods. Areas that consist of largely impermeable surface geology are more susceptible to flooding [25, 26, 35].

The lithology distribution layer for this study area was manually digitized from an assembly of several geological maps of different authors [36–42]. An attribute

Table 1 Classification of GlobeLand30

Code	Type	Content
10	Cultivated land	Lands used for agriculture, horticulture, and gardens, including paddy fields, irrigated and dry farmland, and vegetation and fruit gardens
20	Forest	Lands covered with trees, with vegetation covering over 30%, including deciduous and coniferous forests, sparse woodland covering 10–30%, etc.
30	Grassland	Lands covered by natural grass by over 10%
40	Shrubland	Lands covered with shrubs by over 30%, including deciduous and evergreen shrubs, desert steppe by over 10%, etc.
50	Wetland	Lands covered with wetland plants and water bodies, including inland marsh, lake marsh, river floodplain wetland, forest/shrub wetland, peat bogs, mangrove and salt marsh, etc.
60	Water bodies	Water bodies in the land area, including rivers, lakes, reservoirs, fish ponds, etc.
70	Tundra	Lands covered by lichen, moss, hardy perennial herbs, and shrubs in the polar regions, including shrub tundra, herbaceous tundra, wet tundra, barren tundra, etc.
80	Artificial surfaces	Lands modified by human activities, including all kinds of habitation, industrial and mining areas, transportation facilities, interior urban green zones and water bodies, etc.
90	Bare land	Lands with a vegetation cover lower than 10%, including deserts, sandy fields, Gobi, bare rocks, saline and alkaline lands, etc.
100	Permanent snow and ice	Lands covered by permanent snow, glacier, and ice cap

database associated with each formation unit provides information on the lithology and stratigraphic age and an indication of the shallow permeability [33].

The resulting layer has been converted into a grid by choosing 3 arc-second resolution (30 m) through the polygon to the Raster function of ArcGIS to correspond to the characteristics of the study area. The lithology of the Souss River basin is freely redistributable and is reported in Fig. 5.

3.1.4 Soil Type

Nyarko [19] and Todini et al. [31] report that soil type and texture play a role in determining the water holding and infiltration characteristics of an area and consequently affect flood susceptibility.

The soil type layer for the study area has been compiled from two separate sources: the Harmonized World Soil Database (HWSD) version 1.2 and the Souss Plain Soil.

The Harmonized World Soil Database (HWSD) version 1.2 at 30 arc-second resolution was produced in 2012 [43] by the International Institute for Applied

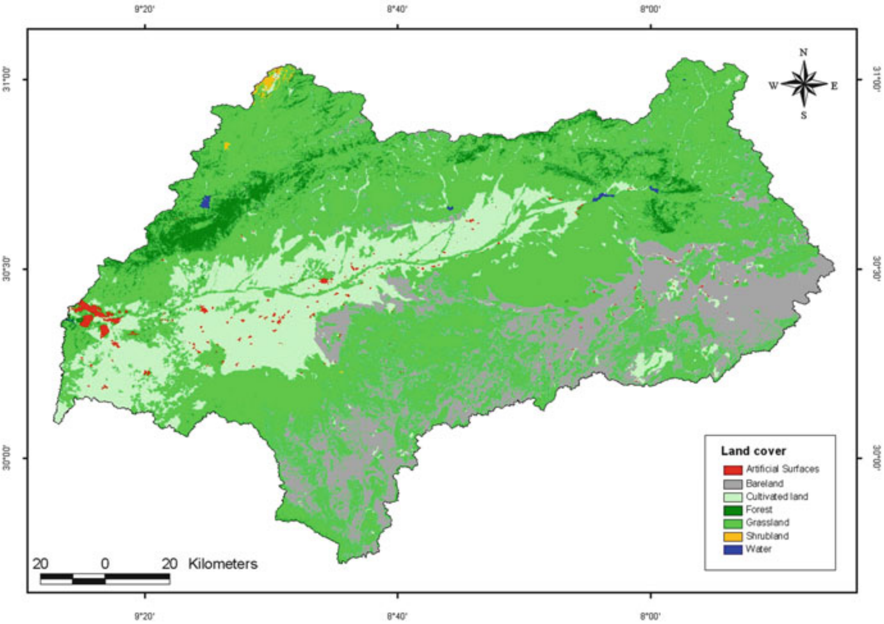


Fig. 4 Land cover distribution in the Souss River watershed

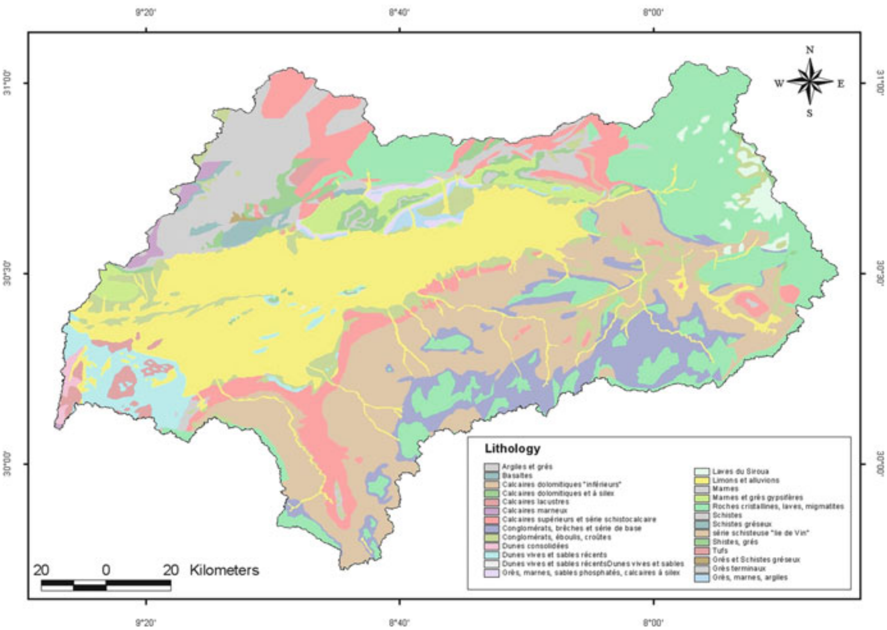


Fig. 5 Lithology distribution for the Souss River watershed

Systems Analysis (IIASA) in partnership with ISRIC–World Soil Information, the Food and Agriculture Organization of the United Nations (FAO), the European Soil Bureau Network, and the Institute of Soil Science, Chinese Academy of Sciences. The HWSD is composed of a GIS image file that can be linked to an attribute database in Microsoft Access format. These two components are separate data files that can be linked through ArcGIS.

The Souss Plain Soil (SPS) was generated by Watteeuw, in [44] at a scale of 1:200,000, within the framework of Morocco soil mapping conducted by the National Agricultural Research Institute. This map was digitized using ArcGIS and covers only the Souss valley [33].

In order to obtain the distribution of the soil type in Esri grid format, the following procedure was followed:

1. Download the **HWSD** containing a raster soil map in **.bil** file format, the file containing the soil attribute database in Microsoft Access format from the International Institute for Applied Systems Analysis (IIASA) website http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/HWSD_Data.html?sb=4 [accessed September 30, 2015], and link these two components through ArcGIS.
2. Clip the resulting grid to cover the Souss River basin.
3. Resample this map into 3 arc-second (30 m) resolution using the ArcGIS Resample function to correspond to the characteristics of the study area.
4. Digitize manually an SPS map using ArcGIS to create a vector layer covering only the Souss valley.
5. Convert the resulting vector into a grid by choosing 3 arc-second resolution (30 m) through the polygon to the Raster function.
6. Aggregate the **HWSD** and **SPS grids** into one grid by using the Mosaic function to generate a soil type layer covering the study area, reported in Fig. 6. This dataset is licensed and is not redistributed through this work.

3.1.5 Flow Accumulation Volume and Distance from the Flow Accumulation Path

Areas located close to the flow accumulation path and in particular when a large volume has accumulated upstream are more likely to get flooded [16, 19, 25–27, 31]. These two factors have been combined into one in the context of the present work.

Flow accumulation in this work is derived from the 1 arc-second (30 m) resolution Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) by using the ArcGIS flow accumulation function. This layer is calculated for each cell by determining the number of upstream cells that drain into it. Grid cells with high flow accumulation values are areas of concentrated flow and are identified as stream channels according to the specified flow accumulation threshold. Grid cells with flow accumulation values of zero are topographic highs or ridges.

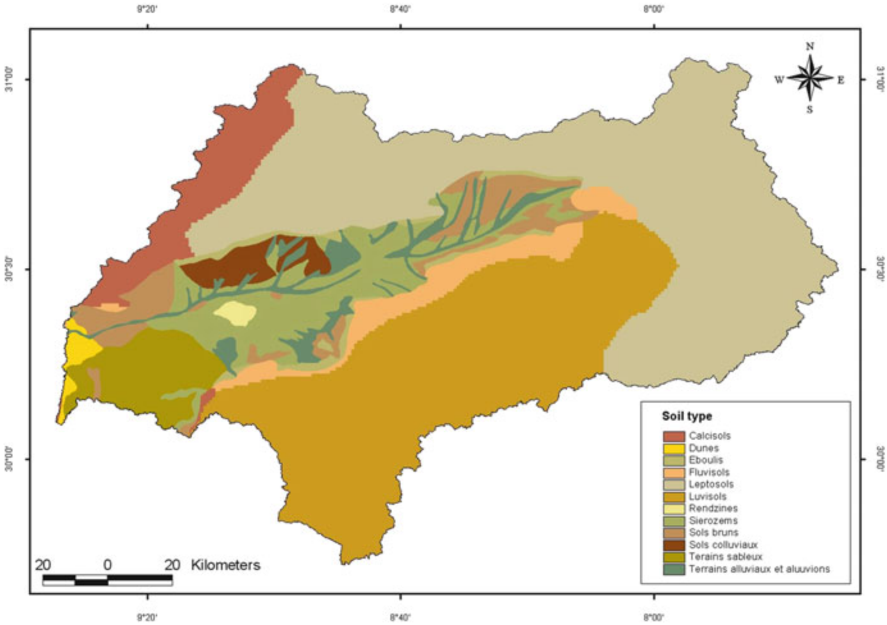


Fig. 6 Soil type distribution for the Souss River watershed

In order to estimate a stream network from a flow accumulation layer, a flow accumulation threshold must be chosen. The threshold is the minimum number of cells that must drain into a cell for it to be determined to be part of a stream network. The use of a lower flow accumulation threshold results in a more detailed (and computationally intensive) stream network.

In the literature there is no agreement on the ideal threshold value for reproducing actual stream networks. In practice the determination of the threshold is an interactive process in which several values are used until the desired resolution of the stream network is achieved. In this study, after testing numerous thresholds, a threshold value of 10,000 cells (equating to a drainage area of 9 km^2) was used.

Once the threshold is set, cells with flow accumulations greater than the threshold are designated as “stream channel” cells and will comprise the estimated stream network (Fig. 7). Ultimately, the stream network is buffered to determine the distance of a location from the nearest stream channel.

In this study, the following steps have been applied in order to calculate the distance from the flow accumulation path:

1. Derive the flow accumulation layers from SRTM1 by using the ArcGIS flow accumulation function.
2. Keep only cells presenting a flow accumulation value bigger than 10,000 cells 9 (km^2) representing a drainage area of 9 km^2 using the Reclassify function.

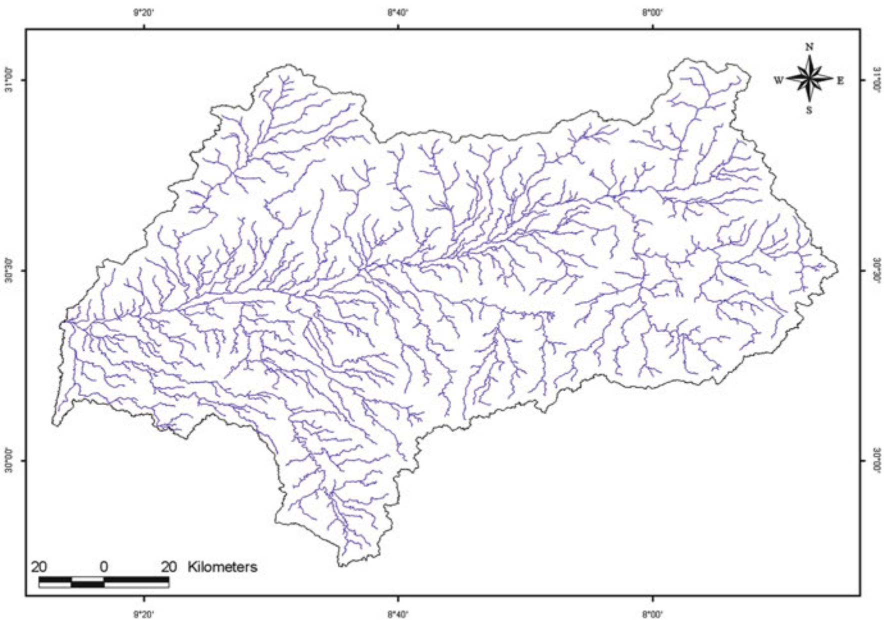


Fig. 7 Stream network derived from the DEM for the Souss River watershed

Table 2 Table used for the reclassification of the active flow accumulation path distribution grid

Accumulated volume range	Ordinal class after reclassification	Corresponding level of accumulation
10,001–100,000	1	Very low
100,001–1,000,000	2	Low
1,000,001–10,000,000	3	Medium
>10,000,000	4	High

3. Reclassify the resulting grid into four ordinal classes corresponding to the surface that each cell is draining using the Reclassify function and the information reported in Table 2.
4. Compute the distance from these four classes separately by using the Euclidean distance function.

From there, the spatial distribution of the distance depending on the accumulated volume of water, created in step 4, has been reclassified according to four flood likelihood classes as reported in Table 3 in order to account at the same time for the distance to the flow accumulation path and the accumulated volume of water along it. In this regard, a high level of flow accumulation will potentially have an impact further away from the flow accumulation path than a low flow accumulation.

Table 3 Table used for the reclassification of the grids containing the distance to the flow accumulation path for the four classes of flow accumulation

Flow accumulation class	Proximity to flow accumulation (m)	Flood likelihood class
4: High	Intervals 0–480	**3**
	Intervals 480–750	**2**
	Intervals 750–900	**1**
	Intervals >900	**0**
3: Medium	Intervals 0–300	**3**
	Intervals 300–480	**2**
	Intervals 480–690	**1**
	Intervals >690	**0**
2: Low	Intervals 0–210	**3**
	Intervals 210–300	**2**
	Intervals 300–390	**1**
	Intervals >390	**0**
1: Very low	Intervals 0–120	**3**
	Intervals 120–210	**2**
	Intervals 210–300	**1**
	Intervals >300	**0**

The literature does not provide indications about the optimum ranges to be used; the values reported in Table 3 are therefore reflecting choices that yield rationalized behavior in the modeling process as well as the distribution and extension of past flood events over the Souss River basin.

3.1.6 Precipitations

Precipitation is an important parameter that contributes to an area's flood susceptibility. The likelihood of a flood increases as the amount of rain and snow at a location increases [19, 31].

In this study, this parameter is represented by the annual maximum total precipitations over 3 consecutive days with a return period of 10 years map in order to better assess the flood hazard.

The process used to generate the annual maximum total precipitations over 3 consecutive days' distribution maps for a 10-year return period goes through the following steps:

1. Preparation and preprocessing of the daily precipitation data.
2. Calculating the total daily precipitations for a given period of 3 consecutive days and year of observation (1978–2010).
3. Applying the Gumbel frequency analysis on the measures from point 2 to obtain the annual maximum precipitations for different return periods (2, 5, and 10 years).

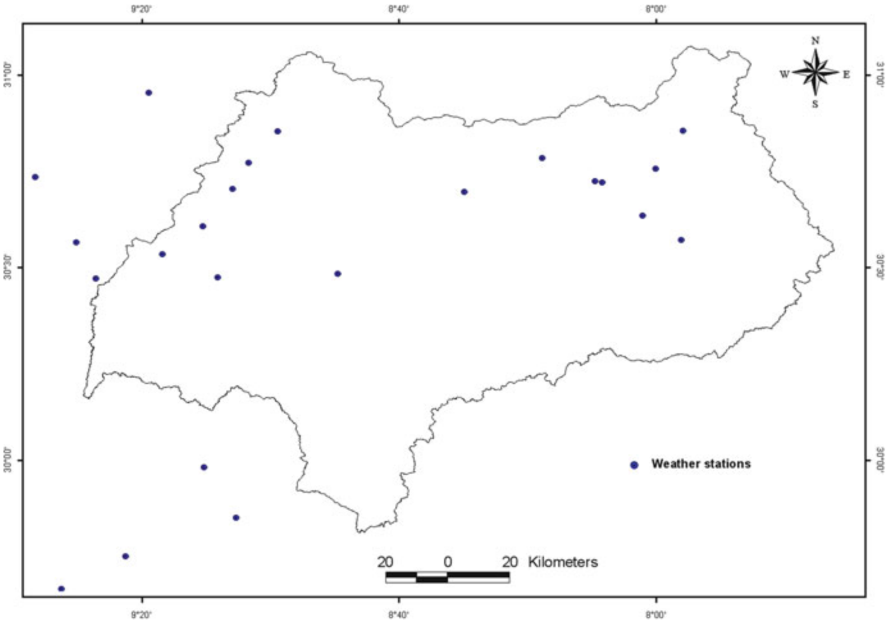


Fig. 8 Location of the weather stations within and around the Souss River watershed

Steps 1 to 3 have been performed by the EatlasClimMod 1.0 application used in the context of the second version of the WHO e-atlas of disaster risk [5].

4. Identifying the relevant parameters and selection of the regression model to spatialize the annual maximum precipitations using a stepwise regression analysis under the S-Plus software.
5. Performing the spatial interpolation of the annual maximum total precipitations over 3 consecutive days map using the selected regression models to cover the Souss River basin through ArcGIS.

Preparation and Preprocessing of the Daily Precipitation Data

The daily precipitations for the 1978–2010 period were mined for 24 weather stations located within and around the study area (Fig. 8) from the Souss Massa Draa Hydraulic Basin Agency (ABHSMD).

The preparation of the daily precipitation data consisted of creating a file for each year of observation (1978–2010); these files are needed for the preprocessing in order to remove the records with no data for precipitations (lines with a value of 9999.9) then to sort the records by station and by date. The preprocessing step is done using the EatlasClimMod 1.0 application that we have developed with the World Health Organization (WHO) collaboration in the context of the WHO e-atlas of disaster risk [5].

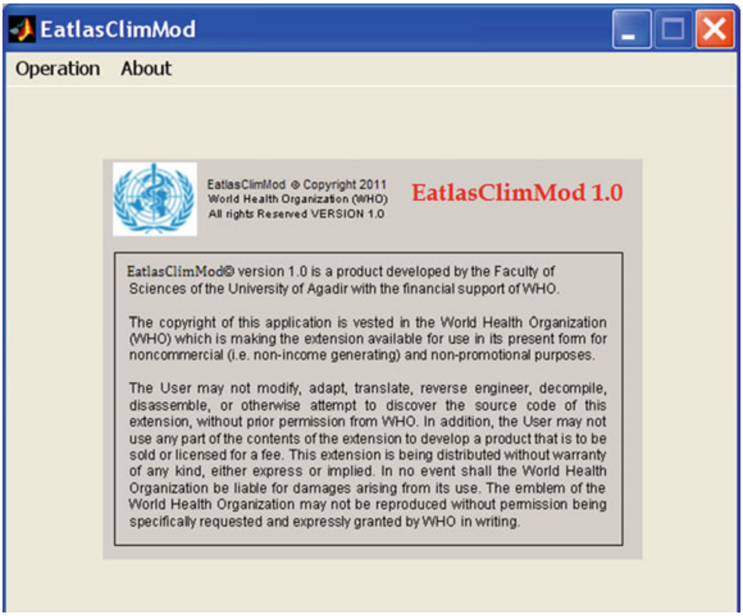


Fig. 9 EatlasClimMod 1.0 application start-up screen

We present in this section a summary description of the EatlasClimMod 1.0; for more details please refer to the [5] publication.

The EatlasClimMod © 1.0 application has been developed under the Matlab software to calculate and estimate the several climatic parameters needed for spatially distributing the natural hazards. Figure 9 shows the start-up screen of this application. It gives access to two menus: **Operation** and **About**.

The **About** menu gives the user access to the Help file or to the summary screen window (Fig. 9).

The **Operation** menu gives access to five options:

- **Preprocessing**: used for data preprocessing
- **Heat index**: used for the calculation of the daily heat index
- **Wave modeling**: used to calculate the annual maximum wave for any climatic variable over a given number of consecutive days
- **Unique stations files**: used to save the data of each weather station in a separated file
- **Gumbel analysis**: used to predict the climatic data for different return periods; this option contains two sub-options:
  - **All stations**: used to apply the Gumbel method on all weather stations
  - **One station**: used to apply the Gumbel method on a single weather station
  - **Exit**: used to close the application

Calculation of the Total Precipitations for a Given Period of Consecutive Days and Annual Maximum Total Precipitation for Each Weather Station and Year of Observation

EatlasClimMod 1.0 has been programmed in such a way that it can directly calculate the total precipitations for a given period of consecutive days and the annual maximum precipitations for each period of observation and weather station. The user specifies the number of consecutive days to be considered for measuring the total precipitations. In the context of this study, a period of 3 consecutive days has been used.

Here is an example of the resulting file "**final_*year*.txt**" (example **final_2004.txt**) produced by wave modeling the **EatlasClimMod 1.0** for each year containing the annual maximum total precipitation over 3 cobsecutive days and the annual frequency for each station. The annual frequency has been computed using the formula $=n/365$, where n is the total number of days of observations per year. Figure 10 presents one example of such file.

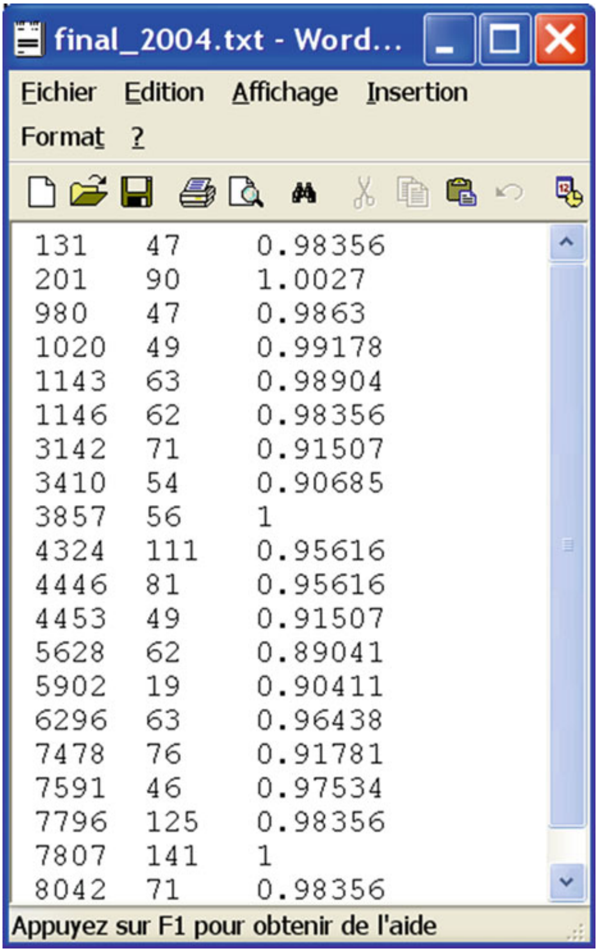
Calculation of the Annual Maximum Total Precipitations Over Three Days for a Two-, Five-, Eight-, and Ten-Year Return Period Using Gumbel Frequency Analysis

In our study, it has been decided to apply the frequency approach on past trends observed to estimate future meteorological trends at the weather station level. This estimation is based on the use of a probability distribution function as directed by several authors [45–56]. A probability distribution function yields expected meteorological conditions over various time periods (return periods) in the future.

This approach does not require a comprehensive understanding of meteorology or meteorological phenomena but examines the relationship between the past magnitude and the frequency of occurrence of the phenomena in order to identify some statistical regularity between them. In effect, the past is extrapolated into the future.

Frequently used probability distribution functions include Gumbel, lognormal, Pearson type 3, log Pearson type 3, and gamma. Despite the extensive literature on the topic, there is no preferred distribution function for the frequency analysis of meteorological data because each function has a unique set of advantages and disadvantages. The problem is complicated by the necessity to evaluate meteorological data for return periods that exceed the length of the observed record.

In our context, the Gumbel extreme value distribution function [13, 24, 33, 49, 57–62] was the most appropriate function because it seeks to identify the temporal distribution of extreme values for various return periods.



final_2004.txt - Word...

Fichier Edition Affichage Insertion Format ?

131	47	0.98356
201	90	1.0027
980	47	0.9863
1020	49	0.99178
1143	63	0.98904
1146	62	0.98356
3142	71	0.91507
3410	54	0.90685
3857	56	1
4324	111	0.95616
4446	81	0.95616
4453	49	0.91507
5628	62	0.89041
5902	19	0.90411
6296	63	0.96438
7478	76	0.91781
7591	46	0.97534
7796	125	0.98356
7807	141	1
8042	71	0.98356

Appuyez sur F1 pour obtenir de l'aide

Fig. 10 Example of file resulting from the wave modeling operation in EatlasClimMod 1.0 (final_2004.txt) (with column 1: station, column 2: annual maximum total precipitations over 3 consecutive days, column 3: annual frequency)

Additionally, this probability distribution function (Eq. 1) is one of the most widely used for extreme value prediction when analyzing hydrological and meteorological data [63]:

$$F(x) = e^{-e^{-\frac{x-a}{b}}} \tag{1}$$

with $F(x)$ = cumulative distribution function

a and b = adjustment parameters; a is a location parameter and b is a scale parameter

Replacing $\frac{x-a}{b}$ with the reduced variate u, the cumulative distribution function becomes:

$$F(x) = e^{-e^{-u}} \rightarrow u = -\ln[-\ln F(x)] = -\ln\left[-\ln\left(1 - \frac{1}{T}\right)\right] \quad (2)$$

with $F(X) = 1 - \frac{1}{T}$ and $T =$ the return period.

The Gumbel frequency analysis technique has been programmed and included in the EatlasClimMod 1.0 application in order to calculate the annual maximum total precipitations over 3 consecutive days for any given climatic station and return period.

The use of this application requires the introduction of two thresholds which are used as filters to remove any weather station from the calculation in case these are not respected. These two thresholds are annual frequency and minimum number of years of observation.

While the user can specify these thresholds in EatlasClimMod 1.0, a weather station would not be taken into account if:

- the dataset for that given station does not contain a daily observation for at least 70% of the days in the year (255 days)
- the number of year of observation for that station, after applying the first filter, is lower than 10 years

The threshold at 10 years will give a good prediction of the annual maximum total precipitations over 3 consecutive days for return periods that do not exceed 10 years.

After application of the EatlasClimMod 1.0, a graph is produced, plotting the annual maximum total precipitations over 3 consecutive days versus the Gumbel-reduced variate for each of the station, and this graph is stored as an image file, named ***numSTN*.jpg** (with *numSTN* = the station number, e.g., 131.jpg, 201.jpg, 7807.jpg). Figure 11 presents one example of such graph.

In addition to these graphs, the application also generates the summary file **WaveModelledVariable_allSTN_return_2-5-8-10_Fq-0.7_NbrY-10.txt**. This file contains, for each station, the annual maximum total precipitations over 3 consecutive days for 2-, 5-, 8-, and 10-year return periods as well as the correlation value between the annual maximum precipitations and a Gumbel-reduced variable. Figure 12 presents an example of such a file.

On the basis of the graph and summary file, the user then identifies any potential errors (Fig. 13) in the original datasets, potential outliers (points far from the regression line on the graph) and/or correlation value lower than 0.80, for example, and correcting in the original dataset in order to improve the correlation in the analysis and therefore reduce the error on the final values for the annual maximum total precipitations over 3 consecutive days for these stations.

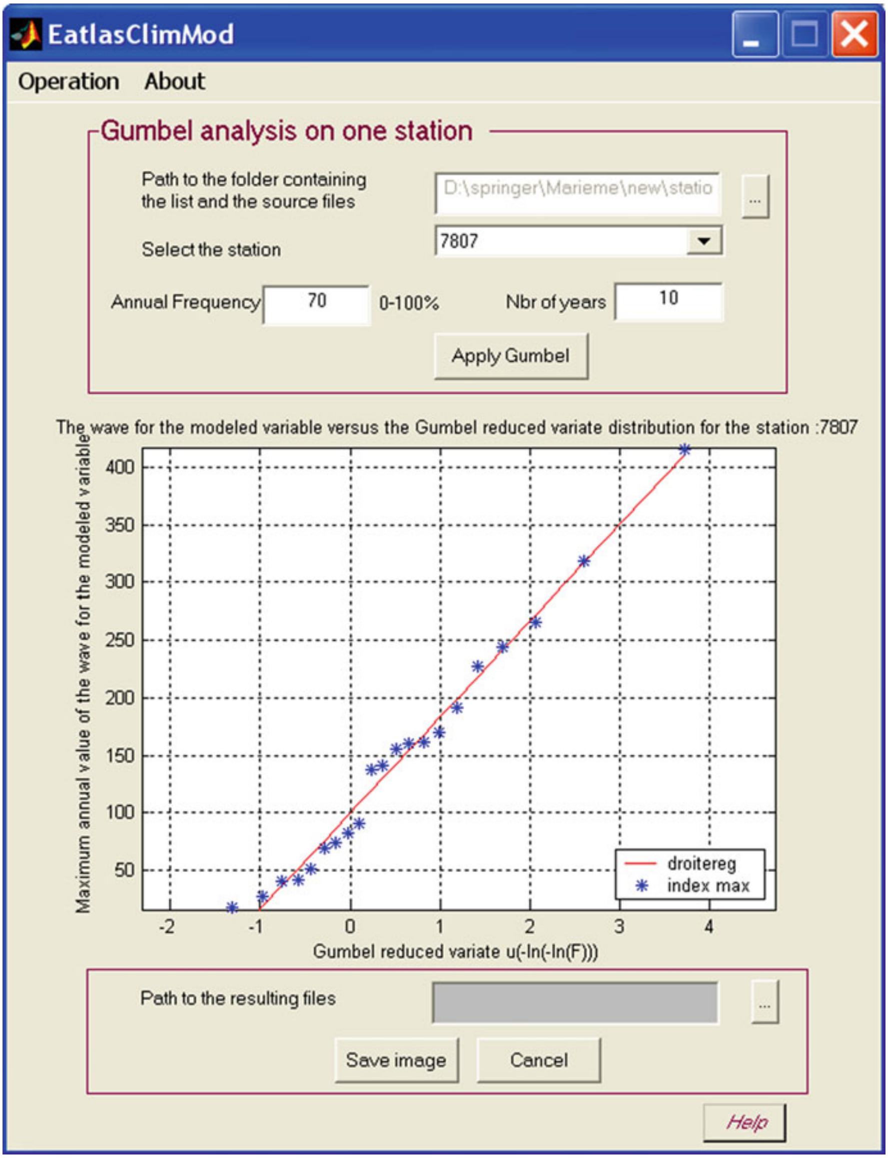
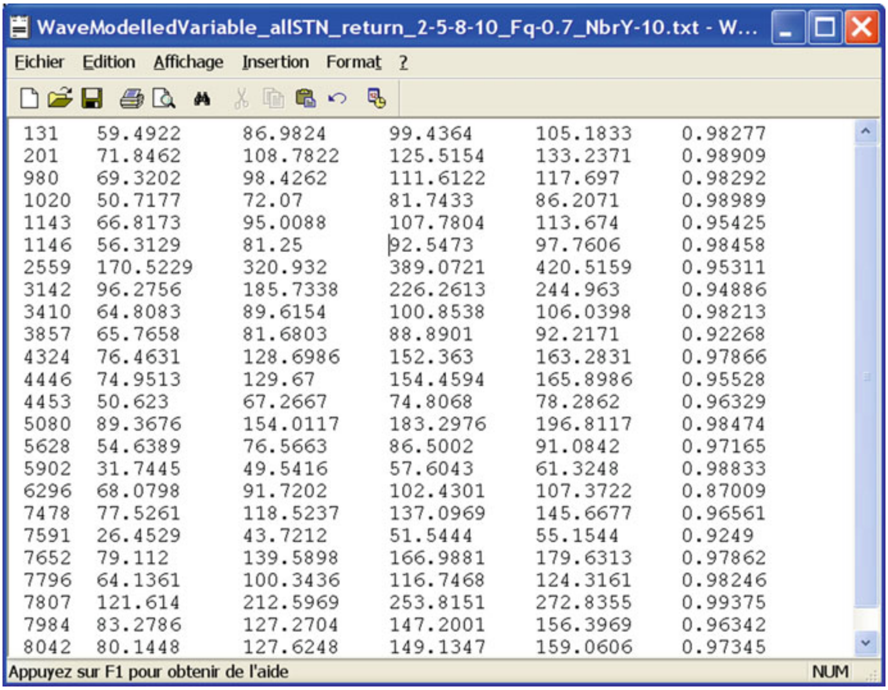


Fig. 11 Example of window appearing as the Gumbel analysis is completed on each weather station. The annual maximum total precipitations over 3 consecutive days versus the Gumbel-reduced variate distribution for weather station 7807 with the annual frequency threshold of 70% and a 10-year return period



131	59.4922	86.9824	99.4364	105.1833	0.98277
201	71.8462	108.7822	125.5154	133.2371	0.98909
980	69.3202	98.4262	111.6122	117.697	0.98292
1020	50.7177	72.07	81.7433	86.2071	0.98989
1143	66.8173	95.0088	107.7804	113.674	0.95425
1146	56.3129	81.25	92.5473	97.7606	0.98458
2559	170.5229	320.932	389.0721	420.5159	0.95311
3142	96.2756	185.7338	226.2613	244.963	0.94886
3410	64.8083	89.6154	100.8538	106.0398	0.98213
3857	65.7658	81.6803	88.8901	92.2171	0.92268
4324	76.4631	128.6986	152.363	163.2831	0.97866
4446	74.9513	129.67	154.4594	165.8986	0.95528
4453	50.623	67.2667	74.8068	78.2862	0.96329
5080	89.3676	154.0117	183.2976	196.8117	0.98474
5628	54.6389	76.5663	86.5002	91.0842	0.97165
5902	31.7445	49.5416	57.6043	61.3248	0.98833
6296	68.0798	91.7202	102.4301	107.3722	0.87009
7478	77.5261	118.5237	137.0969	145.6677	0.96561
7591	26.4529	43.7212	51.5444	55.1544	0.9249
7652	79.112	139.5898	166.9881	179.6313	0.97862
7796	64.1361	100.3436	116.7468	124.3161	0.98246
7807	121.614	212.5969	253.8151	272.8355	0.99375
7984	83.2786	127.2704	147.2001	156.3969	0.96342
8042	80.1448	127.6248	149.1347	159.0606	0.97345

Fig. 12 Example of summary file resulting from the application of Gumbel analysis on all the stations in a given region

Identification of the Relevant Parameters and Selection of the Regression Model Used in the Spatial Interpolation

Spatial interpolation is widely used for translating irregularly scattered meteorological data (data collected at discrete locations [i.e., at points]) into continuous data surfaces (rasters).

The choice of interpolation method is especially important in the Souss River basin where meteorological data are sparse, and there are large value changes over short spatial distances. Additionally, the spatial density, distribution, and spatial variability of sampling stations influence the choice of interpolation technique [64].

Given a set of meteorological data, researchers are confronted with a variety of stochastic and deterministic spatial interpolation methods to estimate meteorological data values at unsampled locations:

- ***Deterministic*** estimation methods including *inverse distance weighting* [65–71] and spline methods [72–74]
- ***Stochastic techniques*** including the *kriging* and *cokriging* techniques [33, 69, 70, 75–78] and *polynomial regression* [33, 79–85].

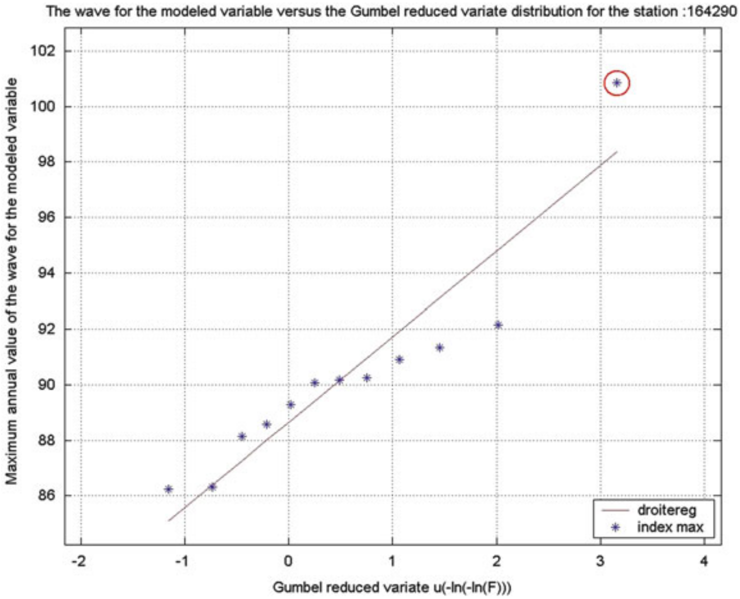


Fig. 13 Graph resulting from the Gumbel frequency analysis for weather station 164290 with the isolated point indicated by the *red circle*

For a summary description of these methods, refer to Collins and Bolstad [69] and El Morjani [33].

The characteristics of the data of the Souss River basin (low spatial data density and a high spatial variability) resulted in implausible outputs when applying the inverse distance weighted and kriging interpolation methods, more specifically as follows.

The application of the inverse distance weighting method generated specking or "bird's eye" effects around the station locations, which was not plausible as the spatial variation for climatic variables was not following a regular trend.

The application of the kriging technique produced results that were inconsistent with the original data. Whatever the model used (spherical, exponential, or Gaussian), the statistical cross-validation was not able to fit the theoretical spatial semivariogram. This might be because the density of weather stations is too low to use the kriging interpolation method.

It has therefore been necessary to find another model that produces results of good quality.

A literature review was carried out to first identify a set of variables that are significantly correlated to the precipitations, namely:

- ***Elevation (Z)***, known to be a dominant factor in the small scale of the precipitation variations [86, 87]
- ***Mean elevation within a 3×3 pixel window of each cell (Z9)*** to measure the wider influence of elevation on precipitations at any one location [62]
- ***Aspect (Asp)*** as a measure of the local climate effect (microclimate) that can be generated by the orientation of the slope
- ***Slope* (Slp)** as a factor determining the amount of solar radiation received and could have an impact in spatial distribution of the precipitations [84]
- ***Distance from the relative longitude (d_X) and latitude (d_Y)*** to account for large-scale gradients of the precipitations
- ***Distance to the nearest coastline (d_coast)*** to account for maritime influences on the precipitations

The process used has been implemented in three steps as follows:

1. Preparation of the GIS layers containing the spatial distribution of the causal factors reported in above, and dependant variable (annual maximum total precipitations over 3 consecutive days for a 10 year return periods), resulted from EatlasClimMod 1.0. This step was carried out using Section 4.8.4.1 of the protocol for the preparation of the datasets for the second version of the WHO e-atlas of disaster risk [5].
2. Preparation of a table of the stepwise regression analysis, which contained, for each weather station, the annual maximum total precipitations over 3 consecutive days for a 10-year return period as well as the variables extracted from each GIS layer generated in point 1 by using the ArcGIS Extract Values to Points function.
3. Application of the stepwise regression analysis: Once the stepwise regression table was ready, the stepwise regression analysis was performed using the S-Plus software. The validation of each regression was carried out using R^2 variance analysis as well as a detailed probability and residual analysis in order to identify the significant variables and therefore select the best regression model possible.

The stepwise regression analysis for a 10-year return period applied on the 24 weather stations gives the results shown in Table 4.

Four of the five independent variables explain most of the variation of the annual maximum total precipitations over 3 consecutive days for the 10-year return period (PRC_10). The variables (longitude [d_X], latitude [d_Y], and the coastline [d_coast]) expressed in meters, mean elevation [Z9] in meters, and slope in degrees were used to derive the following regression in Eq. (3) for a 10-year return period:

Table 4 Regression model for the annual maximum total precipitations over 3 consecutive days for a 10-year return period

Variable	Regression coefficient	Standard error	*t*-value	Probability Pr(>|*t*|)
Z9	0.027359713342	0.01104	−0.06915	0.94498
Slp	3.533228831728	0.00707	5.86524	0.00000
d_Y	0.000824835748	0.00078	−20.03714	0.00000
d_coast	−0.001083837055	0.00050	−5.01369	0.00000
d_X	0.001017035205	0.00027	−6.38177	0.00000
Residual standard error	6.36629			
Degrees of freedom	18			
Multiple *R*-squared	0.83			
F statistic	17.67142			
Probability (*F* statistic)	0.0000			

$$\begin{aligned} \text{PRC\_10} = \big(&0.027359713342 * z9 + 3.533228831728 * slp \\ &+ 0.000824835748 * d\_Y - 0.001083837055 * d\_coast \\ &+ 0.001017035205 * d\_X \end{aligned} \qquad (3)$$

This equation shows a positive correlation between d_X, Z9, slp, d_Y and the annual maximum total precipitations, and an inverse correlation with d_coast. This means that the annual maximum total precipitations increase with elevation, slope, longitude, and latitude and decrease with distance from the coast.

The aspect does not appear in the regression equation because it does not significantly explain the variation of the maximum precipitation.

Eighty-three percent of the variance in annual maximum total precipitations are explained by the four variables retained in the regression equation ($R^2 = 0.83$). The model is considered valid and reliable because of the strong correlation ($R = 0.91$) and the high degree of confidence that exists in the selected variables (very small probability [*F* statistic]). This is clearly statistically significant, so the true slope of the regression line is probably not zero.

Spatialization of the Predicted Annual Maximum Total Precipitations Over Three Consecutive Days

Once the regression model had been found, it was applied to generate the annual maximum total precipitations over 3 consecutive days' distribution map for a 10-year return period, covering the Souss River basin (Fig. 14). This layer is freely redistributable.

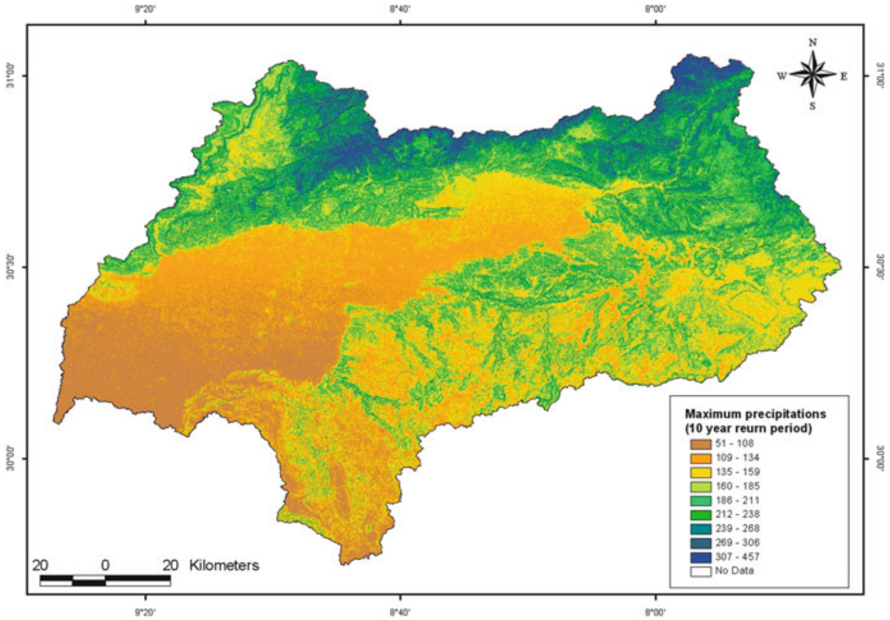


Fig. 14 Annual maximum total precipitations over a 3-day-period distribution for a 10-year return period for the Souss River watershed

3.2 Creation and Classification of the Number of Past Flood Events Distribution Map

The distribution of the number of previous flood events, which can be considered as a measure of the flood frequency, was extracted from the flood polygons compiled by the Dartmouth Flood Observatory between 1985 and 2015 in its Global Active Archive of Large Flood Events.

This archive is derived from a wide variety of news, government, and direct and remote sensing sources and can be freely downloaded in Esri shape file format from: http://floodobservatory.colorado.edu/Archives/index.html [accessed September 30, 2015].

The flood frequency layer for the study area has been generated by the frequency script applying in ArcGIS. This script is available in the tools section of the WHO e-atlas of disaster risk [7] and allows both to combine the flood polygons for each observation between 1985 and 2015 and convert them in to grid layer. The resulting grid was then classified into four specific levels of historical hazard through the Reclassify function (Table 5).

Table 5 Correspondence between the number of past flood events and the historical flood hazard level

Number of past flood events in 1985–2015	Historical flood hazard level
0	Nonhazardous: **1**
1–3	Low: **2**
4–7	Medium: **3**
>7	High: **4**

3.3 Estimation of the Weighted Scores

The causal factors described in Sect. 3.1 are weighted based on their spatial correlation with the distribution of the historical flood hazards. When value ranges for a factor occur largely in areas where floods have occurred in the past, the weighted score for the value range is high. Consequently the value range for the factor is significant in predicting the susceptibility of the area to future floods.

In this study area, the following steps have been used to estimate the weighted score for each causal factor:

1. Crossing the reclassified flood frequency distribution map with each causal factor distribution grid by the Tabulate Area function to obtain the area distribution of each class/category according to the historical flood hazard classification (Table 5). For the continuous causal factors (elevation and annual daily maximum precipitation), the distribution maps first need to be reclassified into appropriate value ranges, nine classes using the natural breaks (Jenks) approach before proceeding with the weighting.

Tables 6 and 7 show, respectively, an example of the area of each type of the discrete factor (land cover) and continuous factor (elevation) in each class of historical flood hazard (flood frequency) in square kilometers.

2. Calculating the percentage area distribution of each class/category causal factor by historical flood hazard level by dividing the area observed in each level by the summed area observed for the each class/category causal factor. For example, the percentage area for the land cover category cultivated land located in the no hazard historical flood level gives: $(12.11/3079.68) \times 100 = 0.39$. The results of this operation for the land cover categories reported in Table 6 are shown in Table 8.
3. The weighted score for each category is then calculated as the sum of the products between the area percentage of the category for each historical flood hazard level and the associated damage coefficient using Eq. (4) [25]:

$$\text{weighted score} = (0 \times A) + (1 \times B) + (3 \times C) + (5 \times D) \tag{4}$$

with A = area percentage of the category in areas with no historical flood hazard
B = area percentage of the category in areas with low historical flood hazard

Table 6 Area distribution measured in square kilometers for the different historical flood hazard levels for the different land cover categories observed in the study area

Land cover category	Historical flood hazard level				Sum
	None	Low	Medium	High	
Cultivated land	12.11	723.27	836.87	1507.44	3079.68
Forest	3.60	17.83	8.53	804.58	834.53
Grassland	300.19	1526.88	1672.68	5754.95	9254.70
Shrubland	0.00	0.00	0.67	36.31	36.98
Water bodies	0.00	0.72	0.22	15.92	16.86
Artificial surfaces	0.00	17.86	56.15	21.26	95.27
Bare land	441.18	1318.44	1658.05	439.42	3857.08

Table 7 Area distribution measured in square kilometers for the different historical flood hazard levels for the different elevation classes observed in the study area

Land cover category	Historical flood hazard level				Sum
	None	Low	Medium	High	
4–282	10.16	1005.26	987.11	932.58	2935.12
283–556	0.00	283.84	239.07	1244.37	1767.29
557–857	0.00	216.88	221.33	1268.06	1706.28
858–1145	37.20	280.46	816.05	1339.52	2473.23
1146–1417	306.53	351.08	1034.75	1021.62	2713.99
1418–1696	280.98	527.40	736.70	756.70	2301.78
1697–2060	117.93	927.26	168.86	895.32	2109.37
2061–2565	3.88	11.37	28.92	847.38	891.55
2566–4160	0.00	0.00	0.00	276.06	276.06

C = area percentage of the category in areas with medium historical flood hazard

D = area percentage of the category in areas with high historical flood hazard

0, 1, 3, 5 = corresponding damage coefficients attached to each specific historical flood hazard class to express the severity of each level of historical flood hazard

As an example, Table 8 shows the resulting weighted score obtained for each land cover class observed in the Souss River basin. Basically, the more frequently a category is found in areas with high historical flood hazard, the higher the weighted score is.

3.4 *Standardization of the Weighted Scores*

Once the weighted scores for all of a factor's categories had been calculated, they are standardized using the linear interpolation technique to allow them to be comparable across factors. In this process all the causal factors are standardized

Table 8 Example of calculation of the weighted scores and the standardized weighted scores (SWS) for each land cover category

Land cover category	Historical flood hazard level				Weighted score	SWS
	None (%) **A**	Low (%) **B**	Medium (%) **C**	High (%) **D**		
Cultivated land	0.39	23.49	27.17	48.95	349.75	1.94
Forest	0.43	2.14	1.02	96.41	487.25	2.93
Grassland	3.24	16.50	18.07	62.18	381.64	2.17
Shrubland	0.00	0.00	1.81	98.19	496.38	3.00
Water bodies	0.00	4.24	1.31	94.45	480.41	2.88
Artificial surfaces	0.00	18.74	58.94	22.32	307.15	1.63
Bare land	11.44	34.18	42.99	11.39	220.11	1.00

into ordinal classes according to a scale going from 1 to 3, where 1 indicates categories with the lowest likelihood for a flood to occur in a given area and 3 the categories with the highest. Table 8 shows an example of calculation of the standardized weighted scores (SWS) for the land cover categories.

3.5 *Creation of the Intensity Level of the Flood Hazard Distribution Map*

Each causal factor distribution map was reclassified by using the Reclassify function to contain the distribution of the corresponding standardized weighted score before being combined using the multiplicative overlay method through the Raster Calculator function. For each cell, this method multiplies the score of all the causal factors together to produce the distribution of the flood hazard index (FHI).

Finally, the flood hazard index distribution map was reclassified into five intensity levels (very low, low, medium, high, and very high) using the Reclassify function and a natural breaks method (also referred to as the optimal breaks method and Jenks method). This classification technique identifies break points between classes based on the natural patterns in which the data are clustered. Class boundaries are set where there are relatively big jumps in the data values. The map resulting from the application of this approach for the Souss River basin is presented in Fig. 15.

It is important to remember that the result obtained in this map is more qualitative than quantitative. This means that this map shows the spatial distribution of the relative probability for floods to occur in the Souss River basin at least once every 10 years if the climatic conditions are presenting the worst combination possible.

Areas in red on this map are therefore representing areas where the probability for a flood to occur is higher than in areas presenting another color.

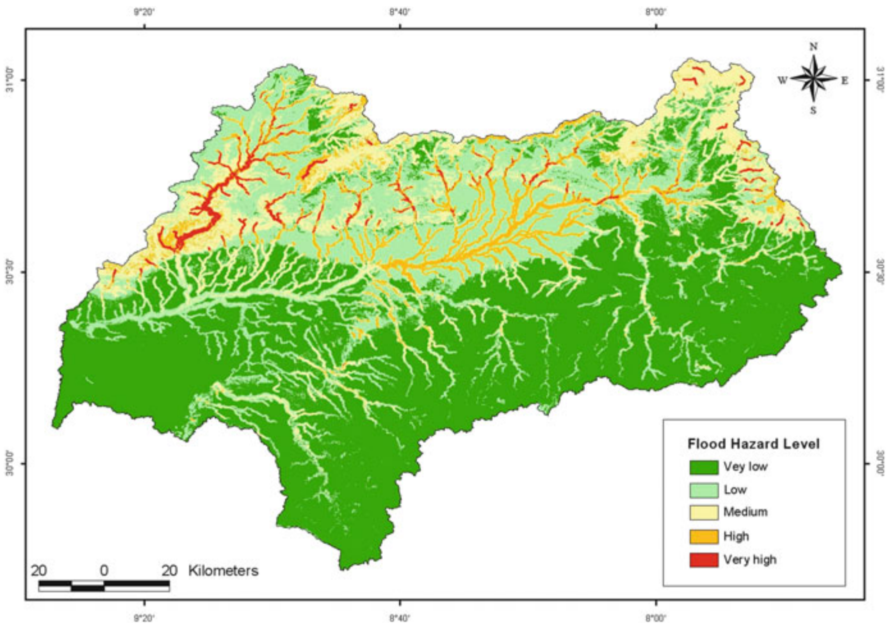


Fig. 15 Flood hazard distribution map for the Souss River basin

4 Validation of the Flood Hazard Distribution Map

The five classes of the flood susceptibility map classified were covering 52% (very low susceptibility), 27% (low susceptibility), 14% (medium susceptibility), 6% (high susceptibility), and 1% (very high susceptibility) of the total study area (Fig. 15). In general, 21% of the total watershed area is under very high, high, and medium hazards.

This map has been assessed by field inspection information coming from the Souss Massa Draa Hydraulic Basin Agency (ABHSMD), providing the relevant information concerning 123 flooding sites (Fig. 16). The cross-validation between the model result and the ABHSMD data indicates that the accuracy of the flood hazard distribution map is 85% (85% of the ABHSMD flood sites fall into very high, high, and medium classes).

5 Conclusions and Recommendations

This study shows a simple and cost-effective methodology to accurately delineate the flood hazard areas in the Souss River basin from the available database using a geographical information system.

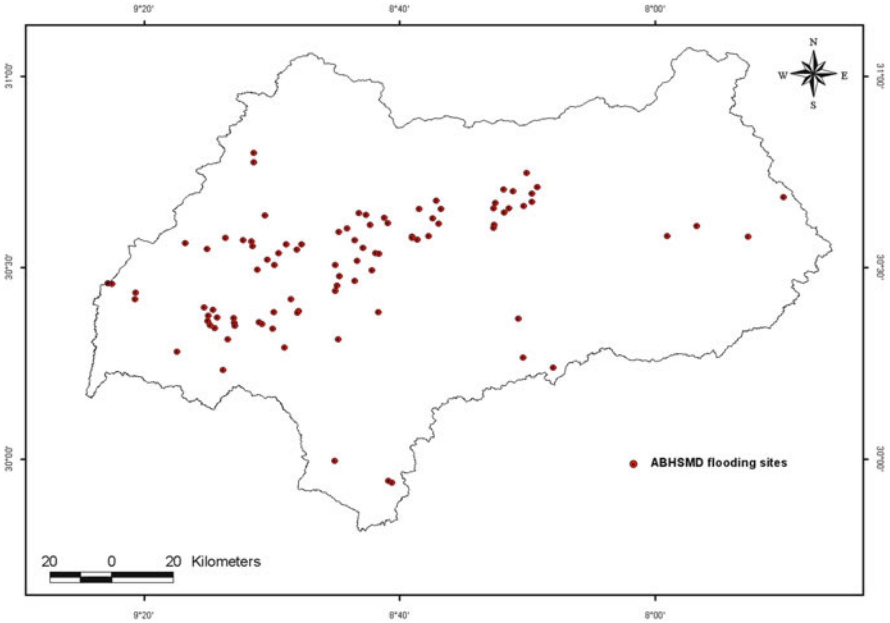


Fig. 16 ABHSMD flooding sites distribution map for the Souss River basin

The methodology used to spatially distribute flood hazard combines the extent of past flood events with the spatial distribution of causal factors. This combination enables the calculation of a weighted score for each individual causal factor. The spatial distribution of the weighted scores are then aggregated to derive the distribution of the flood hazard index (FHI) before being reclassified to obtain the spatial distribution of the relative intensity level of flood hazard.

This map with a high resolution of 30 m is designed to provide actionable information to the decision-making process on development planning, emergency preparedness, and mitigation measures by helping to identify and prioritize areas with high probability of hazard occurrence or intensity in order to avoid any dramatic disaster.

It is important to remember that the GIS applications in this work played a central role in integrating, organizing, compiling, homogenizing, processing, modeling, and visualizing the spatial data from multiple sources. Its application in addition to the EatlasClimMod is fundamental to create a spatial distribution flood hazard and to update and improve the spatial information in future research.

At the same time, this work should also be seen as a first step aiming at improving information management in the study area. An important amount of data and information have been compiled, homogenized, updated, and generated.

Nevertheless the following recommendations need to be addressed:

1. The model developed to spatially distribute flood hazard is semiquantitative and should therefore not been seen as a potential replacement to any hydraulic based model.
2. The causal factors and the resulting map should be validated by specialists before using for decision making. The current result map has been assessed by ABHSMD flooding sites information, indicating that the accuracy of the flood hazard distribution map is 85%.
3. The 1 km resolution of the soil used in this study could have direct impact on the occurrence or intensity of the flood hazard. Access to more complete, more accurate soil data from other sources could increase the quality of the results obtained through the application of the proposed model.
4. This process could be transferred and implemented in other basins or regions of Morocco by creating their own accurate and reliable information. Indeed, any change on the list of indicators or the method used to spatially distribute flood hazard would of course modify the results.
5. The next step of this study will be to further develop the health component and produce additional maps such as the distribution of population and vulnerabilities in order to target a flood risk map and therefore to support emergency preparedness, response, recovery programs, and also development planning.

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Dams Siltation and Soil Erosion in the Souss–Massa River Basin

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Abstract Siltation of 26 large and small dams, spatially distributed in the Souss–Massa basin, has been investigated. The disparity observed in the reservoir's silting reflects the variability of each watershed's physical parameters that control the water erosion. These parameters include in particular lithology, topography, climate, vegetation, hydrology, and human actions.

The hardness of the water erosion quantification due to the lack of data and variability of climate in the region pushes many researchers to suggest the deduction of the watershed's specific degradation from the annual siltation stored in reservoirs. This approach enables us to characterize the erosion phenomenon exerted in the basin.

In our study area, the most eroded areas are (1) the western High Atlas with alpine orogeny, tectonically unstable, marl lithology, and meandering rivers and (2) areas of high altitudes where igneous rock alteration offers an arena easily carted by bed load transport favored by steep slopes. In contrast, the least eroded areas are (1) the Anti-Atlas watersheds with Pan-African orogeny, tectonically

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stable with low steepness of terrain slopes, (2) areas of plains, and (3) watersheds with successful management practices as stone bands. This distribution is consistent with the results of previous studies by modern methods that are partial and localized.

So, when the high erosion risk areas are assessed in a specific region, this kind of study allows us to indicate the areas which need the management practice in the aim to reduce erosion and maybe to select the suitable sites for large and small dams.

Keywords Dams, Erosion, Morocco, Siltation, Souss–Massa–Draa

Contents

Acronyms

ABHSMD	Agence du Bassin Hydrographique Souss Massa et Draa (Hydrographic Basin Agency of Souss Massa and Draa)
AFP	Agence Francaise de Developpement (French Development Agency)
CESE	Conseil Economique, Social et Environnement (Economic, Social and Environmental Consulting)
CRTS	Centre Royale de Télédétection Spatiale (Royal Centre for Remote Sensing)
FAO	Food and Agriculture Organization
FCDR	French Committee on Dams and Reservoirs
ICOLD	International Commission on Large Dams

1 Introduction

Dams are considered as the most efficient way to manage surface water [1]. Geographically, they are distributed on all continents and in all climates [2, 3]. At first, dams were used to control the water level, and then, gradually, the stored water was used for various needs including irrigation, human consumption, industrial use, aquaculture, and navigability all over the world. Nowadays, population growth and increased industrialization push the building of more dams and reservoirs.

Under the arid and subarid climate covering much of the south Moroccan territory, dams are the prime necessity to remedy the climatic changes and human pressure on water resources [4, 5]. In Morocco, the strategy of building large dams had been a priority for more than 80 years [6]. The number of large and small dams reaches 130 and 200, respectively. Moreover, an objective to reach 1,000 small dams is also in the global strategy of the hydraulic department.

However, the durability of these necessary structures depends on an unavoidable problem which is the siltation [7–13]. This natural phenomenon induced by water erosion is linked to watershed characteristics in terms of topography, lithology, vegetation cover, hydrology, and also human activities [14–19]. Water erosion becomes increasingly aggressive because of climate change repercussions and torrential rains during extreme events.

The measurement of the soil's loss caused by water erosion in the watershed is a sensitive task. Thus several studies use the sedimentation rate in dams to assess the watershed's specific degradation. The annual silting rate (m^3/year) can be transformed to specific degradation (t/km^2/year) [11, 17, 18, 20].

The quantification of the watershed's specific degradation using the sediment yield in reservoirs was one of the most applied methods to specify the areas with high erosion and to suggest a model for silting prediction which constitute a negative impact on water resources mainly in the area showing water shortage [16, 21–24]. Now, the geographic information system (GIS) is an effective tool to generate a spatial analysis of high-risk erosion areas [25].

The Souss–Massa basin (Figs. 1 and 2) located under arid climate contains 8 large and 16 small dams distributed throughout the basin (Fig. 10). The watersheds of these dams are contrasting in terms of topography, lithology, hydrology, vegetation cover, and a silting yield data. This spatial situation is very helpful to produce spatial and quantitative information on soil erosion studies and risk assessment mapping. Several studies dealing with the erosion process were carried out within the basin [26–31]. Our study is focused on the silting of different dams in the Souss–Massa catchment with the main aim to assess the erosion rate in the sub-catchment and predict the potential impact of this silting on the water resources in the area.

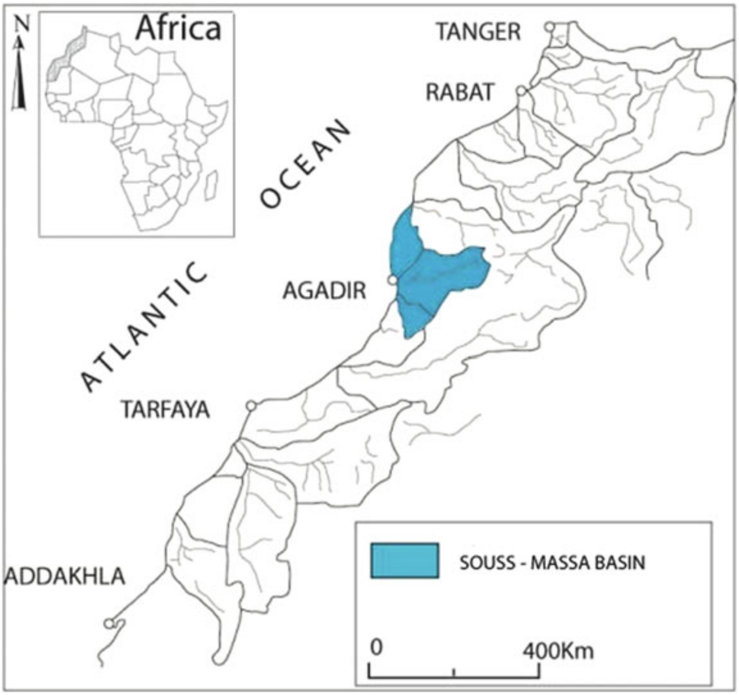

Fig. 1 Geographic situation of the Souss–Massa basin

2 Study Area Characteristics

2.1 Geographic Setting

The Souss–Massa basin and related coastal catchments are located in the center of Morocco at 29° and 31° of latitude north and 7° and 10° of longitude west. This zone is situated between the Atlantic Ocean in the west and High Atlas and Anti-Atlas mountains, respectively, in the North and South. The whole surface of the studied basins is about 28,000 km^2 that is corresponding to 25% of plains and 75% of mountains (Figs. 1 and 2).

2.2 Geomorphologic Context

The geomorphology of the basin is drawn by the south side of the High Atlas, the north side of the Anti-Atlas, and the Siroua mountain range. The alluvium and colluvium deposits produced by the tow Atlas at the quaternary period induced the

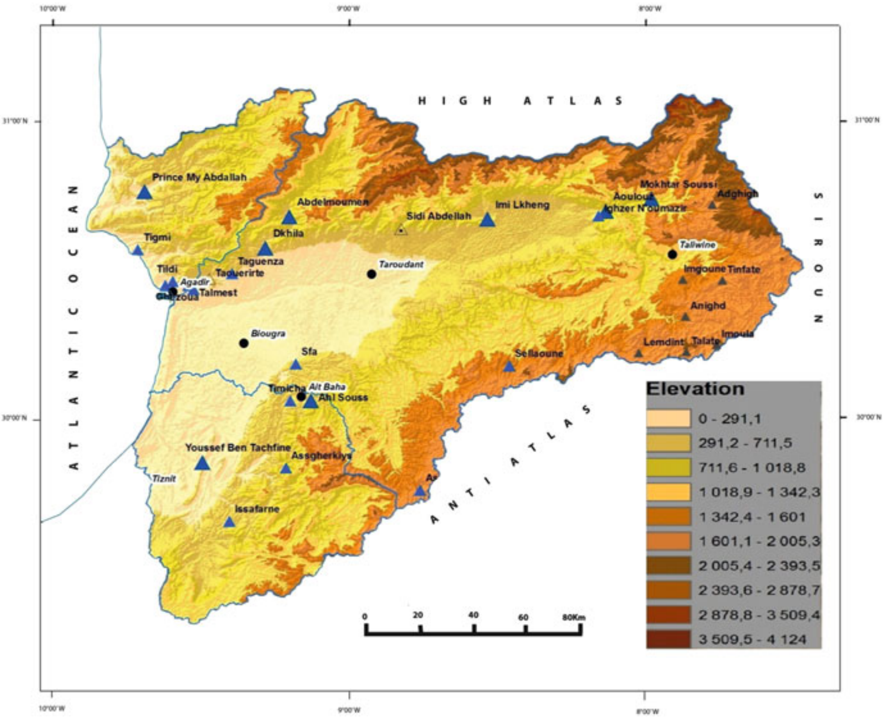

Fig. 2 Digital elevation model map of the Souss–Massa basin

shaping of the Souss and Chtouka plains that include the Souss–Massa aquifer (Fig. 2).

2.3 *Geological Framework*

Two main structural zones constitute the Souss–Massa basin: the Precambrian western Anti-Atlas and the Paleozoic and Mesozoic western High Atlas (Fig. 3). Both chains are separated by the so-called southern Atlasic fault. Igneous and metamorphic rocks crop out in the western and central Anti-Atlas (Siroua mountain) as well as major carbonate units, which make up significant tableland relief. Paleozoic shale and sandstones, Triassic sandstones and mudstones, and Jurassic marly limestone overlie the High Atlas basement [33, 34]. A Cretaceous–Eocene succession, which is structured as an east–west trending syncline, crops out on the piedmont of the High Atlas and as some hillocks in the Souss plain. Thick Pliocene and Quaternary deposits overlay this Cretaceous–Eocene succession, including significant fluvial–lacustrine sequences [35], which are overlain by coarse-grained, often carbonate, encrusted alluvial deposits [36].

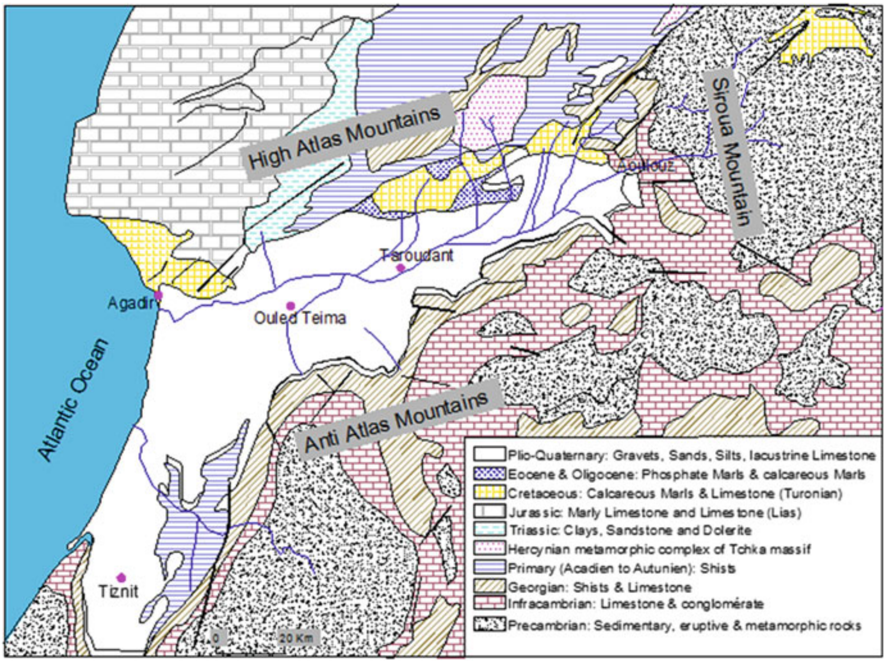

Fig. 3 Geological map of the Souss–Massa basin ([32], modified)

2.4 Climate Framework

Considered as a buffer area between the interior part of Morocco and its desert, the climate tends toward aridity and subaridity. However, the proximity of the ocean and the influence of the cold current of the Canary Islands mitigate the climate of the area. The mountain barrier that constitutes the Anti-Atlas protects this area against the winds from the south (Chergui). The climate varies from wet to cold winter on the top elevations and subarid to cool winter on the plains. Rainfall is unevenly distributed on the area with an average of 250 mm. Drought is considered as a structural problem in the studied basin (Fig. 4). Actually, the minimum and maximum flows recorded are 35 million m^3 (1960–1961) and 2,160 million m^3 (1962–1963) with a tendency to drought phenomena [37–39].

The temporal variability of the rainfall and the spatial distribution are also significant in the area showing by time the extreme events (Figs. 4 and 5) [40–42].

2.5 Souss–Massa Hydrology

The surface water is limited and very irregular. Flows of rivers are erratic within a year. The runoff is only observed during short periods when it is flooding, and sometimes it is so fast and violent [43]. The surface water potential of the Souss–

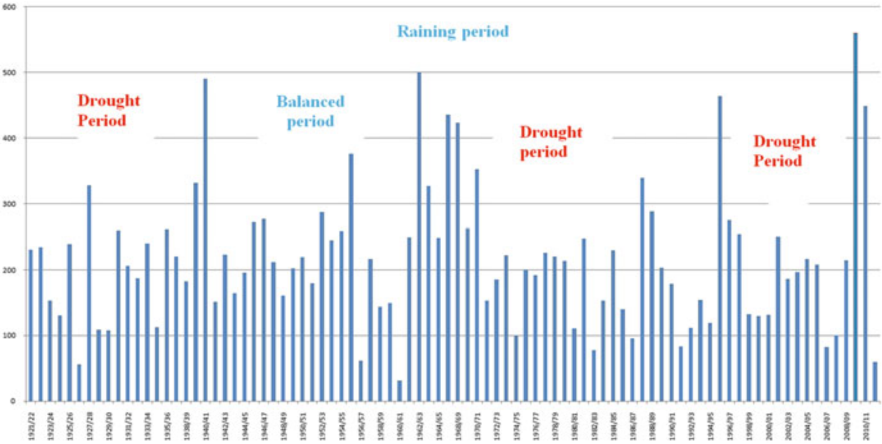

Fig. 4 Rainfall histogram at Taroudant station (1921–2010, ABHSMD)

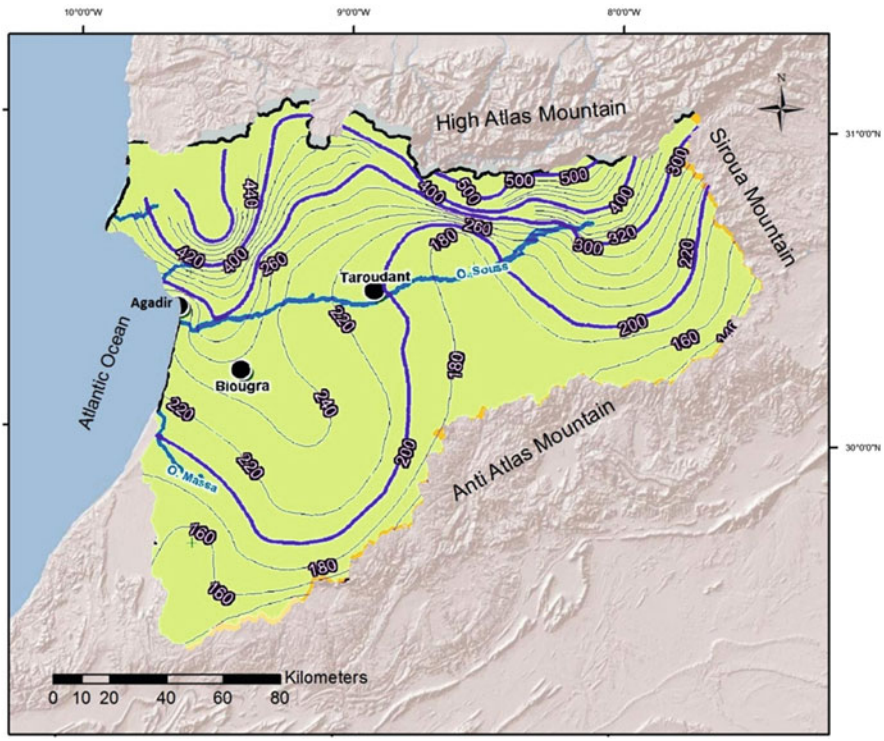

Fig. 5 Isohyets map for the period 1932–2007. *Source*: ABHSM

Massa region is estimated to be 668 mm^3/year. The eight existing large dams provide 364 mm^3/year unlike the small and hillside existing dams that produce only 15 mm^3/year [44–46] (Fig. 6).

During the last decades, current climate change generated torrential rains that cause devastating floods such as in February 2010 (3,400 m^3/s) and November 2014 (2,257 m^3/s) (Fig. 7).

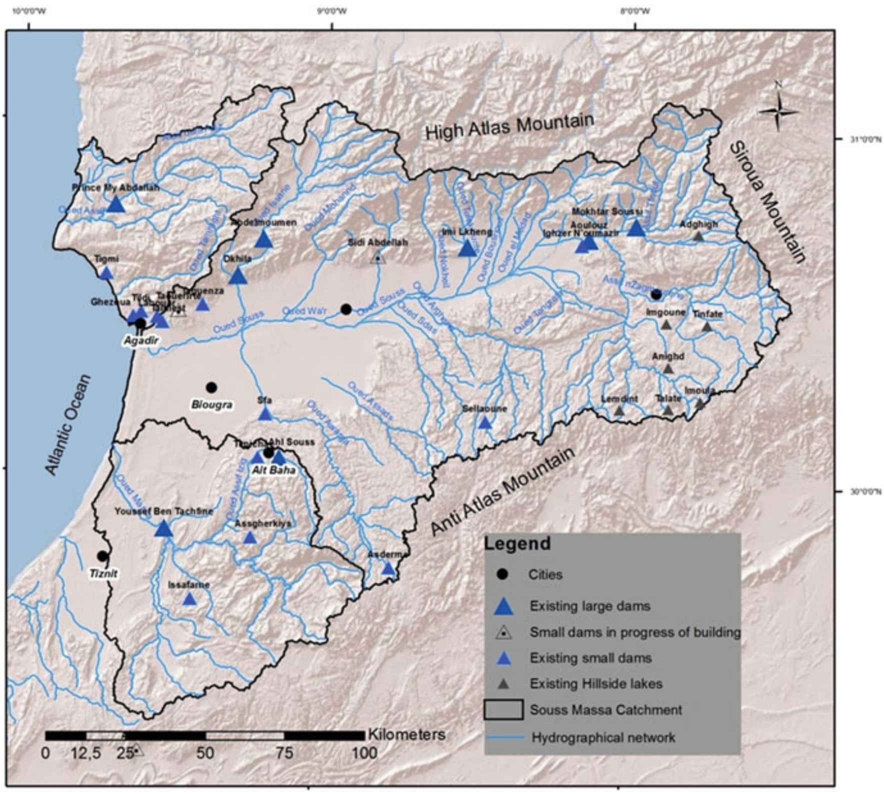

Fig. 6 Hydrographic network in the Souss–Massa basin

Fig. 7 Example of Souss floods (November 2014)

2.6 Vegetation Cover and Agriculture

The most widespread tree species in the basin is *Argania spinosa*, which is very scattered on a large part of the Souss plain, in Anti-Atlas and High Atlas and in Siroua piedmonts. Moreover, *Tetraclinis* plantations characterize the semiarid mountainous level. A *Juniperus–Quercus* assemblage characterizes the subhumid to humid zones located from about 1,500–2,500 m above sea level [47, 48].

Agriculture is the strength economic activity in the Souss–Massa region. It produces around 30% of citrus exports and 25% of vegetable production in the country. An area of 250,000 ha as a potential irrigable land is mostly located on the Souss plain with 134,295 ha (60%) modernly irrigated. The agricultural production of the region is 34% vegetables, 25% citrus, 10% cereals, and 28% livestock. According to CRTS, the quality of vegetation cover and rain-fed cultivation in March 2015 was medium [49] (Fig. 8).

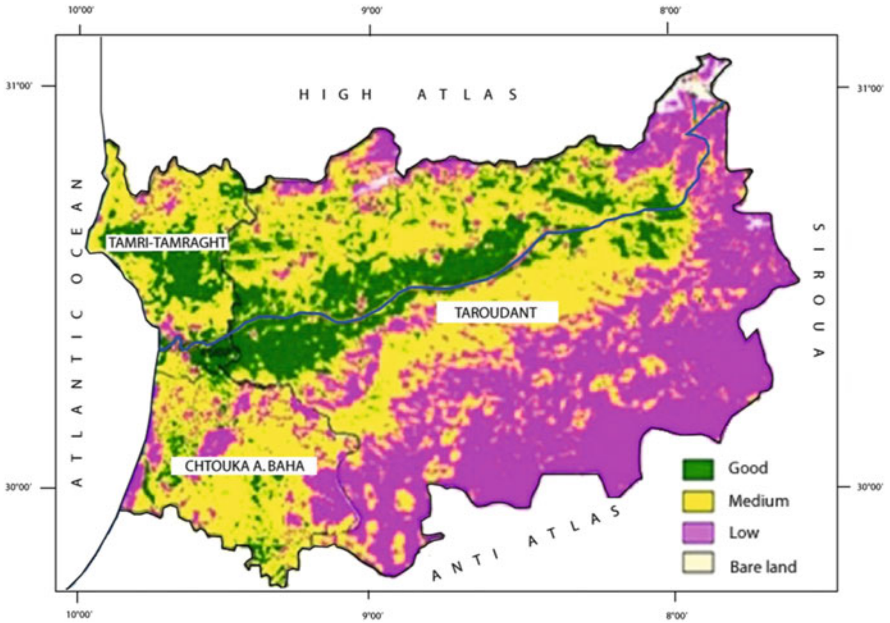

Fig. 8 Vegetation cover quality in the Souss–Massa basin (March 2015 in IMAGE MODIS) (Modified map derived from report 05-2014–2015 established by CRTS)

3 Main Hydraulic Management in the Basin

Large dams are being defined by ICOLD as any dam with maximum height (H), measured from deepest foundation level to highest structure crest level, more than 15 m or 10 m < H < 15 m, and with the following conditions: dam length more than 500 m, reservoir storage capacity more than 3 million m^3, and flood discharge more than 2,000 m^3/s [50] (Fig. 9).

The small dams have a height of 10–25 m and a storage capacity of up to 2 million m^3, while the hillside dams are smaller with a height of 5–10 m and the reservoir volume almost 50,000 m^3 [51, 52].

Since 1970, building dams in the Souss region becomes the strategy used to supply water for the population. Currently, 8 large dams and 16 small dams are now operational in the basin; 7 small dams are still under construction (Fig. 10, Tables 1 and 2).

3.1 Large Dams

Eight large dams are built in the basin and regulate between 345 million m^3 and 364 million m^3 depending on hydrological data and representing just over half of the water surface discharge (Table 1).

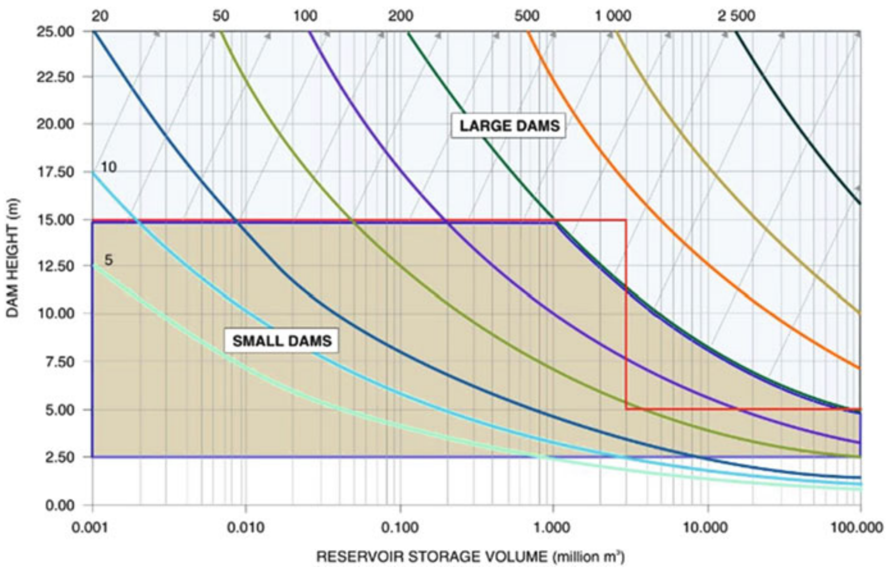

Fig. 9 Classification of small and large dams [50]

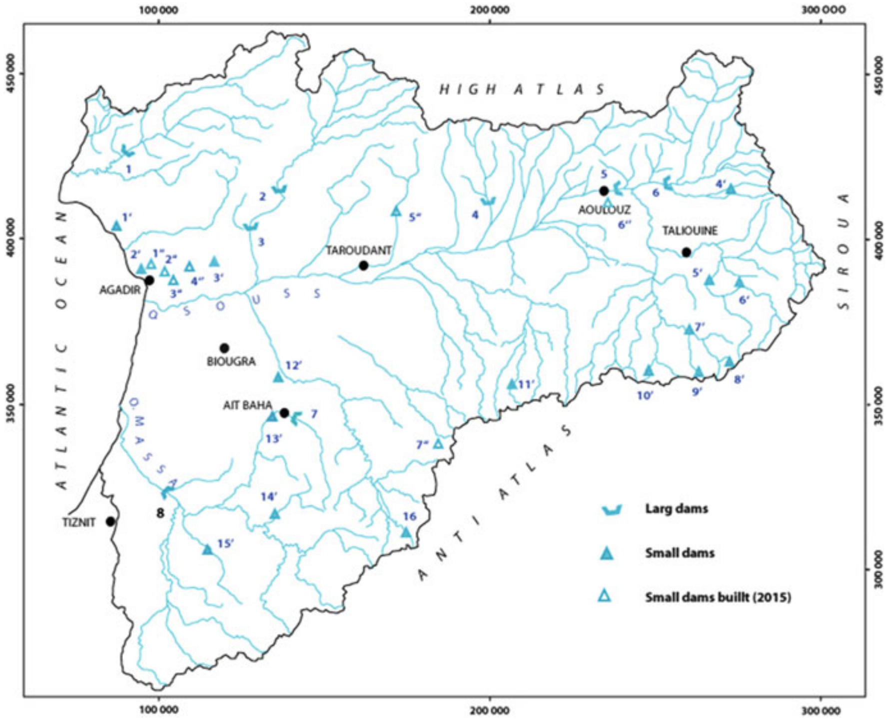

Fig. 10 Existing dams in the Souss–Massa basin (the dam's numbers are include in Tables 1 and 2)

The Aoulouz dam was built in 1981 and aims to support the artificial recharge of Souss aquifer and irrigation. This dam is enhanced by Mokhtar Soussi dam on the downstream in 2002. The second one was built to promote the irrigable area of Sebt Guerdane which was very threatened by drought and groundwater overexploitation. Aoulouz dam regulates about 177 mm^3/year instead of 184 mm^3/year initially expected because of climate change impacts in this region.

The Abdelmoumen dam, built in 1980, supplemented also by Dkhila as dam outlet, with the average discharge expected about 70 mm^3/year. Now, it regulates between 54.9 and 67.4 mm^3/year. This structure aim is to supply drinking water for Agadir city since 1985 and irrigation of 13,000 ha area since 1988 through a supply gallery with a capacity of 5 m^3/s.

The Moulay Abdellah dam, operating since 2002, was also devoted to supply drinking water for Agadir but also for industrial activities. This dam regulates 27.1 mm^3/year, in which 1.26 mm^3/year was nevertheless reserved for irrigation as water right.

The Imi El Kheng dam, operating since 1992, is intended for irrigation of traditional areas located in downstream and for the enhancement of the artificial

Table 1 Synoptic table of large dams

N°	Name	Coordinates	Operating date	Volume (mm³)	Catchment surface (km²)	Aim
1	My Abdellah	30°45′42″N 09°41′ 03″W	2002	110	1,258	WS
2	Abdelmoumen	30°40′30″N 09°11′57″W	1981	201	1,300	I, WS
3	Dkhila	30°34′10″N 09°17′08″W	1986	0.7	100	CD
4	Imi Lkheng	30°40′03″N 08°31′ 55″W	1993	12	293	I, AR
5	Aoulouz	30°41′36″N 08°08′18″W	1991	108	4,744	AR
6	Mokhtar Soussi	30°44′06″N 07°58′48″W	2002	50	1,300	I, AR
7	Ahl Souss	30°03′13″N 09°07′42″W	2004	5	187	WS
8	Youssef ben Tachfine	29°50′45″N 09°29′39″W	1972	302	3,784	I, WS

LV livestock watering, *I* irrigation, *DW* domestic water, *WS* drinking water supply, *AR* aquifer artificial recharge, *CD* compensation dam

recharge of Souss aquifer. The initial regulated volume was 5.5 mm^3/year and updated to a volume between 5 and 5.2 mm^3/year.

The Ahl Souss dam operating since 2005 regulates 2.6 mm^3/year to supply drinking water to Ait Baha city and the suburbs.

Finally, the oldest Youssef Ben Tachfine dam, operating since 1973, is intended to supply drinking and industrial water to the cities of Tiznit and Sidi Ifni and the suburb in the way of supply. The dam aims also to irrigate the Massa and Tassila perimeter. The initial expected volume of the dams was 90 mm^3/year but was updated to 81.8 and 84.6 mm^3/year.

3.2 Small Dams and Hillside Lakes

In the 1980s, the driest years, the government initiated a program to build small dams in order to create opportunities to work in rural areas and reduce poverty (National Promotion Program); the dams built during this program are Tigmi N'Ait Bihi, Tildi, Taguenza, Sellaoun, Sfa, Timicha, Assgherkiss, Anou Issafarn, and Asderm. Other dams are founded by nongovernmental organizations, especially Migration and Development Association, in the Taliouine region: Adghigh,

Table 2 Synoptic table of small dams and hillside lakes

N°	Name	Coordinates	Starting date	Volume (m³)	Watershed surface (km²)	Aim
1′	Tigmi N'Ait Bihi	30°33′50″N 09°42′51″W	1992	80,000	7.95	LW
2′	Tildi	30°27′25″N 09°35′43″W	1991	60,000	15	LW, TF
3′	Taguenza	30°29′00″N 09°23′40″W	1987	348,000	24.5	LW, I
4′	Adghigh	30°43′07″N 07°46′29″W	2000	18,000	32.6	I
5′	Imgoune	30°27′56″N 07°52′30″W	1995	6,000	0.62	A.R.
6′	Tinfate	30°27′46″N 07°44′28″W	1996	10,000	0.88	I
7′	Anighd	30°20′26″N 07°51′55″W	1996	9,000	23.97	I, LW
8′	Imoula	30°14′45″N 07°45′37″W	1999	6,600	4.66	I, LW
9′	Talate	30°13′18″N 07°51′45″W	1998	18,000	16.48	I, LW
10′	Lemdint	30°13′03″N 08°01′21″W	1998	9,000	2.74	I
11′	Sellaoun	30°10′29″N 08°27′7″W	1992	150,000	17.85	I, LW
12′	Sfa	30°10′50″N 09°10′50″W	1985	538,000	8.43	TF
13′	Timicha	30°03′10″N 09°11′40″W	1989	150,000	5.6	LW
14′	Assgherkiss	29°49′32″N 09°12′40″W	1991	67,000	8.25	I, DW
15′	Anou Issafarn	29°38′45″N 09°24′15″W	1989	15,000	2.23	LW
16′	Asderm	29°45′06″N 08°45′40″W	1989	66,000	11.13	LW

LV livestock watering, *TF* tackling the floods, *I* irrigation, *DW* domestic water, *WS* potable water supply, *AR* aquifer recharge

Imgoune, Tinfate, Anighd, Imoula, Talate, and Lmdin [53] (Table 2). Seven others are in progress in order to protect downstream areas against floods: Ghezoua, Lahouar, Talmest, Taourirt, Sidi Abdellah, Ighzer N'Oumazir and Had Imaoune (respectilvely 1″ to 7″ in Fig. 10).

Actually, small dams were found to be very important in the communities' well-being as they contribute a number of uses, which are livestock watering, domestic use, irrigation, groundwater recharge, tackling the floods, fishing, etc.

4 Method and Approach

Several authors have highlighted the relationship between the reservoir's siltation and erosion exerted in their catchments which in turn are linked to the physical parameters of these basins [17, 23, 30, 54–56]. Indeed, the variability of the reservoir's siltation rate is closely related to disparities in water erosion parameters as rainfall, lithology, topography, and vegetation cover [57–59]. Thus, the specific degradation of dam's watersheds can be used for spatial characterization of water erosion exerted in the area [18].

The large and small dams of the Souss–Massa basin are well spread in the area. Their watersheds show lithologic, topographic, hydrologic, and climatic contrasts. Hence, we will use the silting rates of the reservoirs to calculate the specific degradation of their watersheds.

To estimate the annual siltation in different dam's catchments, we have used three approaches:

- Triangulation of the estimated silting level [60]: used for hillside reservoirs
- Bathymetric approach is made by hydraulic agency (BHSMD) to estimate the silting rate in big and in few small dams mainly in Taguenza, Timicha, and Assgherkiss
- The electrical tomography approach applied in Tigmi N'Ait Bihi small dam [60]

The transformation of the annual silting yield to a specific degradation within each catchment is generated using the following equations:

$$\underline{\mathrm{Sy} = \text{Sediment yield (t/year)}:} \qquad \mathrm{Sy} = 100 \times \frac{\mathrm{SV} \times \mathrm{dBD}}{\mathrm{TE} \times Y}$$

where SV represents sediment volume (m^3) estimated by measures based on the three approaches described above and dBD is dry-bulk density (t/m^3) estimated as 1.3 [61]. Y is the age of a reservoir (years), and TE is the reservoir trap efficiency and is calculated by the following equation:

$$\mathrm{TE} = 100 \times \left(1 - \frac{1}{1 + 0.0021 \times D \times \frac{C}{A}}\right)$$

where C is the reservoir storage capacity (m^3), A is the catchment area (km^2), and D is a constant ranging from 0.046 to 1 with a mean value of 0.1 considered in this study [62].

$$\underline{\text{Watershed's specific degradation } \left(\mathrm{m^3/km^2/year}\right):} \qquad \mathrm{SSy} = \left(\frac{\mathrm{Sy}}{1.3 \times A}\right)$$

5 Results

5.1 *Siltation Rates in Large Dams and Deduced Specific Degradation*

Dam's siltation phenomenon preoccupies the managers of these structures. Thus, the yearly monitoring of the silting yield in large dams is one of the main tasks of ABHSMD (Table 3). This measured silting yield is used to deduce the specific degradation of the catchment with an aim to study and analyze the erosion risk in the area.

In Table 3, reservoirs can be divided into three classes (Figs. 10 and 11, Table 1):

- Reservoirs with accelerated siltation and specific degradation (>1,000 m^3/km^2/year): My Abdellah and Mokhtar Soussi
- Reservoirs with medium siltation and specific degradation (from 500 to 700 m^3/km^2/year): Abdelmoumen and Imi El Kheng
- Reservoirs with low siltation and specific degradation (<500 m^3/km^2/year: Youssef ben Tachfine, Aoulouz, Dkhila, and Ahl Souss)

These results, compared to other regions of the country, show that Souss dams are less silted than other dams especially those of the Rif region with marly lithology and humid climate (North basins, Moulouya and Sebou).

The overall rate of sedimentation in the dams of Morocco is about 75 million cubic meters per year. The total sedimentation from all of the dams of Morocco is 1,600 million cubic meters. The latter account is about 9.4 % of the total storage capacity of these dams [63].

Silting yield varies from region to region in Morocco; some dams are more affected than others because of their localization (Table 4) [10, 16, 21, 25, 61, 64–67].

5.2 *Siltation Rates in Small Dams and Deduced Specific Degradation*

The monitoring of the siltation in the small dams was not regular as the large dams. Actually just four of these structures (Taguenza, Timicha, Assgherkiys, and Sfa) are monitored by regular bathymetry measures supervised by ABHSMD. In the other small dams and hillside lakes, the siltation is evaluated by other methods [60]. Table 5 shows the siltation rate in dams of the Souss–Massa basin and the corresponding specific degradation of their catchments.

In the same way as the large dams, the small ones can also be divided into three classes (Fig. 10 and Table 5):

Table 3 Large dam's siltation and specific degradation in the Souss–Massa basin (internal report of ABHSMD, 2014)

Dam	Initial capacity (mm^3)	Initial volume last bathymetry (mm^3)	Date of last bathymetry	Lost volume (mm^3)	Percentage loss (%)	Duration (years)	Annual silting (mm^3/an)	Specific degradation ($m^3/km^2/y$)
Youssef Ben Tachfine	313.77	298.2	2010	15.57	5.0	38	0.41	108
Abdelmoumen	222	198.4	2011	23.6	10.6	30	0.79	605
Aoulouz	108.245	89	2011	19.25	17.8	20	0.96	216
Dkhila	0.716	0.2	2003	0.516	72.1	17	0.03	304
Imi El Kheng	12	9.76	2007	2.24	18.7	14	0.16	546
Mokhtar Soussi	52.16	39.8	2010	12.36	23.7	8	1.55	1,188
My Abdellah	110	90.6	2011	19.4	17.6	9	2.16	1,713
Ahl Souss	5.05	4.6	2010	0.45	8.9	6	0.08	401

Fig. 11 Specific degradation (m^3/km^2/year) in large dams of the Souss–Massa basin

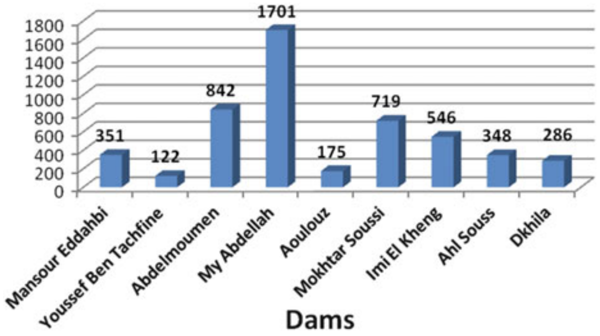

Table 4 The siltation rate of other dams in Morocco

Basins	Dams	Initial capacity (mm^3)	Lost volume (mm^3)	Lost volume (%)	Average lost volume/year (mm^3)
North basins: Loukos, M'hargar, Hashef, Mediterranean coastal, and Nekor	O. Elmakhazine	807.0	35.6	4.4	3.2
	Ibn Battouta	43.6	8.5	19.5	0.6
	Nakhla	13.0	7.3	56.2	0.2
	Smir	43.0	–	–	0.2
	9 Avril 1974	300.9	–	–	0.5
	MB. Alkhatabi	43.0	9.5	22.1	1.0
Moulouya	Mohamed V	725.0	314.0	43.3	11.6
	M. Hommadi	:42.0	35.4	84.3	1.0
Sebou	Idriss Ier	1,217.0	40.0	3.3	1.9
	Allal Elfassi	81.5	7.3	9.0	1.2
	Alwahda	3,770.4	–	–	11
	Sidi Echahed	170.0	–	–	0.24
	Elkansera	330.0	69.6	21.1	1.2
Oum Er Rbia, Atlantic coastal, and Tensift	S.M.B. Abdellah	509.0	52.0	10.2	2.5
	Bine El Ouidane	1,484.0	183.7	12.4	4.5
	My Youssef	197.0	39.6	20.1	2.5
	Hassan Ier	272.0	24.9	9.2	2.5
	Sidi Driss	7.0	3.3	47.1	0.4
	Al Massira	2,785.0	25.0	0.9	3.1
	Lalla Takerkoust	78.0	9.2	11.8	0.2
South basins: Souss, Massa Draa, Ghriss, and Ziz	Abdelmoumen	216.0	1.0	0.5	0.1
	Aoulouz	108.0	–	–	1.2
	Y.B. Tachfine	320.0	17.9	5.6	0.8
	Mansour Eddahbi	592.0	106.0	17.9	4.8
	Hassan Eddakhil	369.0	22.0	6.0	1.2

Table 5 Small dam's siltation and specific degradation in the Souss–Massa basin

Area	Dam's name	Dam's age (until 2012)	Siltation rate (%)	Annual silting (t/year)	Specific degradation ($m^3/km^2/y$)
Anti-Atlas	Sfa	27	16	4,872	248
	Timicha	23	10	951	191
	Assghrekiss	20	15	1,112	85
	Issafarne	23	30	435	150
	Asderme	23	45	3,058	211
High Atlas	Tiguemi A. B.	21	75	5,472	529
	Tildi	21	95	8,117	381
	Taguenza	25	42	7,129	291
Siroua Taliouine	Sellaoun	17	53	9,586	413
	Lemdint	10	28	618	174
	Talate	10	100	10,422	486
	Imoula	10	44	1,453	240
	Anighd	13	61	8,245	265
	Imgoune	14	10	306	179
	Tinfate	13	56	313	275
	Aguelmim	9	18	2,793	310
	Adghigh	9	100	24,598	592

Fig. 12 Example of high and moderate dam's siltation: Assgherkiss dam with low siltation and Tildi dam completely silted

- Very rapidly silted lakes (between 5,472 and 24,598 t/year) that correspond to a high specific degradation of watersheds (381–592 m^3/km^2/year): Sellaoun, Tigmi N'Ait Bihi, Tildi, Adghigh, and Talate. The last four lakes are completely silted up and are currently out of use (Fig. 12).
- Lakes with moderate siltation (306–1,112 t/year) with specific degradation of watersheds are also very moderate (between 85 and 191 m^3/km^2/year): Assgherkiss, Issafarne, Imgoune, Lemdint, and Timicha.

- The other lakes show a medium silting (between 313 and 8,245 t/year) that corresponds to a watershed's specific degradation between 211 and 310 m^3/km^2/year: Aguelmim, Tinfate, Anighd, Imoula, Taguenza, Sfa, and Asderm.

6 Discussion: Dam's Siltation and Erosion

It has been possible to calculate the specific degradation of watersheds from the siltation rate of the various dams in Souss–Massa. It is noted that these degradations are related to the basins characteristics. So, the watersheds can be subdivided into three classes:

- Heavily degraded watersheds including those of My Abdellah and Mokhtar Soussi large dams and Sellaoun, Tigmi N'Ait Bihi, Tildi, Adghigh, and Talate small dams. My Abdellah, Tigmi N'Ait Bihi, and Tildi dams are located in western High Atlas Jurassic age, formed by marl and limestone known to be very brittle and highly erodible [68–70]. The meandering morphology of rivers and tributaries accelerates the erosion phenomenon by bank erosion (Fig. 13) [71, 72].
  Mokhtar Soussi, Sellaoun, Talate, and Adghigh watersheds are situated in the Anti-Atlas and Siroua high altitudes of Precambrian age where physical alteration of igneous rocks (especially the granite) provides an arena easily carted by bed load transport especially at steep slopes (Fig. 14) [73, 74].
- The least degraded watersheds including Youssef Ben Tachfine, Aoulouz, Dkhila, and Ahl Souss large dams and Assgherkiss, Issafarnes, Asderm, Timicha Lemdint, and Imgoune small dams. Such low specific degradations are explained as follows:
  - The watersheds are located in the Western Anti-Atlas mountain of Precambrian age, compound by volcano-sedimentary and metamorphic rocks known

Fig. 13 Bank erosion and its consequence in Tildi dam. The turbid color of water reflects the eroded marl formation

Fig. 14 Dam's silting by bed load transport in high altitude: case of Adghigh and Talate dams

Fig. 15 Example of watersheds managed by anti-erosion structure in Anti-Atlas Mountains

to be resistant to erosion [33, 34]. Moreover, the tectonic stability of the Anti-Atlas creates low hydraulic slope (case of Youssef Ben Tachfine, Ahl Souss Assgherkiss, Issafarnes, Asderm)

- The watershed situated in the plains (case of Timicha)
- The watersheds managed by anti-erosion structure (case of Lemdint and Imgoune, Fig. 15)

• Moderately degraded watersheds including Abdelmoumen and Imi El Kheng large dams and Aguelmim, Tinfate, Anighd, Imoula, Taguenza, Sfa, and Asderm small dams. Abdelmoumen and Imi El Kheng watersheds are located at the High

Atlas of primary age with argillaceous, sandy, and schistous lithology [33, 34]. The others watershed are situated in areas formed by moderately erodible lithology, in areas covered by vegetation (case of Taguenza) or watersheds of restitution dams (Dkhila and Moukhtar Soussi).

- This spatial repartition of specific degradations shows that:
- Water erosion in the Souss–Massa basin is mainly controlled by lithologic, topographic, hydrologic, tectonic, and human factors. Indeed (1) the most eroded watersheds are those formed by erodible geological formation such as limestone and marl of western High Atlas and granitic formation of central Anti-Atlas and Siroua; (2) steep slopes at high altitudes generate runoff and bed load transport; (3) the meandering morphology of river causes bank erosion especially in marl regions such as High Atlas; and (4) tectonic instability operated in the High Atlas with alpine orogenesis (Cenozoic, 66 million years ago until present) generates more aggressive erosion than at the tectonically stable Anti-Atlas with Pan-African orogeny (640 at 600 million years ago) [75–79].
- There is remarkable soil loss in the whole basin, but it is especially significant in two main regions, which are located in the southern slope of the western High Atlas and in the high altitude area. This spatial distribution of water erosion in the Souss–Massa basin agrees perfectly with previous researches (Fig. 16) [26–31, 80].

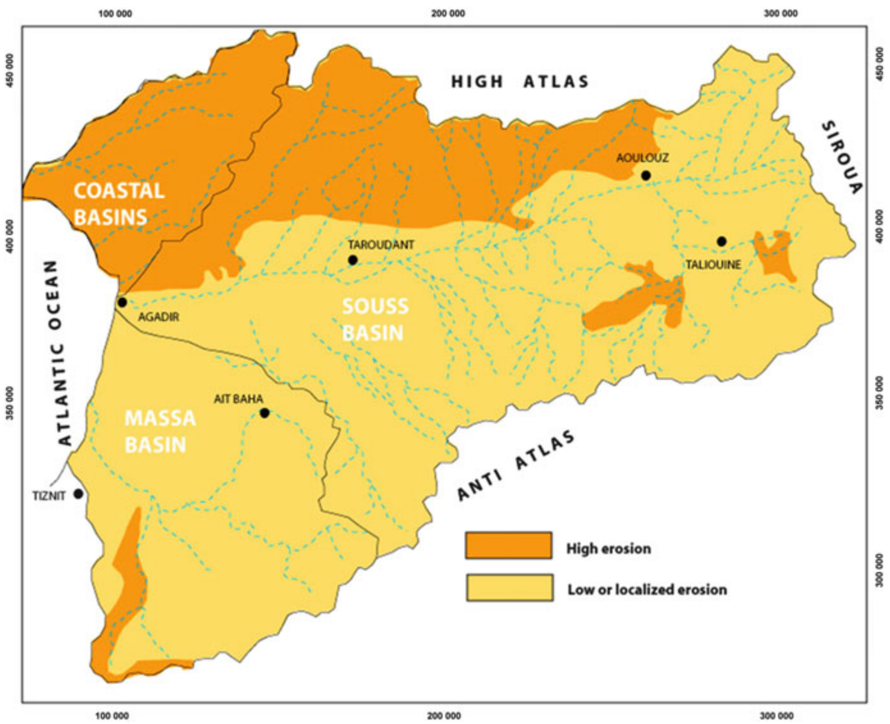

Fig. 16 Erosion quality in the Souss–Massa basin (ABHSMD in [80])

The water erosion throughout the Souss–Massa catchment estimated between 340 and 660 t/km^2/year seemed to be very low compared to other catchments in Morocco especially the Rif region in northern part of the country where the specific degradation exceeds 2,000 t/km^2/year [22, 64]. Currently, in the Souss basin as in all Moroccan territory, the impact of climate change is clearly observed since 1980. Erosion is widely accelerated because of successive drought periods and the erratic and unpredictable rainfalls [5, 81].

7 Conclusion

Dam's siltation is a natural phenomenon induced by water erosion exerted in their watershed that is linked to watershed characteristics in terms of topography, lithology, vegetation cover, hydrology, and also human activities.

Indeed, it is possible to deduce the watershed's specific degradation from the annual siltation of these lakes and consequently to characterize water erosion especially if those dams are well distributed in the region.

Dam's silting study in the Souss–Massa basin shows that water erosion is closely controlled by geology, river morphology, topography, and tectonic history of Anti-Atlas and High Atlas mountains. Indeed, the High Atlas where alpine neo tectonic is active induces accelerated erosion especially in areas containing marl and calcareous rocks. However, in the Anti-Atlas with stable Pan-African tectonic, erosion is currently low except in high altitudes where physical alteration of magmatic rocks produces sandy materials easily carted by bed load transport in mostly high latitude areas. We note that the meandering morphology of rivers and tributaries accelerates the erosion phenomenon by bank erosion.

These results will be useful for decision makers to select the future sites of dams and to develop efficient water resource management.

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Assessment of Climate and Land Use Changes: Impacts on Groundwater Resources in the Souss-Massa River Basin

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Abstract This work investigates the current climate situation in Souss-Massa river basin (southwestern Morocco) and the impacts of climate change and land use on groundwater resources in Morocco. The annual rainfall amount ranges from 100 mm in the plains to 600 mm in the High Atlas Mountains. However, climate data indicate an overall decrease of precipitation during the three last decades, coupled with an increase of temperature. This recent climate situation, faced with growing population and increasing water demands, results in depletion of surface and subsurface water resources. Indeed, recurrent droughts and decreasing recharge of aquifers affect groundwater levels. Moreover, the overexploitation of groundwater resources explains the witnessed water crisis in the study area, which is predicted to be particularly more affected by climate change in the future. The depletion of groundwater level induced by limited recharge and overexploitation has induced degradation of water quality in the Souss-Massa plain aquifer. The climatic change effect coupled with the pressure of human activities manifested in the intensification of agricultural activities using fertilizers highly affects the water quality with high nitrate contents.

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Contents

1 Introduction

Global warming is the observed century-scale rise in the average temperature of Earth's climate system [1]. It is one of the most complex challenges of the twenty-first century. No country is immune to its effects, and no country can alone deal with controversial political decisions, underlying technological changes, and other issues inextricably linked with serious consequences across the globe. At the same time, as the atmosphere warms, rainfall patterns change and extreme events such as droughts, floods, and forest fires become more frequent [2].

Since the late 1970s, the occurrence of drought years increased in Northwest and West Africa presenting a major constraint to the future economic and agriculture developments of these regions [3]. In Morocco, the climate is controlled by two main climatic systems: the Mediterranean Northern coastal system and the Southern interior systems, which lie on the edge of the hot Sahara desert [4]. The latitudinal extension of Morocco, the geographical and hypsometric diversities, and the ocean influence also play a role in determining climate types. As a matter of fact, drought has always been present in the history of Morocco, but during the recent decades, it has forcefully become a structural element of the country's climate. Morocco is currently experiencing the longest dry period in its modern history, which is characterized by a decrease in precipitation and a clear trend of rising temperatures [5]. This fact is also confirmed by Tramblay et al. [6, 7], who predict a decrease in surface runoff and precipitation and an increase of temperatures. On the other hand, the limited water resources in Morocco are threatened by increasing demands, non-equitable distribution, and accelerated quality degradation. In addition, the Intergovernmental Panel on Climate Change (IPCC) predicts that the annual rainfall is likely to decrease in much of Mediterranean Africa and northern Sahara, with the likelihood of a decrease in rainfall increasing as the Mediterranean coast is approached ([8], Chapter 11, p. 866). Consequently, projections for future renewable water resources in Morocco are bleak, and climate change coupled with increasing water demands is likely to exacerbate the water crisis in Morocco.

Due to its large geological diversity, a broad range of aquifers from almost all the geological periods are present in Morocco. Overall, 32 deep (200–1,000 m) and 48 shallow aquifers are tapped in Morocco. The deep aquifers are often not accessible due to the high economic cost of drilling, whereas the shallow aquifers are more accessible, but also more vulnerable to climate change, pollution, and evaporation.

The present study focuses on the Souss-Massa river basin, which is the transition zone between the Atlantic and Saharan Moroccan regions. Bordered by the Atlantic Ocean to the west, the High Atlas ranges to the north, and the Anti-Atlas ranges to the south (Fig. 1), this basin extends on an area of 22,600 km^2, with only 5% of lowlands (5,550 km^2) and 75% of mountainous area (17,050 km^2).

In this chapter, we review the observed aspects showing the current state water resources in Morocco through the case of the Souss-Massa basin under the pressures of demographic growth and climate change and natural climate variability. This study aims to evaluate the recent climate variability and trends observed in the Souss-Massa region and the potential impacts that these changes could have on groundwater resources in terms of quantity and quality, along with land use.

2 Climate and Water Resources in the Souss-Massa Basin

2.1 Climate Context

Souss-Massa basin's mean climate is semiarid to arid, with exception in the western High Atlas peaks to pre-Saharan, where it varies from humid with cold winter to with cold winter in the plain area, respectively. The arid nature is mitigated by the proximity to the Atlantic Ocean. In this region, climate is under the influence of the cold Canary Current and the mountain barrier of the Anti-Atlas, which provides a protection against the southern winds [9]. As shown in Table 1, the annual temperatures range from 14°C in the High Atlas area in the north to 20°C in the Anti-Atlas area in the south. However, the mean annual temperature estimated for the period 1981–2010 (Fig. 2) indicates that mountainous areas in the east present the lowest temperature values, while the highest temperatures exist in the southwestern part of

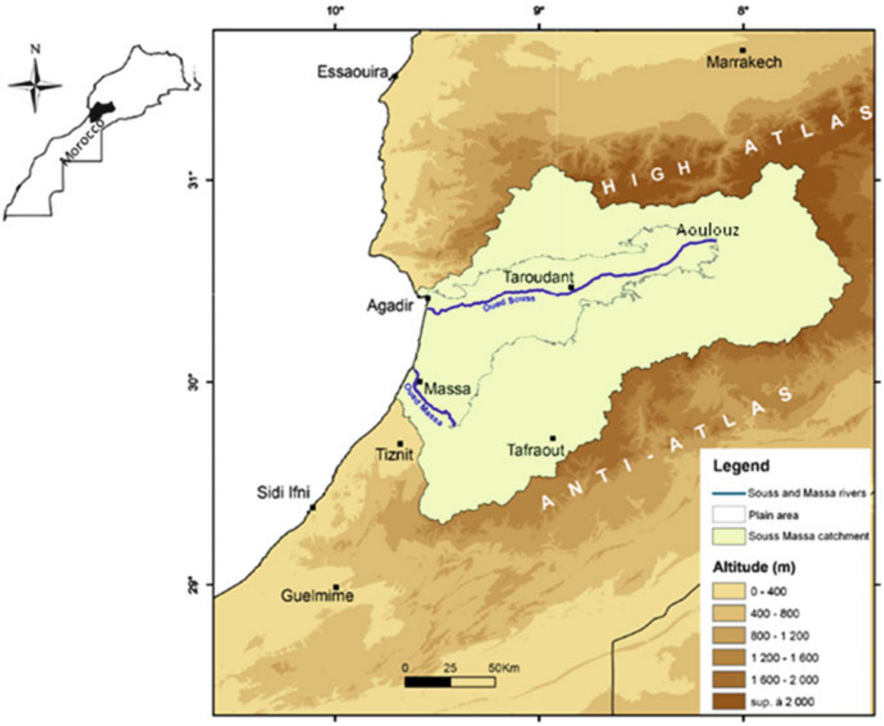

Fig. 1 Location of the Souss-Massa river basin

Table 1 Annual temperature in Souss-Massa basin

Station	Agadir	Abdelmoumen Dam	Aoulouz Dam	Issen Pont	Taroudant	Youssef Ben Tachfine Dam
T (°C)	18.3	20.6	19.9	19.3	19.7	19.9

the basin. The maximum daily temperature reaches, during the summer, 49°C, and the minimum temperature, during the winter, drops to −3°C. The temperature difference between the minimum and maximum daily temperatures is also high and can reach 48°C.

The annual evaporation varies from 1,400 mm in the mountains and near the Atlantic coast to 2,000 mm in the plains of Souss, Massa, and Tiznit. The minimum (maximum) is recorded in January (July) with an average of 35 mm (240 mm) in the mountains and 100 mm (270 mm) in the plains.

Precipitation events in the study area have a high spatial and temporal variability. The rainy season extends from November to March and the dry season from April to October (Fig. 3). Locally, the rainfall varies in time and space, ranging from 200 mm/year in the plain (mean altitude, 460 m.a.s.l.) to more 600 mm/year in the mountains (altitude 700 m.a.s.l.). Inside the wet season, rainfall occurs in two

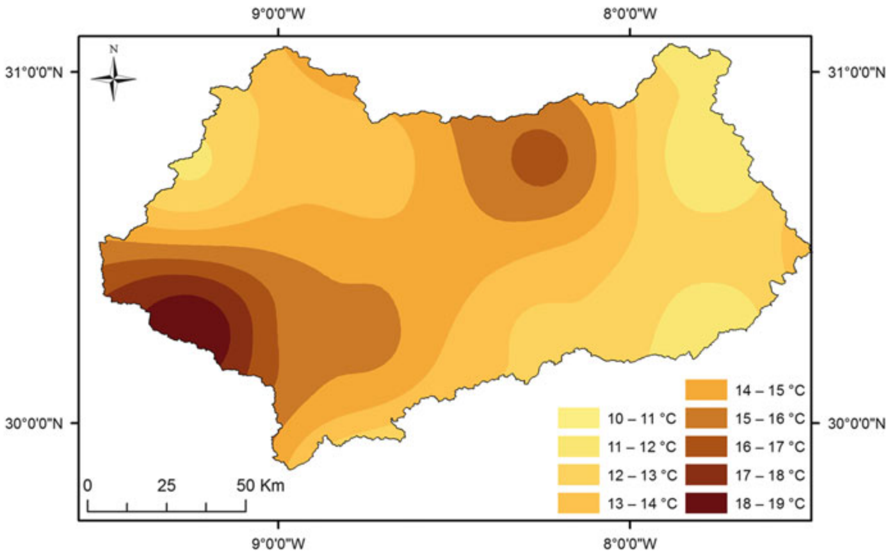

Fig. 2 The mean annual temperature in the Souss-Massa river basin (1981–2010)

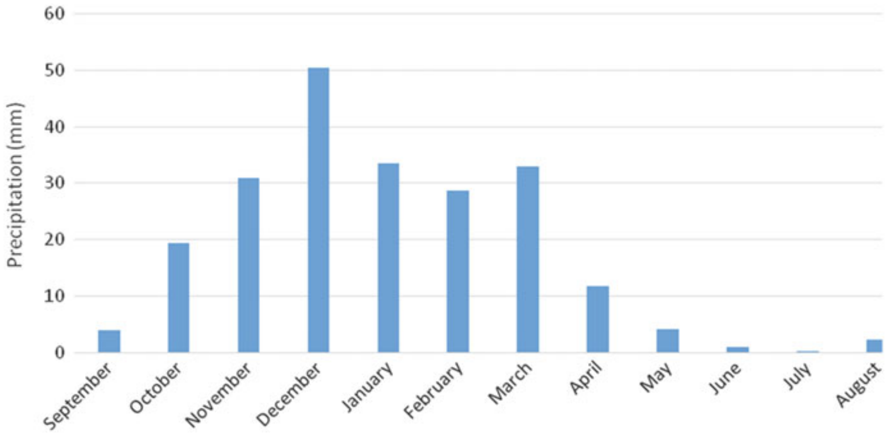

Fig. 3 Annual cycle of precipitation in Souss-Massa basin, based on monthly data at Agadir station from 1980 to 2013

rainy periods: during the winter with a peak in December and during the spring with a peak in March.

On interannual timescales, the mean annual precipitation, calculated for the period 1998–2015 (Fig. 4), indicates that the highest rainfall amounts occur in the High Atlas mountain areas (600–650 mm/year), while the lowest values exist in the southeast (100–150 mm/year).

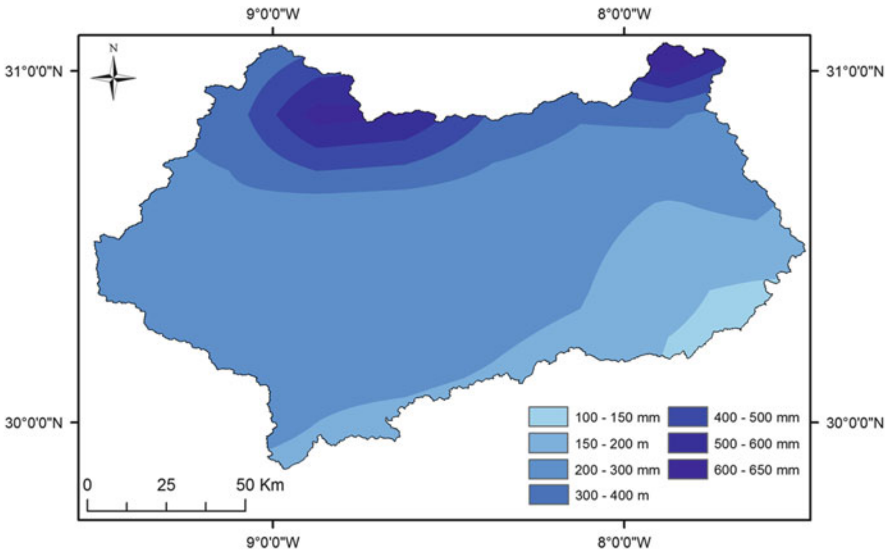

Fig. 4 The mean annual precipitation in Souss-Massa river basin (1998–2015)

The average annual rainfall varies from 600 mm in the north on the peaks of High Atlas Mountains to 150 mm in the south on the eastern part of the Anti-Atlas. The plain receives about 200 mm of rain. As a general rule, the rainfall decreases from the north to the south and from the west to the east.

For the plain of Tiznit, the rainfall amount decreases from the east to the west, from the Kerdous inlier (200 mm/year) to the center of the plain (180 mm/year), and from the north to the south, from the plain to Sidi Ifni inlier.

2.2 Surface Water Resources

Surface water resources in the regions of Souss-Massa, Tiznit, and Sidi Ifni are limited and very irregular. Like rainfall, the discharge of rivers has a high interannual irregularity. The average annual discharge of the Souss-Massa river is estimated at 652 million m^3. It varies from a minimum of 35 million m^3 (1960–1961) and a maximum of 2,160 million m^3 (1962–1963).

- The Souss Basin: the average annual discharge of Oued Souss at Aoulouz station is about 185 million m^3. It is supplied by tributaries of the High Atlas and Anti-Atlas ranges for which the contribution is about 237 million m^3 (190 million m^3 from the right bank and 47 million m^3 of the left bank).
- The Massa Basin: the Massa river is drained by the tributaries of Amaghouz and Assaka, which both start from the Anti-Atlas ranges. The average annual discharges of Massa river are estimated at 138 million m^3.

- The Atlantic coastal basins of Tamri and Tamraght: the Atlantic coastal basins in this area are drained by two main rivers: the Tamri and Tamraght which originate from the Western High Atlas. The average annual contribution of these rivers is estimated at 25 million m^3 in Tamraght and 50 million m^3 in Tamri.
- The Tiznit-Adoudou basin: the average annual contribution of Adoudou Basin is estimated at 8.7 million m^3.
- The Sidi Ifni basin: the average annual contributions of Sidi Ifni basin is estimated at 6.15 million m^3 per year.

2.3 Groundwater Resources

The groundwater system consisting of Souss and Chtouka aquifers is the main aquifer in the Souss-Massa region. This system contains the most important part of water resources in the region and plays a key role in its socioeconomic development.

2.3.1 Souss Aquifer

The hydraulic basin of Souss aquifer extends over an area of 4,150 km^2. It is bordered by the High Atlas to the north and the Anti-Atlas to the south and leads to the Atlantic Ocean in the west. The Souss valley is formed by filling formations, with ages ranging from Eocene to Quaternary, and contains the largest aquifer in the country.

The thickness of the aquifer varies from 150 m approximately, between Arazane and Taroudant, to 500 m in the downstream of Oulad Teima. The depth of water increases gradually with distance from the river of Oued Souss. It is comprised between 10 and 30 m near the river, drops to 25–35 m downstream Oulad Bourbia, and exceeds 70 m upstream Loulija and Sebt El Guerdane. The general groundwater flow occurs from the east to the west, and the average hydraulic gradient decreases from upstream to downstream.

2.3.2 Chtouka Aquifer

The aquifer of Chtouka is a southwest extension of the Souss valley that covers an area of over 940 km^2. It is bordered by the road of Agadir-Biougra to the north, the Anti-Atlas outcrops of primary formations to the east, the Massa river to the south, and the Atlantic Ocean to the west. The main reservoir of this aquifer consists of sandstone dunes with sandy formations and Quaternary intercalated lacustrine limestone levels. In the Biougra area, the aquifer thickness varies from 50 to

300 m. Along the Massa river, the water table is shallow, except the dune area where groundwater can be found at depths of 65 m.

3 Observed Climate Change in the Souss-Massa Basin

3.1 Trends in Temperature and Precipitation

According to Bouchaou et al. [10], the monthly values of temperature in Morocco indicate an increase during the last decades since 1970. The interannual evolution of temperature in Morocco is more significant in the continental areas than the coastal regions. This fact is confirmed in the Souss-Massa basin, as the highest positive temperature anomalies are observed in the eastern part, while the lowest anomalies are recorded in the coastal zone in the western part of the basin (Fig. 6a). Moreover, the slight increase observed in the annual temperature data from Agadir-AlMassira station (Fig. 5a) is explained by its proximity to the coast. On the other hand, the average number of rainy days in Souss-Massa basin is about 30 days/year and can reach a maximum of 60 days in the High Atlas area. The time evolution of the annual number of rainy days in the Souss-Massa basin shows a high variability without any significant trend (Figs. 5b and 6).

According to Tramblay et al. [11], Morocco is highly vulnerable to extreme precipitation events. In the Souss-Massa basin, precipitation data exhibit a high variability. This irregularity depends on atmospheric circulations (including the movement of Azores High toward southwest and the installation of depressions on the Moroccan offshore), which would produce interesting rainy disturbances over the country [12]. The long-term mean annual precipitation data, from the stations of

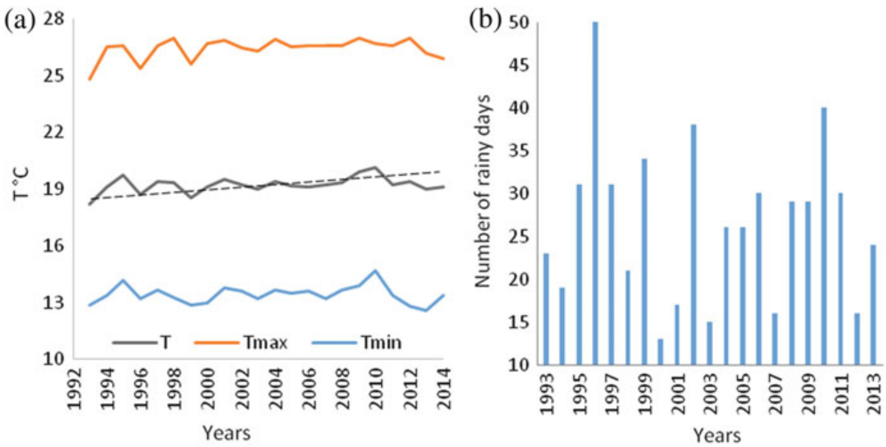

Fig. 5 Evolution of interannual temperature (**a**) and number of rainy days (**b**) in the Souss-Massa river basin

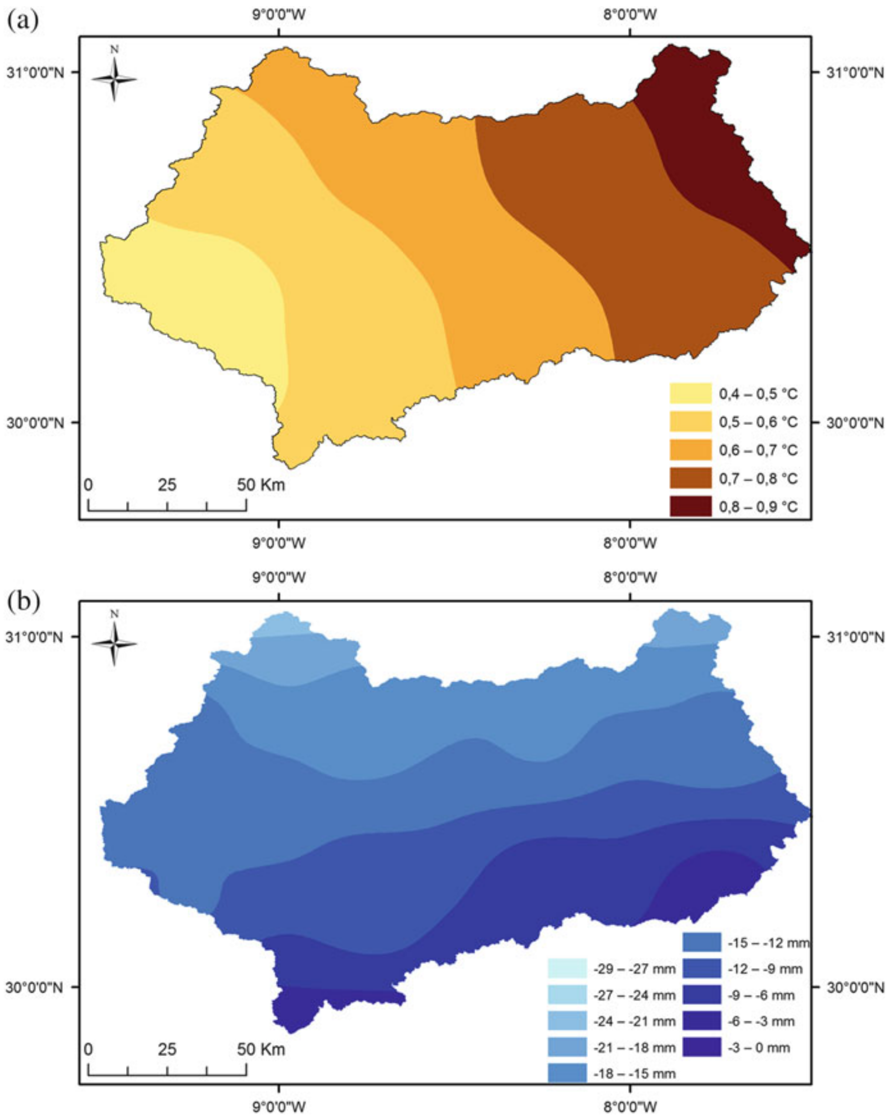

Fig. 6 Temperature (**a**) and precipitation (**b**) anomalies in the Souss-Massa river basin, calculated as the departure between 1981 and 2010 and the reference period 1951–1980

Agadir, Taroudant, Aoulouz, and Youssef Ben Tachfine, reveal a clear decrease in 48 years (1960–2007) in the Souss-Massa basin (Fig. 7). The variation of rainfall is very important in time and space showing a clear decrease from the north (−28 mm/year) to the south (less than 3 mm/year) (Fig. 6b). The monthly values indicate a decrease over the last three decades after the most important intensity during the 1960s.

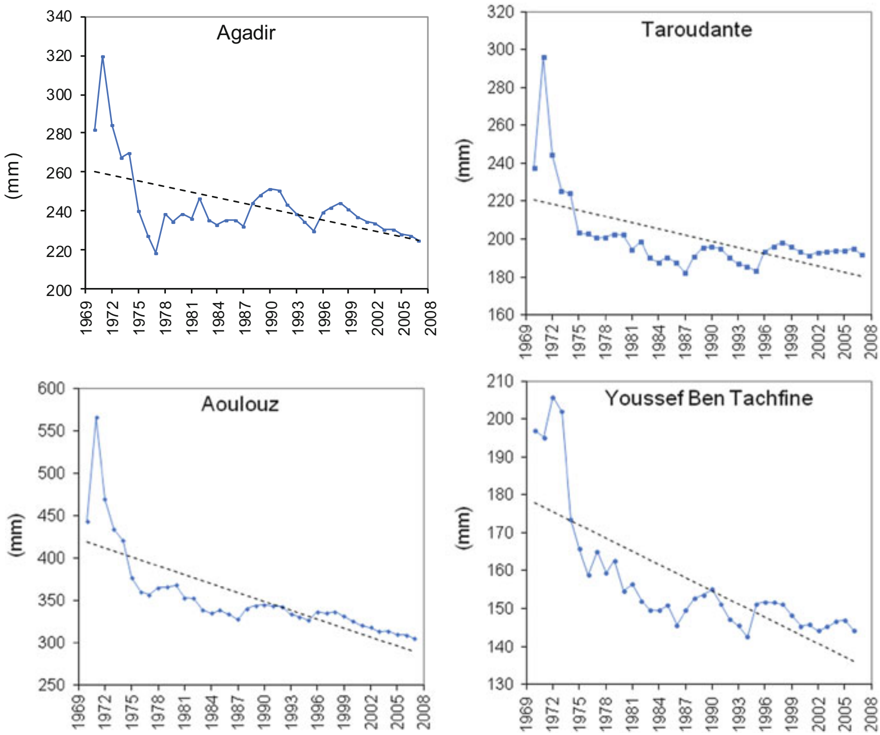

Fig. 7 Annual variation of precipitation in the Souss-Massa basin

The Souss-Massa river basin experiences a high interannual variability of the scarce rainfall distribution making it most vulnerable to climatic change. In this context, increased variability of rainfall and temperature in the region, associated with climate variability and change, implies increased vulnerability. This is likewise true for changes in land use, agricultural production, and other climate variability that affects and responds to the water resources. These changes are often amplified by an increase in population numbers or density or decreasing water supply (Bouchaou et al. [10]).

3.2 *Drought Periods*

Drought is an extreme hydrological phenomenon, usually unpredictable. It results in a significant reduction of water resources for a sufficiently long period of time, over a wide geographical area. Morocco suffers from more severe and recurrent droughts combined with an increasingly growing water demand [13]. During the last three decades, the random fluctuations in precipitation (disorderly succession of dry years and wet years) are superimposed to an overall downward in precipitations.

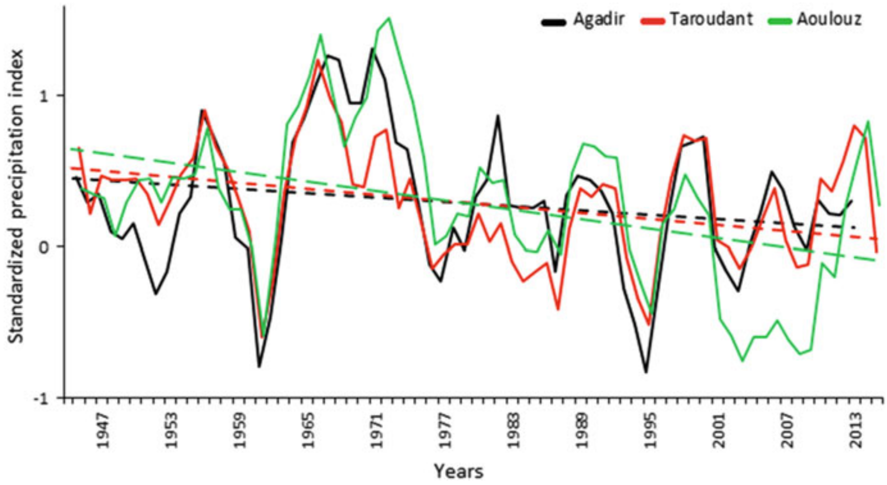

Fig. 8 5-year moving average of SPI in Souss-Massa river, calculated using precipitation data from Agadir, Taroudant, and Taroudant stations, covering the period 1945–2015. Superimposed dashed lines indicate the corresponding long-term trends

According to Sebbar et al. [14], this decrease varies, by region, between 3% and 30%. According to Gommes et al. [15], the deficit areas in precipitation (north and central Morocco) correspond, paradoxically, to the areas of intense agricultural activities and large population concentrations.

A number of problems associated with increasing water scarcity and recurrent and extended droughts have been noticed in the Souss-Massa area particularly in the past few decades [16, 17]. The extended drought periods are often thought to be related to climate variability arising and can be indicators of climate change. The studies supporting these observations in the area are being carried out. The analysis of drought periods in the Souss-Massa basin, herein, is based on the calculation of the standardized precipitation index (SPI) and standard discharge index (SDI). The SPI was calculated from precipitation data at two stations: Agadir and Taroudant, while the SDI is calculated based on the annual discharge of Souss-Massa river.

The annual evolution of SPI shows a high variability in both stations (Fig. 8). However, the annual trend of SPI indicates a clear decrease for both stations. Likewise, the frequency of dry years ($SPI < 0$) has clearly increased since 1970. As for the interpretation of the SDI, drought periods are identified as those with a permanently negative annual SDI values and a cumulative SDI reaching an intensity of -1 or less. The phenomenon ends when the annual SDI becomes positive. Therefore, the severity of a dry period depends on the cumulative SDI of all the years within the same period (Fig. 9).

The calculations allowed the identification of the following drought periods as presented in Table 2:

- The period 1956–1961 seems to be the driest and longest (5 years) from all the data. The average discharge in this period is equal to 436 million m^3.

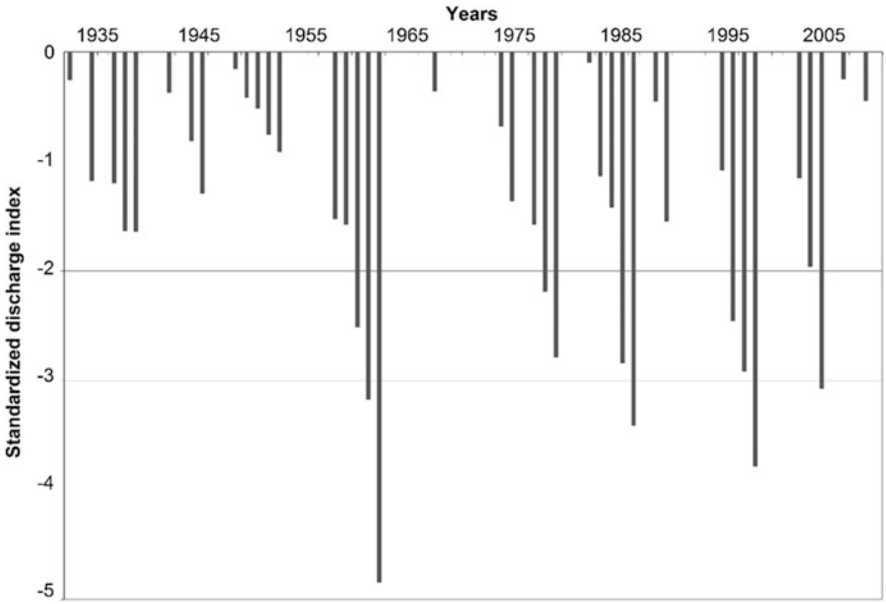

Fig. 9 Annual variation of SDI in the Souss-Massa basin

Table 2 Severe and extreme drought periods in the Souss-Massa river basin between 1930 and 2007

Period	Duration (years)	Average surface water discharge (Mm^3/year)	Classification
1936–1939	3	537	Severe
1956–1961	5	436	Extreme
1975–1977	3	445.5	Extreme
1981–1984	4	470	Extreme
1992–1995	4	441.5	Extreme
1999–2001	3	423	Extreme

- The short-term period (3 years) from 1998 to 2001 is characterized by 2 years of extreme droughts. The average discharge is the lowest record with only 423 million m^3.

The rainfall decrease observed in precipitation series (1970–2007) clearly explains the general decline of surface water discharge in the study area since the early 1970s. It also reveals that drought periods are interspersed with wet years (1987–1990 and 1995–1998).

In general, since the early 1970s, the frequency of extreme droughts has increased remarkably. These periods, which could be potential manifestations of climate change, acquire a particular attention.

Their impacts on groundwater resources appear particularly on two levels:

- The decrease of rainfall and surface water discharge reduces substantially the groundwater table level. In fact, the hydrologic balance of aquifers showed high recharge deficits of around 40–50%.
- The decrease of surface water inputs and the increasing water demand resulted in the increase of the pressure applied on the groundwater resources.

4 State of Land Use in the Souss-Massa Basin

4.1 Land Cover

The land use map, made by using the global land cover data from the Food and Agriculture Organization (FAO), shows the presence of eight soil classes that are the most abundant in the Souss-Massa region (Fig. 10). The detailed statistics related to different soil cover classes are shown in Table 3. They indicate that the most abundant soil classes correspond to sparse vegetation, bare soil, and cropland.

The analysis of the table associated with the land use map revealed these remarkable facts:

- 75.26% of the area is equally split between the sparse vegetation and bare soil. This high proportion demonstrates aridity, overgrazing, and forest degradation plaguing the Souss region [18]. This phenomenon is directly related to human activity and climate conditions.

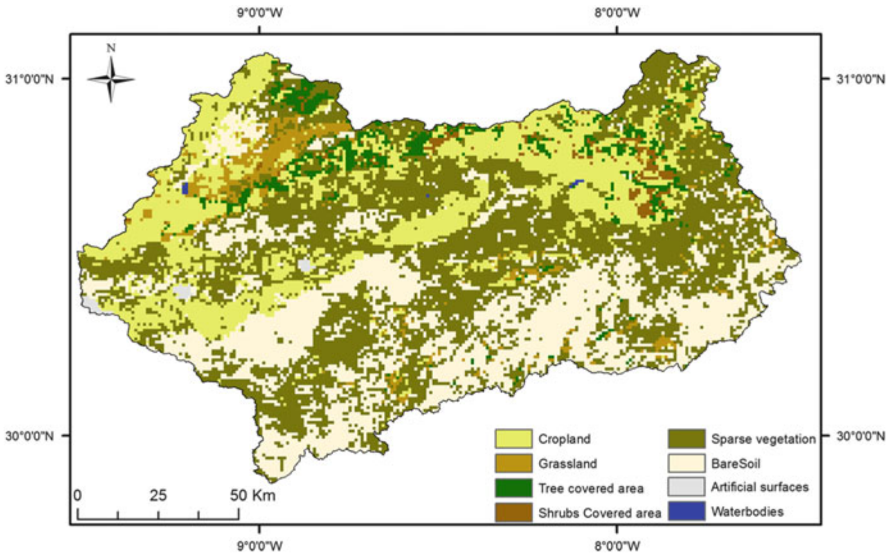

Fig. 10 Land cover map, based on the FAO data, showing the most abundant soil classes in the Souss-Massa basin

Table 3 Statistics of different categories of land cover in the Souss-Massa basin

Global land cover Souss-Massa 2013	Approx. km^2	% of total area in 2013
Sparse vegetation	14,790	37.66
Bare soil	14,767	37.60
Cropland	6,614	16.84
Grassland	1,646	4.19
Tree-covered areas	922	2.35
Shrubs-covered areas	305	0.78
Artificial surfaces	130	0.33
Water bodies	98	0.25
Total catchment	39,272	

- 16.84% of the area is mainly cultivated with cereals (35%), citrus fruits (21%), and vegetable crops (14%) (Table 4). However, the cultivated area varies from one year to another depending on the market demand. The crop year depends on the availability of water.

Actually, there are two forms of changes in agricultural areas in the Souss-Massa region: (1) trends to deterioration or (2) trends to the development of an adapted irrigated farming [19]. The first case is mainly related to the pressure of urbanization (western part), degradation of soils (southern part), and overexploitation/ depletion of groundwater (El Guerdane). The second case is considered as the most dominant, since the study area is experiencing the appearance of new irrigated farms which add more pressure on groundwater resources, along with the reduction of renewable resources following the succession of drought years.

4.2 *Overexploitation of Groundwater Resources*

Only 0.25% of the Souss-Massa area is occupied by surface waters. This is justified by the arid climate and scarce rainfall. Consequently, the use of groundwater is essential to meet the needs of the population, especially in agriculture. Manifestations of water scarcity include, among others, an alarming decline of groundwater resources. An increasing number of private wells were developed to circumvent these restrictions, which in turn resulted in a further adverse impact on the groundwater table by increasing the extractions. Increased water shortage during the last 20 years, often perceived to be caused by recurrent droughts, led to the cancellation of the plans to extend the area irrigated by the main dams in the region. There are concerns that the recurrent droughts will further deplete the available water resources. In fact, the sheet of Souss and Chtouka is confronted to excessive exploitation with an alarming annual rate (Fig. 11).

By analyzing the history of the evolution of groundwater samples of the sheet of Souss between 1943 and 2007 (Fig. 11), it seems that the pumping volume of water in 2007 is 500 times higher than in 1943. The irrigation was exclusively based on

Table 4 Evolution of cropland surface (ha) from 2009 to 2014 in the Souss-Massa region

Year	2009–2010	2010–2011	2011–2012	2012–2013	2013–2014	Average	% Average
Cereals	79,801	83,648	34,378	86,042	28,930	62,560	35.21
Fodder	17,698	16,713	21,173	23,126	23,385	20,419	11.49
Gardening	24,028	25,692	24,476	25,921	24,116	24,846	13.98
Citrus	35,671	36,285	45,099	39,635	39,808	38,048	21.41
Olivier	19,910	20,154	20,706	20,694	20,689	20,431	11.49
Banana tree	4,449	4,424	4,519	4,502	4,595	4,498	2.53
Floriculture	0	6	6	0	0	3	0.001
Total	190,755	193,272	150,357	206,163	147,801	177,670	100

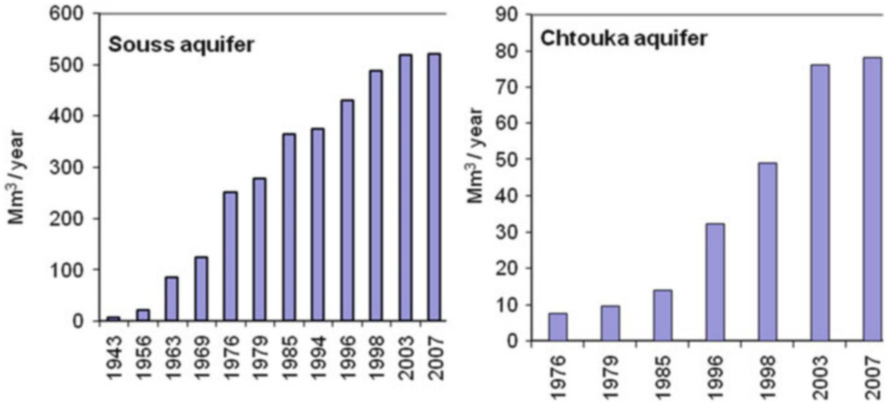

Fig. 11 Historical groundwater pumping from Souss and Chtouka aquifers

surface waters, khettaras, and springs before 1943. Afterward, the pumping rate has multiplied in an uncontrolled way in the last three decades, along with the modernization and the intensification of agriculture, reaching 500 million m^3 in 2007.

According to surveys conducted by the Hydraulic Agency of Souss-Massa-Draa basin in 1968, the aquifer of Chtouka irrigates 400 ha and 1,400 ha with traditional wells and pumping, respectively. Over the years, this pumping has increased to pass from 10 million m^3 in 1976 to 80 million m^3 in 2007. The structure of this pumping was 92% for irrigation and 8% for drinking and industrial water [20].

According to the study conducted by Bouchaou et al. [10], the effect of climate change associated with overexploitation of groundwater deteriorates water quality, especially in irrigated areas, with increased salinity native from intrusion and anthropogenic pollution (fertilizers, waste water).

5 Impacts on Groundwater Resources in Souss-Massa Basin

As mentioned above, groundwater resources are seriously affected by the succession of drought years and the overexploitation mainly caused by agriculture, and this deterioration is observable in different areas of Souss-Massa basin. Indeed, the assessment of groundwater level evolution of both Souss and Chtouka aquifers indicates a decrease over time. This decrease concerns even the modern irrigation areas (Issen, Massa) and artificial recharge areas (upstream Souss). In order to assess the evolution of water table, we analyzed the historical data from the wells and boreholes of the monitoring system of the Hydraulic Agency of Souss-Massa-Draa basin between 1970 and 2010 (Figs. 12 and 13).

Fig. 12 Evolution of groundwater table in Souss aquifer between 1970 and 2010

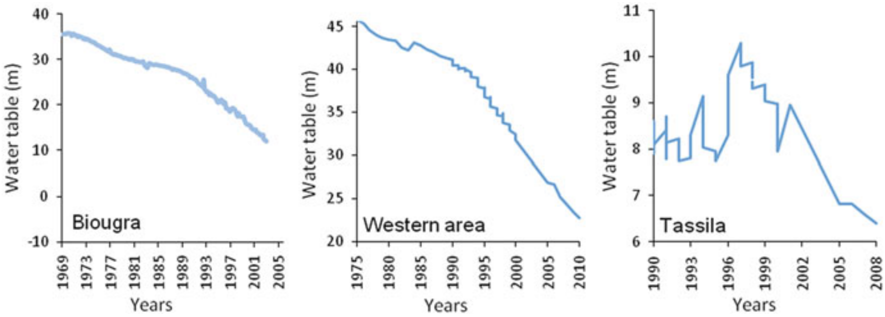

Fig. 13 Evolution of groundwater table in Chtouka aquifer between 1970 and 2010

Actually, the spatiotemporal evolution of groundwater levels in different sectors of the area shows that the decline observed can be connected to the successive years of drought as well as the considerable intensification of pumping. However, the advent of some unusually rainy years, particularly 1996, led to a provisional reconstitution of water reserves in some areas. In addition to that, the establishment of irrigation schemes, characterized by the construction of dams and the adoption of drip irrigation, attenuated the damage experienced in Souss and Massa aquifers.

5.1 Decline of Groundwater Table

5.1.1 Souss Upstream

After the rise of water table recorded in 1971, there was a gradual drawdown of 20 m in 1987. The return of normal rainfall at the end of the 1980s and the exceptionally rainy year 1995–1996 induced a significant rise of 15 m. In 1999, a marked decrease was observed up to 5-m depth.

5.1.2 Middle Souss

In the middle Souss, the perimeters of El Guerdane-Oulad Teima are the most affected areas. The monitoring well recorded a quite moderate decline of the water table in the early 1970s. After 1974, the water table rose to reach 34 m in 1986 and 75 m in 2006 with an average of 2 m per year. In the perimeter of Issen, a significant decline was registered in the last years which marks reduction of supplies for irrigation from the complex Abdel-Moumen Dkhila.

5.1.3 Souss Downstream

In the Souss downstream sector, in the south of Ait Melloul area, some important declines of water table have been recorded. The coastal belt in the south of Agadir also showed a decrease of groundwater level of around 12 m.

5.1.4 Chtouka Aquifer

Chtouka aquifer is located in the northern part of Souss-Massa basin. The piezometers considered in this aquifer show that the groundwater level is experiencing a continuous decline since the year 1971. The decline is about 25 m in Biougra and becomes lower in the direction of the ocean (10–15 m). The monitoring data of water table in the perimeter of Tassila, starting from 1990, indicates a slight increase of about 3 m. This rise of groundwater level can be connected to the exceptional precipitations in 1996. Subsequently, the aquifer knows a decrease of nearly 4 m between 1997 and 2010 (Fig. 13).

5.2 Decrease of the Discharge in Springs and Khettaras

The abundance of sources and khettaras was one of the main features of the Souss-Massa basin in the 1970s. Khettaras are actually considered as one of the oldest water management systems in the study area. They represent an ancient sophisticated technique which enables underground water resources to be tapped for irrigation. However, the number of springs and khettaras has remarkably decreased. In fact, 62 springs were identified along the valley of Souss and most of them have dried up after 1980.

The average discharge of springs and khettaras in the valley of Souss signals important interannual variations (Fig. 14). The correlation with local rainfall data is highly significant ($R = 0.8$) and clearly indicates the important influence of the succession of drought years. As for the basin of Tiznit, the discharge data exhibits less variability when compared to Souss basin, despite of the important rainfall

Fig. 14 Evolution of the total discharge from the main springs in Souss and Tiznit basins

irregularities. This result is explained by the fact that most of the springs in this area belong to the Adoudounian-Georgian aquifer, which is more potent and less exploited than Souss aquifer.

5.3 Deterioration of Groundwater Quality

Climate change affects the quality of water resources as well as the quantity. The deterioration of groundwater quality in Souss and Chtouka is an issue that has long held the authorities responsible for the management of water resources. Several studies have been made in order to identify the geochemical processes that control the salinity and evolution of groundwater in the Souss-Massa aquifer system [16, 17, 21–24]. These studies indicate that the salinity of groundwater originates from multiple sources and not only from seawater intrusion as previously thought. They have revealed a complex hydrogeological system in which several sources of salinity have been identified, including seawater intrusion, entrapped saline groundwater within the aquifer, saline water derived from salt dissolution, and infiltration of agricultural return flows.

According to Bouchaou et al. [10], the depletion of groundwater level induced by limited recharge and overexploitation has induced degradation of water quality in the Souss-Massa plain aquifer. This indicates that the Souss-Massa basin is highly vulnerable to contamination processes, such as salinization (e.g., seawater intrusion) and anthropogenic contamination. The climatic change effect coupled with the pressure of human activities manifested in the intensification of agricultural activities using fertilizers highly affects the water quality with high nitrate contents. Given the study made by Tagma, irrigation water evaporated infiltrate into groundwater. Then, the nitrate is leaching in the unsaturated zone of the aquifer.

6 Conclusion

The Souss-Massa basin is very vulnerable to climate change effects along with the increasing land use and demographic growth. Groundwater resources are experiencing a serious decline of water table levels and deterioration of groundwater quality. The precipitation events in the Souss-Massa area are highly variable, as typical for semiarid climates. The direct impact of climate change in this area suggests a significant decrease of rainfall amount and an increase in temperatures, which threatens the availability of water resources. These facts are confirmed by the meteorological stations, which indicate growing rainfall deficits, especially over the High Atlas Mountains, which are the main source of water for the entire hydrosystem in southern Morocco. Obviously, the increasing land use induces more overexploitation of groundwater resources. This water utilization in the coastal and near-coastal areas would further increase the depletion of water resources and degradation of groundwater quality.

Adaptation to climate change and land use impacts over groundwater resources should be seriously considered in the water management policy of the Souss-Massa basin. Some of the solutions would be the practice of agricultural crops that require small quantities of water and the sewage treatment. The abstraction of groundwater should be shifted from the heavily populated areas along the coast, which are more vulnerable to contamination, toward the high quality and renewable water resources along the upper zone of the basin. This can affect the recharge area in the upstream and limit the contribution supplying the downstream part. Therefore, the application of artificial recharge in the area and improving of the irrigation schemes may help substantially to anticipate further aggravation of the water resources situation, both quantitatively and qualitatively. Desalinization of brackish or seawater can be an option in the cases of crisis. Convincing the farmers to use the treated wastewater is as important as challenging in the country. Furthermore, understanding of the natural climate variability during the past and its evolution during the future will help a better resource management.

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Assessment of Groundwater Quality: Impact of Natural and Anthropogenic Contamination in Souss-Massa River Basin

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Abstract Groundwater quality in Souss-Massa Basin is influenced by natural and anthropogenic contaminations. In fact, the geological formations are the main sources of mineralization in Souss-Massa aquifer. The impact of marine intrusion is noticed in the coastal area. However, human activities are also responsible for the deterioration of groundwater quality. Indeed, agriculture is the main activity in the region with the presence of some industrial food unities which contribute to the degradation of water quality due to different uses of water resources as well as the reject of industrial and urban wastewater. The evaluation of urban pollution shows

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that it is directly linked to demographic changes, the rate of connection to the sanitation system, and wastewater treatment. However, wastewater treatment activity is quietly growing in the area. In fact, more than six treatment plants are operational in different cities. Furthermore, the Hydraulic Basin Agency and its partners have initiated several studies for new treatment plant implementation in other locations. Despite this progress, sanitation sector is still in remarkable delay. In fact, the total liquid discharges through the Souss-Massa Basin are equal to 28.8 million m^3 of which 54.7% are only treated, and 45% are rejected directly in the environment and consequently generating a pollution load of more than 7.1 T/year of BOD, for example. The Agadir City is generating more than 50% of this pollution load. Regarding the production of solid waste, the total amount of waste produced in the area is evaluated at nearly 565.000 T/year. The distribution of waste between provinces shows that for the urban area of Agadir and Inezgane Ait Melloul, agglomeration contributes with over 80% of waste, while Taroudant and Ait Baha contribute with 68%. The assessment of industrial pollution shows that 36% of potential polluting industries are located at the province of Chtouka Ait Baha, 35% at the province of Inezgane Ait Melloul, 24% at Taroudant, 4% at Tiznit, and 1% at the province of Agadir Ida Ou Tanane. Agriculture is the dominant activity in the basin where the agricultural pollution in the Souss-Massa Basin is mainly connected to the agricultural production and the livestock. Citrus and vegetables are considered as a main source of nitrate pollution because of the important quantities of fertilizers used for these crops. The pollution load based on amounts of nitrogen leached is valued at 1,511 tons of nitrates per year.

Keywords Anthropogenic contamination, Groundwater, Impact, Quality, Souss aquifer

Contents

Abbreviations

ABHSM Hydraulic Basin Agency of Souss-Massa
BOD Biological oxygen demand

BPH	Office of Pesticides and Certification
COD	Chemical oxygen demand
COPAG	Copérative Agricole
GW	Groundwater
HCP	High Planning Commission
LAGAGE	Laboratory of Applied geology and Geo-Environment
MADRPM	Ministry of Agriculture and Rural Development and Fisheries
ONEE	National Drinking Water and Electricity Office
ORMVASM	Regional Office of Agricultural Development of Souss-Massa
SM	Suspended matter
TDS	Total dissolved solids
WHO	World Health Organization standards

1 Introduction

The major economic strengths of Souss-Massa River Basin, Southwestern Morocco, are agriculture, tourism, and fishing. The first two sectors depend on the availability and quality of water resources, and therefore any degradation might have severe consequences for the fast-growing economy of the region.

Actually, in addition to the natural salinity in some basins, lack of adequate infrastructure and wastewater treatment involves a rise of surface and GW pollution. Souss-Massa GW is subjected to anthropogenic pollution which is widely recognized as one of the most serious challenges to the sustainable management of GW resources. Indeed, several types of pollution that are differentiated according to their source are found in the area. There are two main pollution sources: urban and industrial related to the discharge of wastewater into rivers and agricultural pollution caused by cumulative use of fertilizers, pesticides, and other chemical products in irrigated areas [1]. Effects of these anthropogenic pollutions are mostly important in the unconfined aquifers (e.g., Beni Amir, Beni Moussa, Maamoura, Coastal Chaouia, and Souss-Massa Basins). Indeed, on the 614 pumping stations monitored by the National Drinking Water and Electricity Office (ONEE), 13% are exposed to domestic pollution. Moreover, agricultural activities consume a large amount of water which leads to an alarming depletion of water ranging from 0.5 to 2.5 m/year and continuing to increase according to the worst scenario of the agency (more than 25,000 wells and boreholes were drilled to pump GW at the year 2008) [2]. In addition to GW overexploitation, the deterioration of water quality is observed in many zones exhibited by an increase of TDS (Total Dissolved Solids) and nitrate contents. Indeed, increasing agricultural production involves increasing use of fertilizers, pesticides, and herbicides that are washed to surface waters and recharged to the shallow unconfined aquifers [3]. Nevertheless, decision makers and economic operators are aware of natural resources overexploitation and degradation in the region, and, in order to ensure and maintain the significant socio-economic development known by the region, the concept of sustainable development should not be neglected. One of the main components of the sustainable development is the preservation of natural capital. Thus, several efforts have been undertaken in order to fight this problem, including the adoption of laws and regulations in areas with direct impact on water resource availability and quality. The main texts that constitute the legal framework on water resources quality are the water law (No. 10-95), waste management and disposal law (No. 28-00), protection and environmental enhancement law (No. 11-03), the law of environmental impact studies (No. 12-03), and decree on water quality standards and water pollution inventory (No. 2-97-787) [1].

Several studies described the hydrochemical characterization of GW in Souss-Massa aquifer during the last decades. The results show that the mineralization of groundwater indicates many origins: (1) water-rock interaction, (2) marine intrusion, and (3) anthropogenic activities [4–11].

The objective of this chapter is to present an overview of the current state of GW quality as well as pollution sources. The study will focus mainly on urban, industrial, and agriculture impacts.

2 Study Area

Souss-Massa Basin is formed mainly by Pliocene-Quaternary formations; it is located between the Atlas Mountains to the north and the Anti-Atlas to the south and represents the largest aquifer in the south of the High Atlas Mountains in Morocco. The Souss-Massa Basin includes three aquifers: Souss, Chtouka, and Tiznit.

The evolution of the hydraulic gradients shows that the GW flows from the east to the west, toward the Atlantic Ocean. In fact, more than 20,000 wells exist in the Souss-Massa Basin; the majority corresponds to irrigation wells and is concentrated in the center of the valley along Souss River. They are also present around the urban centers of Ait Melloul, Taroudant, and Ouled Teima and along the roads linking Massa, Ait Melloul, and Biougra [12].

Overexploitation combined with the arid climate and various sources of pollution in the region (domestic pollution, industrial waste, solid waste, fertilizers, etc.) threatens the quantity and quality of water reserves. To manage these resources, the Hydraulic Basin Agency of Souss-Massa (ABHSM), in charge authority, has implemented a monitoring system of more than 390 control wells and piezometers. This network allows monitoring of water resources state and their temporal changes [2].

3 Methodology

In order to assess the quality of GW resources and identify the main sources of contamination (natural, urban, agricultural, and industrial pollutions), data from the hydraulic agency (ABHSM) and LAGAGE laboratory were used in this study.

In fact, the agency has an operational monitoring network of GW quality, for which measurements are generally carried out once per year for most of water quality parameters including electrical conductivity; pH; temperature; majors cations and anions; pollution parameters as NH_4^+, NO_2^-, NO_3, and PO_4^{3-}; and fecal and total coliforms. The results of these measurements and analyses are compared with the Moroccan and WHO (World Health Organization) standards.

Other surveys and monitoring reports from several departments as the Regional Office of Agricultural Development of Souss-Massa (ORMVASM), the National Drinking Water and Electricity Office (ONEE), the High Planning Commission (HCP), and Ibn Zohr University (LAGAGE) have been collected to assess the evolution of pollution sources and their impacts on water resources. Also, a prediction of pollution load by year 2030 established by the ABHSM is used in this study. This estimation was based on the socioeconomic development planned in the region, especially in urban areas, with reference to global benchmark ratios of the pollution load; assessment of pollution load generated by domestic waste was estimated by the ABHSM in Water Resources Integrated Planning (Pdaire) for the years 2019 and 2030.

In addition, recent surveys were used in order to establish the state of GW quality and assess the influence of anthropogenic pollution combined with geological aspect in water resources.

4 Results and Discussion

4.1 *Urban Pollution*

4.1.1 Wastewater Situation in the Region

Urban pollution is mainly related to the demographic increase as well as the sanitation network, wastewater, and solid waste treatments. Actually, the pollution analysis is based on population data, unit consumption measured in liters per capita per day, and unit pollution loads measured in gram per capita per day.

Souss-Massa region is experiencing a continuous demographic growth. According to the data published by the demographic research center (Table 1), the population has increased from 2.497 million in 2009 to 2.579 million in 2012 [13] and estimated to reach about 3 million in 2030 [1]. This demographic growth increases the need to sanitation networks. Nevertheless, several residential centers are not related to sanitation network and use individual disposal systems, which

Table 1 Demographic evolution of Souss-Massa region from 2004 to 2012

	2004	2009	2010	2011	2012
Agadir Ida Outanan	–	552	564	577	591
Inezgane Ait Melloul	–	492	507	522	538
Chtouka Ait Baha	–	322	327	332	337
Taroudant	–	811	815	820	823
Tiznit	–	320	310	300	290
Total	2,380	2,523	2,479	2,551	2,579

Source: HCP and ABHSM

Table 2 Summary of cities and centers with a sewer system and those being studied by ONEE

Province	Cities and centers with a sewer system	Cities and centers studied by ONEE
Tiznit	Tiznit; Tafraoute	Tiznit; Tlat Lakhsass; Sidi Ifni; Mirleft; Aglou et Tafraoute
Taroudant	Taroudant; Aït Iaaza center; Ouled Teïma center	Taroudant; Aoulouz; Sebt El Guerdane; Aït Iaaza; Ouled Teïma; Taliouine
Chtouka Aït Baha	Biougra; Aït Baha	Biougra; Aït Baha; Massa; Sidi Bibi; Belfaâ
Agadir Ida Ou Tanane	Agadir; Drarga	Agadir
Inezgane Ait Melloul	Bensergao	

Source: ABHSM (rapport sur l'assainissement liquide – programme triennal 2008–2010) Region of Souss-Massa, 2010

generates a pollution load released directly into the environment. The total liquid discharges throughout the basin are currently about 28.8 million m^3 [14], generating a pollution load of 15.841 ton of BOD_5/year [2].

However, the implementation of wastewater treatment plant is one of the efficient actions to reduce environmental pollution and generate alternative water resources to cope with current deficit in the region (280 million m^3). In fact wastewater can be reused through several options depending on the consumer quality requirements. It can be used as drinking purposes that can be direct after intensive treatments (e.g., using desalination and disinfection), or indirect after passing through the natural environment, or nondrinking purposes in agricultural areas (irrigation), artificial recharge, forest irrigation, wetland creation, landscape irrigation, etc.

Wastewater treatment in Souss-Massa Basin is a known continuous development, where the ABHMS and its partners have built several water treatment plants and initiated studies for other plants in various provinces [1]. Table 2 presents cities and centers with a sewer system and those being studied by ONEE.

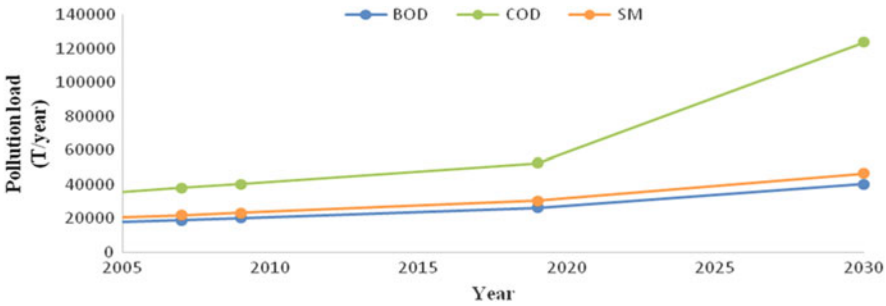

Fig. 1 Evolution of pollution load in the urban area in terms of BOD, COD, and SM from 2005 to 2030 [1]

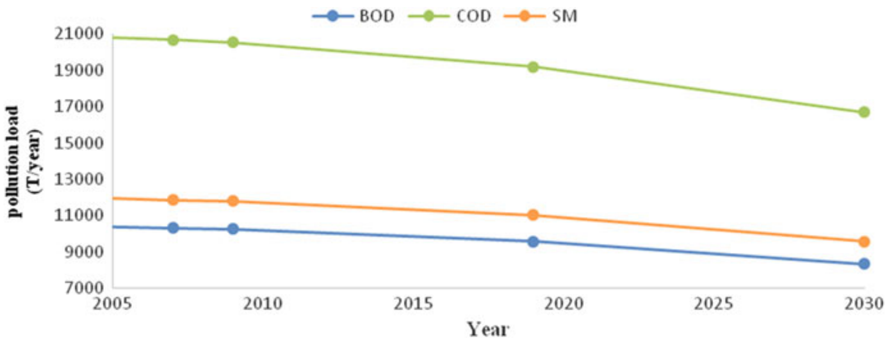

Fig. 2 Evolution of pollution load in the rural area (BOD, COD, and SM) from 2005 to 2030 [1]

4.1.2 Evaluation of Liquid Pollution Load

The urban area of Agadir is in full extension, including the city of Agadir and several peripheral communes (Anza and Aourir toward the north; Bensergao, Dcheira, Inezgane, Ait Melloul, and Tikiouine toward the south) and also some small centers and villages which are considered as parts of Agadir [15]. In this urban agglomeration, nearly 11,872 tons of BOD_5 are generated annually which represent about 68% of the total pollution load at the study area.

Figures 1 and 2 show the trends of different pollution load indicators in both urban and rural areas between 2005 and 2030.

In general, the three indicators show the same trend. Pollution load of urban area tends to increase; on the other hand, it tends to decrease in the rural area. This variation is particularly obvious in the case of COD which has the highest load.

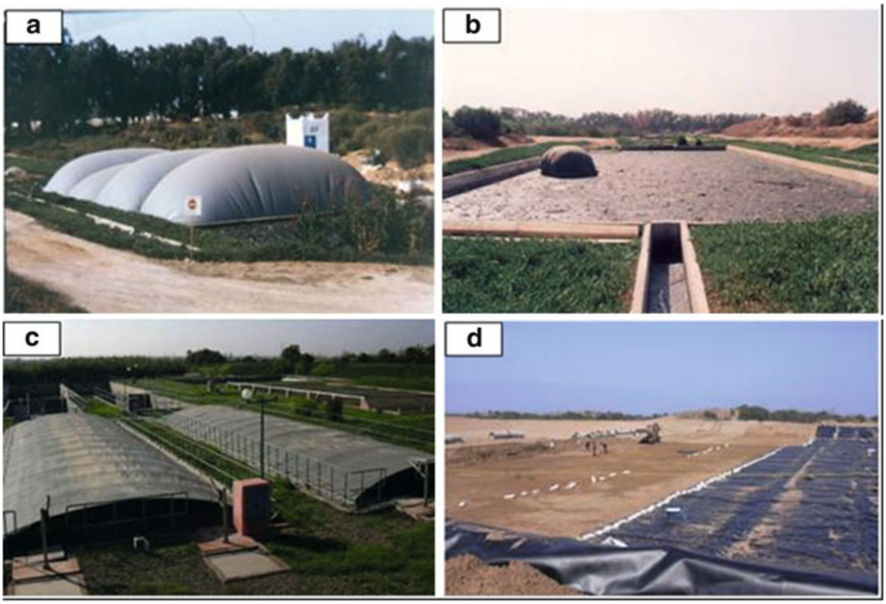

Fig. 3 Treatment plant of Bensergao. Pictures **a**, **b**, **c**, and **d** show the anaerobic lagoons and infiltration/percolation basin in Bensergao plant, anaerobic basins in Drarga plant, and sand filter in Bensergao plant, respectively [14]

4.1.3 Major Achievements

Agadir and surrounding cities have three operational sewage treatment plants [15]. The first, located at Bensergao (Fig. 3a–c), has been constructed in 1986 with a capacity of 750 m^3/day. The treatment starts by (1) primary treatment which consists of anaerobic lagoons, followed by (2) a secondary treatment, percolation infiltration through a sand filter [2]. The purification rate of the treatment plant is about 98%. These results show that the quality of treated water meets the Class "A" of World Health Organization (WHO) standards for water reuse in irrigation without restriction [16].

The second treatment plant is located in Lmzar area at Ait Melloul City. Based on the infiltration/percolation process with a current capacity of 50,000 m^3/day, the treatment process includes (1) a primary treatment by anaerobic phase reducing the pollution load about 60% and (2) a secondary treatment by infiltration/percolation through sand filter.

The third treatment plant is located in Drarga (Fig. 3c). Operational since 1989, the treatment process is based on infiltration/percolation and treats about 650 m^3/day with a purification yield of 98% [15].

The wastewater treatment of Tiznit, operational since 2006, occupies a surface area of 39 ha and was designed for an average flow of 4,900 m^3/day for the first phase and 5,800 m^3/day for the second phase [15]. The treatment plant is based on a

Fig. 4 (**a**) Treatment plant in Tiznit, (**b**) the irrigated crops with treated water from Tiznit treatment plant

natural lagoon system, using a primary treatment (3.1 days retention time in an anaerobic basin), secondary treatment (24.3 days retention time in facultative basin), and a tertiary treatment (12.21 days retention time in the maturation pond) in Fig. 4a.

According to the WHO guidelines, the treated water must reach a sufficient good quality in order to be used with no restriction for irrigation. Actually, two areas are using the treated wastewater of Tiznit Plant in Fig. 4b. One is located downstream of the plant (Attbane) where treated wastewater could be conveyed by gravity, and the second zone is located in the upstream (Doutourga) and the effluents are pumped using a pumping station [15].

For the cities of Taroudant and Ouled Teima, connection to the sanitation network is relatively low. Indeed, the cities have no infrastructure to manage sewage. Respectively, only 63% to 85% of the population are connected to the sanitation canal, and the sewage is directly rejected without any treatment. Furthermore, other centers and small centers in the region like Massa, Sidi Ifni, Biougra, Ouled Berhil, El Guerdane, Ait Iaaza, Taliouine, Tafraout, Ait Baha, L'qlia, and Temsia are recording an imminent delay in the field of sanitation [15].

4.1.4 Evaluation of Solid Waste Pollution Load

Solid waste monitoring in Souss-Massa region is quite weak. Therefore, data needed to evaluate the pollution load of this source remain very limited. However, the ABHSM has made estimations based on population projections and production unit to assess the evolution of solid waste in the region.

Leachate generation is an inevitable consequence of waste disposal practice in landfills. Indeed, once the leachate reaches the bottom of the landfill or an impermeable layer within the landfill, leachate either travels laterally to a point where it discharges to the surface as a seep or it will move through the base of the landfill and into the subsurface formations. As well as leachate, landfill gas contains a high concentration of carbon dioxide which reportedly presents a significant GW

Table 3 Evolution of solid waste for urban and rural areas in the region of Souss-Massa

Year	2007	2009	2014	2019	2024	2029	2030
Urban area							
Agadir Ida Ou Tanane	117,483	128,346	151,977	179,626	211,892	249,469	263,916
Inezgane Ait Melloul	119,310	131,363	159,769	192,924	231,559	274,273	290,091
Chtouka Ait Baha	12,407	13,738	16,701	19,789	22,684	24,952	25,924
Taroudant	55,858	60,370	68,866	76,829	83,432	87,878	90,659
Tiznit	23,932	25,301	27,297	28,874	29,855	30,167	30,899
Total Urban	328,990	359,118	424,610	498,042	579,422	666,739	701,489
Rural area							
Agadir Ida Ou Tanane	18,713	18,661	18,312	17,672	16,829	15,723	15,511
Inezgane Ait Melloul	6,169	6,145	6,025	5,827	5,549	5,159	5,092
Chtouka Ait Baha	47,115	47,190	46,817	45,638	44,092	42,208	41,664
Taroudant	107,579	107,004	104,464	100,638	95,603	88,916	87,675
Tiznit	46,548	45,706	43,330	40,576	37,463	33,809	33,169
Rural	226,124	224,706	218,948	210,351	199,536	185,815	183,111
Total	555,114	583,824	643,558	708,393	778,958	852,554	884,600

pollution potential because of its high solubility [17]. Furthermore, the emission of trace toxic gases within landfill gas has been established to cause a serious threat to air and GW resources [18].

The total amount of the generated waste is estimated to increase from 555,114 T/year in 2007 [1] to 884,600 T/year in 2030 [19] in Table 3. This variation is extremely different between urban and rural areas. In fact, this amount tends to increase for the urban area, while it is more or less stable for the rural area.

The distribution of waste between provinces differs greatly. In fact, in the urban area, Agadir Ida Ou Tanane and Inezgane Ait Melloul are contributing together with over 80% (311,746 T/year) of waste, while for the rural, provinces of Taroudant and Ait Baha are contributing with 68% (151,281 T/year).

4.1.5 Major Achievements

Waste collection rate in urban area is estimated to be equal to 70%. However, about 100,000 tons are not collected and, therefore, causes a contamination of the environment, especially rivers and GW [1]. Furthermore, the collected waste is often deposited in poorly managed landfills without treatment. Moreover, the majority of these discharges are located in areas subjected to surface water flows, especially through streams and sometimes in the abandoned quarries. In both cases, the catchment of waste by runoff and leaching into aquifer is considered a very dangerous source of contamination for GW.

Souss river bed is particularly affected by this situation and has many uncontrolled dumps that proliferate on its shores which establish an imminent threat, particularly for the GW quality of Souss. At Taroudant province, most of solid waste disposal sites are also located on the bed of Souss River.

4.2 Industrial Pollution

The industrial park of Souss-Massa region contains about 489 industrial units, Food industry is the largest component followed by the chemical, pharmaceutical and construction industries [13].

In order to evaluate the current and future pollution load generated by the industrial activity in the region, ABHSM has taken in consideration two indices which are (1) the evolution of the industrial sector in terms of changes in the national economic context and (2) changes in economic conditions of the national and international markets for food manufacturing [2].

However, this assessment is complex because of varied involved factors, especially through the influence of changing technology and requirements for environment safeguarding. Especially Morocco is now moving toward the development of environmental legislation, encouraging the adoption of clean technologies and the introduction of liquid and solid sanitation programs. This probably will be accompanied by reductions in industry-related discharge ratios.

4.2.1 Evaluation of Industrial Pollution Load

The assessment of pollution degree for various industries depends on (1) the use of polluting products as raw material, reagents, or in any other form; (2) the use of water for washing, processing, cooling, or any other purpose that makes it a potential vector of pollution; and (3) the discharge of waste in solid form that may contaminate GW by leaching or affecting surface water resources.

Based on these differentiations, the ABHSM has designed a geographical distribution and considered that 36% of potential polluting industries are located at the province of Chtouka Ait Baha, 35% at the province of Inezgane Ait Melloul, 24% at Taroudant, 4% at Tiznit, and 1% at the province of Agadir Ida Ou Tanane [2].

The largest organic pollution load is recorded at COPAG cooperative (food industry) with about 82% of BOD_5 and 77% of COD. Fruits and vegetable packaging houses generate 18% of BOD_5, 32% of COD, and 90% of SM. The high pollution load disposed by COPAG is explained by the large volume of waste generated annually (474,500 m^3/year). However, these effluents fit more or less with irrigation standards; they contain about 124 mg/l of COD, 55 mg/l of BOD_5, and 41 mg/l of SM [1].

4.3 Agricultural Pollution

Agricultural pollution in Souss-Massa Basin can be connected to two major sources, agriculture and livestock. Actually, any location where animal wastes are concentrated, such as feed lots or poultry farms, can release high levels of nutrients into GW. In addition to nutrients, pesticides and herbicides are other major sources of GW pollution related to agriculture. Thus, to assess the pollution load from agriculture, it is necessary to define the existing crops in the area, quantities of applied fertilizers and pesticides, as well as the number of livestock.

4.3.1 Evaluation of the Agricultural Pollution Load

Nowadays, the intensification of agriculture does not allow the soil to enrich naturally by crop rotation [4]. For this reason, in order to maintain and increase the profitability of farming, each farmer is obliged to supply a quality of essential elements to improve the soil fertility. In fact, farmers are increasingly using modern farming practices including the use of fertilizers and pesticides, without worrying too much about the consequences of these practices on the environment.

In fact, these practices are not always well structured and lead to nitrate pollution of GW [10]. These activities often do not pay attention to the recycling of drainage water. This causes enormous losses of fertilizers, especially nitrogen, which increases the risks of contamination associated with its excessive presence in soil and water. On the other hand, fertilization, as practiced by farmers, does not include organic manure, crop residues, and natural supplies of the soil and could generate significant amounts of residual mineral nitrogen in nitrate form. This residual nitrogen can leach deeply by rain and irrigation water and therefore be a potential risk of GW pollution (nitrates) [12]. Nitrate leaching is especially important where soils are shallow and having light texture [20–24] which is the case of Chtouka and Massa's soil. Indeed, these soils have a sandy texture and a low clay content, which leads to nitrate leaching in the GW.

Also, the mode of irrigation contributes significantly to raise the rates of nitrate pollution. Indeed, the examination of spatial distribution of nitrate concentrations in the Souss-Massa Basin demonstrates clearly that very high levels of nitrate (e.g., >100 mg L-I) are situated within the irrigated areas where agricultural activities involving nitrogen compounds are intensively used. In other respects, some localized spots of nitric pollution spread out in the vicinity of towns as the case is of Ait Melloul and Ouled Teima City (Fig. 5) [10].

Based on data collected by ORMVASM on nutrient needs of the main vegetable crops in the area and changes in production over the last 5 years in Tables 4 and 5, the fertilizer quantity applied between 2009 and 2013 was determined (Fig. 6).

The higher amount of nitrogen is registered for banana, followed by tomatoes and pepper, and the values are more or less stable from 2009 to 2013 mainly due to stable cultivated area. In most of cases, these quantities of fertilizers injected

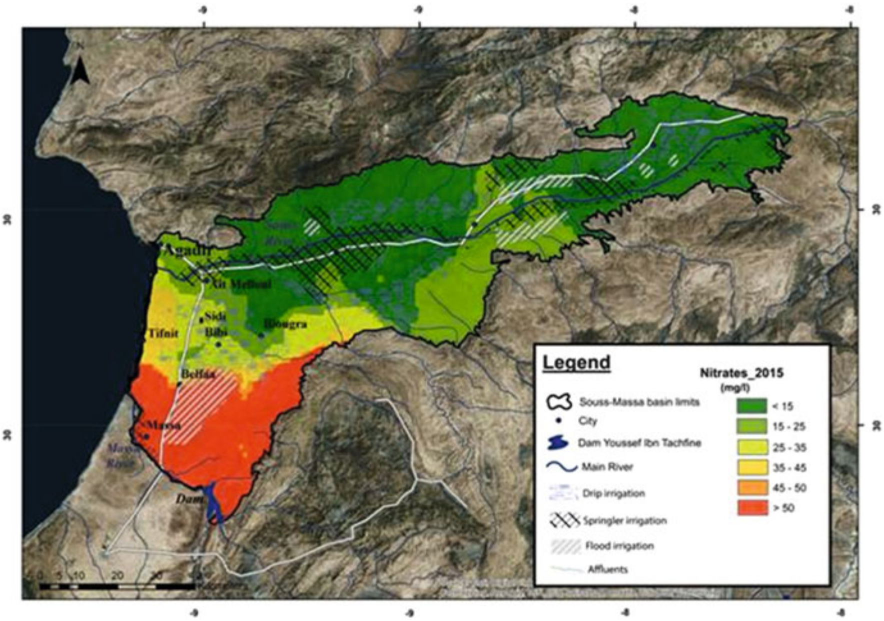

Fig. 5 Spatial distribution of NO_3 contents related to the irrigation mode used in Souss-Massa Basin

through the fertigation system are not all used by crops where a significant portion is leached and become a source of nitrate pollution of GW. The ABHSM has calculated the agricultural pollution load based on the leached nitrogen amounts which were estimated to be nearly equal to 1,511 tons of nitrates per year.

Regarding the use of pesticides, data are not available in Souss-Massa region. However, according to the Office of Pesticides and Certification (BPH) and the Ministry of Agriculture and Rural Development and Fisheries (MADRPM), there are several types of pesticides as insecticides, herbicides, fungicides, and acaricides used in the region. The total annual applied quantity is estimated to be equal to 7,500 tons/year including 3,200 tons of active ingredients used annually in Morocco [2].

The livestock activity has a remarkable increase mainly in the province of Taroudant. Animal pollutant load is important especially that the release of these farming activities do not meet the standards. The total pollution load generated by the livestock for the year 2007 was 1.04903 million kg/year of SM, 563,353 kg/year OM, 63,338 kg/year N, and 14,433 kg/year P [1].

Table 4 Evolution of agriculture production and cultivated surface in the Souss-Massa region from 2009 to 2012

	2009/2010		2010/2011		2011/2012		2012/2013		2013/2014	
Année	SUP	PROD	SUP	PROD	SUP	PROD	SUP	PROD	SUP	PROD
Cereals	79,801	117,869	83,648	134,996	34,378	24,776	86,042	71,752	28,930	265,170
Fodders	17,698	885,489	16,713	876,242	21,173	990,740	23,126	1,106,460	23,385	1,068,350
Fruits and vegetables	24,028	1,403,655	25,692	1,442,523	24,476	1,468,699	25,921	1,568,607	24,116	1,470,481
Arboriculture	64,779	661,622	62,789	710,127	65,805	752,975	66,572	419,549	66,775	906,979
Banana	4,449	181,941	4,424	185,557	4,519	184,420	4,502	183,468	4,595	191,283
Floriculture	0	0	6	2	6	2	0	0	0	0

Source: Office régional de mise en valeur agricole de Souss-Massa (ORMVASM)

Table 5 Nutrient needs of some vegetable species: fertilizer units [25]

Crop	N (U/ha)	P_2O_5 (U/ha)	K_2O (U/ha)
Tomato	500–700	180–300	950–1,500
Pepper	840	140	860
Melon	300	140	500
Cucumber	600	200	950
Banana	1,250	290	1,500
Potatoes	120	150	200

Source: Office régional de mise en valeur agricole de Souss-Massa

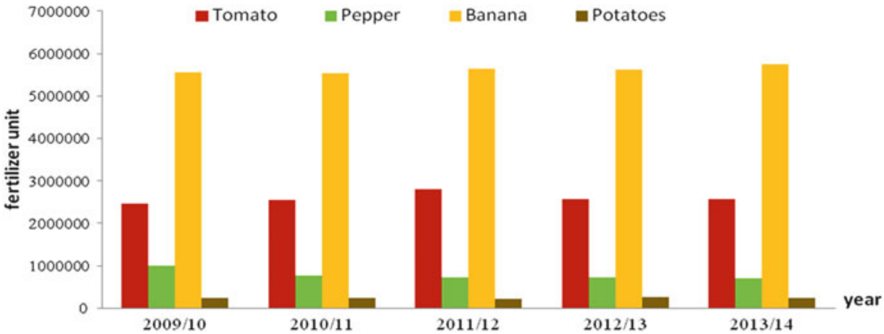

Fig. 6 Evolution of the Nitrogen amount used by the main cultivated crops in Souss-Massa region (*Source*: [25])

4.4 Quality of Souss-Massa Groundwater

The GW quality of Souss-Massa can be described as average in general. In fact, the assessment of Souss-Massa GW quality shows deterioration from the north to the south. Souss downstream GW presents a low quality, while in medium and Souss upstream, the quality is generally good. In Chtouka area, water quality is mainly medium (Fig. 1). This degradation is mainly due to geological (evaporates) and anthropogenic origins (fertilizers and wastewater) [5–7, 10].

Indeed, according to the quality map of the ABHSM, quality degrades from the north to the south in Fig. 7.

This deterioration is related to both natural origins and human behaviors. To better understand the impact of environment on GW mineralization, we plotted samples collected from several studies made in the area and that indicate a good correlation between electrical conductivity and chlorides in Fig. 8.

The study made about the spatial distribution of chlorides in the basin presented in Fig. 9 comes to confirm the first observation, and this result was strongly confirmed by many studies carried in the area [5, 7, 8, 10, 11] which revealed that the chloride levels are very high. It can reach up to 40,000 ppm in Massa area which is impacted by chloride removed from the Paleozoic schist. Consequently, the natural origin of salinity is mainly caused by the abundance of schist in the

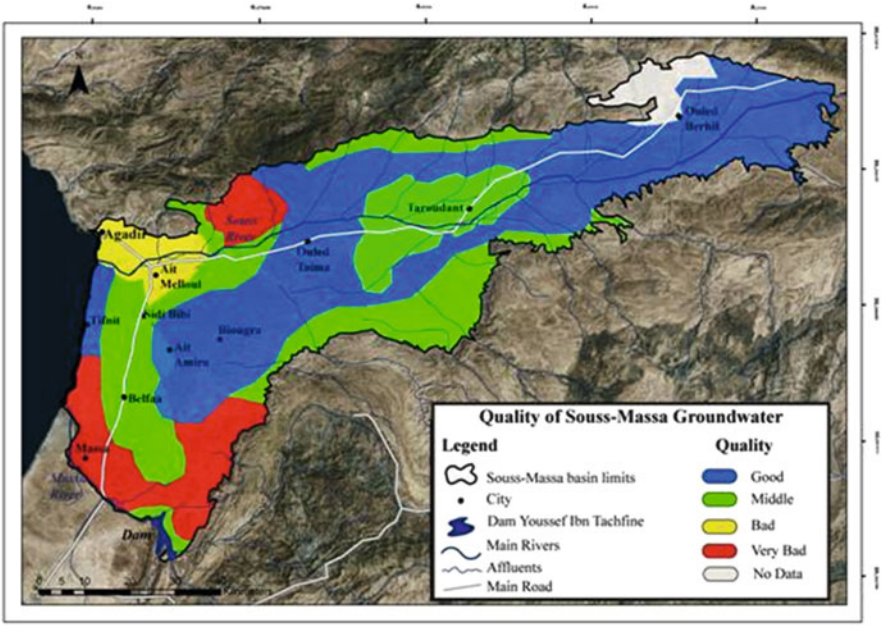

Fig. 7 Map of GW quality according to the Hydraulic Basin Agency monitoring network 2007

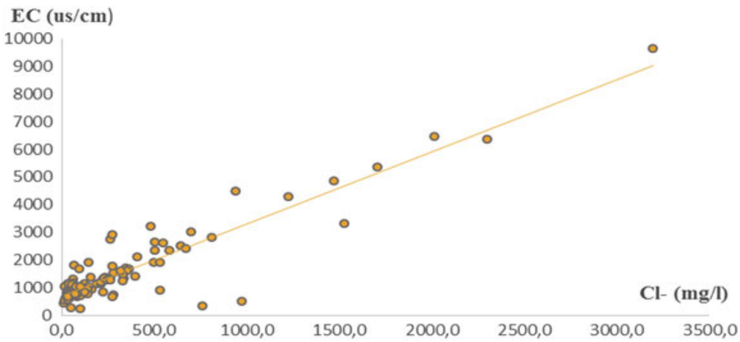

Fig. 8 Correlation between electrical conductivity and chlorides of Souss-Massa GW

south, Triassic and Jurassic formations in the north, and marine intrusion in the west.

4.4.1 Groundwater Vulnerability: Awareness and Maintained Actions

The assessment of Souss-Massa GW quality showed that they are vulnerable to several sources of contamination. Thus, it is necessary to study the degree of

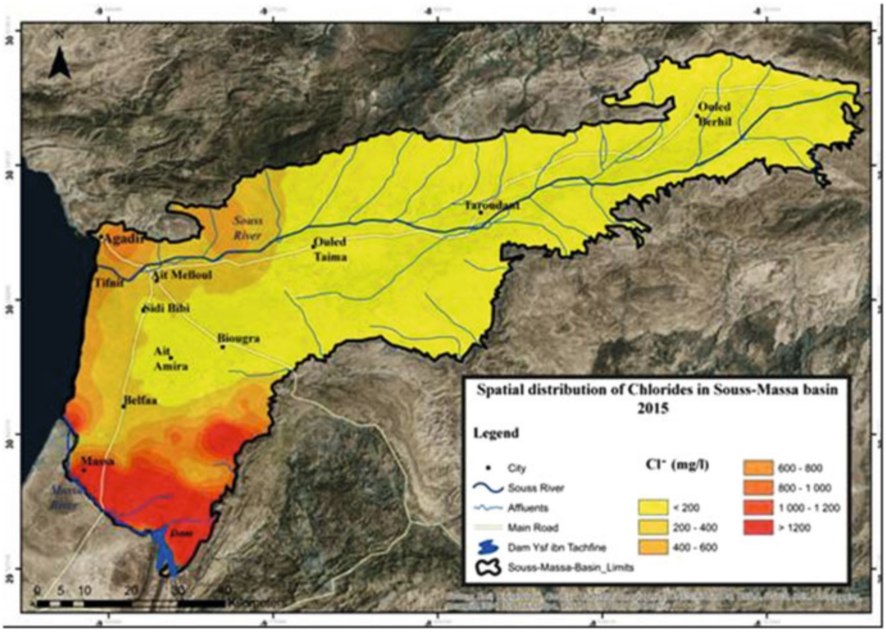

Fig. 9 Spatial distribution of chlorides in Souss-Massa GW for the year 2015

vulnerability to the pollution to better understand the quality degradation problem and link it with the components of natural and anthropogenic environment. In fact, according to previous studies [1, 12], the areas of El Menizla and Aoulouz in Souss upstream, which are the main recharge areas of Souss and Massa aquifers, are moderately vulnerable. However, even if the water quality of these areas is good, there is a risk if no protection measures have been taken to protect against any potential pollution. In Chtouka area, the vulnerability is moderate in general, where we have mentioned before anomalies of nitrate pollution in Fig. 5 and salinity.

Indeed, current salinization phenomena of GW in the Souss-Massa Basin have limited operation of many agricultural activities, and several farms in central Souss Valley had to stop operation completely due to the high salinity of the irrigation water and soil. In spite of this process, there is no systematic monitoring of the water quality or measuring of water quantity used in the basin. Thus, water authorities have no control of neither the amount of water pumping nor the safe yield for sustainable use of GW in this basin. Water management is therefore very limited and can act only after the crisis of salinity occurs, and GW is becoming too saline for agricultural operation. The high salinity of GW also prevents recycling of wastewater to be used for agriculture. Wastewater from Agadir area is treated (second treatment only) and discharged to the Atlantic Ocean. Salinity therefore is the limiting factor for recycling sewage effluents for agricultural uses in Souss-Massa Valley.

In order to manage these problems, water authorities have initiated several operations. First, water reforms became more active this decade: every new well should be allowed by the agency and meet the standards. Consequently, this leads to establish a database for water use in the area. In addition, the sector of agriculture looks for alternative solutions for water resource salinization, including seawater desalination. Some farmers have even considered brackish GW desalination for agriculture, which would be cheaper (relative to seawater desalination) given the site location and the relatively low levels of salts in brackish GW.

5 Conclusion

Overall, the quality of Souss-Massa GW shows deterioration from the north to the south, and this degradation is mainly caused by the influence of geological formation, especially the abundance of schist as well as the impacts of pollution due to anthropogenic origins (fertilizers and wastewater).

This chapter has summarized the main sources of pollution existing in the Souss-Massa Basin. Most of the data are coming from the Hydraulic Basin Agency of Souss-Massa (ABHSM) which is the authority in charge of the management and conservation of water resources in the region. Recent surveys were also used in order to assess the evolution of GW quality over the study area.

In fact, due to the favorable weather and high soil fertility, agriculture occupies more than 50% of economic activities in the Souss-Massa region which allows the Souss-Massa region to be one of the most important economic poles in Morocco with about 80% of the total agriculture exports from Morocco. Therefore, a reduction in agricultural activity would have both local and nationwide implications for the economy and security.

However, given the current situation of GW pollution in the Souss-Massa Basin, all water-related stakeholders and water users should change their behavior and practices in order to reduce the GW pollution by adopting several strategies which can be very efficient and economically reasonable. In fact, it is recommended to increase and upgrade the sanitation networks and wastewater treatment plants and think to recycle the solid waste. At farm level, producers can adopt the soilless cropping system especially with a close drainage system which allows to save more water and fertilizers and thus reduces nitrate leaching. Desalination of seawater is also a good alternative to reduce the overexploitation of water resources by agriculture.

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Groundwater-Dependent Ecosystems in the Souss-Massa River Region: An Economic Valuation of Ecosystem Services

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Abstract Groundwater plays an integral role in sustaining certain types of aquatic, terrestrial, and coastal ecosystems and associated landscapes, both in humid and arid climatic regions. It is thus a key factor in efforts to maintain the ecological integrity of some key ecosystems. In Chtouka Aït Baha region, all ecosystems including the agroecosystem, forest, wetlands, etc., are depending on groundwater for their continuity. Because of lack of reports valuing ecosystem services in the region and to raise the interest and importance of showing the economic value of ecosystems to policy and decision-makers, we have determined the total economic value (TEV) of Chtouka Aït Baha ecosystem focusing on the main ecosystem services having a direct impact on the socioeconomic, ecological, and cultural development of the region. A detailed description of existing ecosystems and their services is presented as well as determination of their economic value. It was shown that the agroecosystem contributes by more than 74% in the TEV of the whole ecosystem. This percentage shows the important development of the agricultural sector especially this region is the most productive region in Souss-Massa region as well as Morocco. The forest ecosystem who contributes by more than 13% in the TEV has more regulating services than provisioning services compared to agroecosystem where climate regulation, CO_2 sequestration, and erosion control services contribute by more than 43% of the TEV of this ecosystem compared to agroecosystem where regulating services contribute only by 3% in the TEV of the

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ecosystem. Recreation and ecotourism represents about 6% in the TEV of the whole ecosystem of Chtouka Aït Baha region which reflects its importance in the ecological and socioeconomic development of the region. Groundwater or aquifer ecosystem contributes by 5%; however, it is the most important ecosystem on which the whole ecosystem is depending for its sustainability. Thus an integrated management of groundwater resources taking into consideration the links between groundwater and other ecosystems should be improved and implemented in water management strategies and policies.

Keywords Climate regulation, Ecotourism, Forest, Recreation, Wetlands

Contents

1 Introduction

In a perfect world, this should not matter that the intrinsic value of ecosystems must be recognized sufficiently so that the environment and its protection should be the priority of social and political action. However, in real world, human beings seriously underestimate ecosystems compared to the economic benefit of the activities that degrade [1]. Therefore, most people do not understand the importance of environmental degradation in terms of their decisions on a daily basis [2]. The concept of ecosystem service addresses this lack of understanding by providing a framework for assessing the economic value of goods and services provided to humans by the environment.

Millennium Ecosystem Assessment [3], an international document treating the relationship between the economy and environment, states that ecosystem integrity is particularly threatened by human activities and that for 50 years, biodiversity will know a considerable global decline. However, these ecosystems provide ecosystem goods and services essential to human well-being but are taken for granted, as considered free. These are often overlooked in decision-making especially not having an economic value, which can lead to degradation of natural capital. According to Dupras et al. [4], ecosystem goods and services (EGS) refers to the benefits that human societies derive from nature. This is a relatively new concept that aims to design ecosystems by a series of attributes and wellness vectors, which make life possible for human beings. Recent developments of this concept have made it – nowadays – a necessary component in the various protection strategies, enhancement, and restoration of natural capital as political and institutional plan in relationship to the business world.

The environmental economy has developed the concept of the total economic value (TEV) of an ecosystem that focuses on two types of measures. The first concerns the material provided by nature that has a market in which it is possible to reveal prices or having marketable substitutes with observed price. The second results from the desire to give a monetary measure to goods and ecosystem functions that have no market: for example, rare species, landscape, a function of recycling, a recreational function, etc. [5]. When market price is not available, investigator creates virtual markets by asking a sample of people's willingness to pay (WTP) to protect the product or function of an ecosystem [6].

Groundwater ecosystems are among the most important freshwater ecosystems as they provide a multitude of goods and services to humans and biodiversity. They also ensure the continuity and survival of other groundwater-dependent ecosystems as the agroecosystem and forest, wetland, and nature park ecosystems. The Chtouka aquifer suffers from a scarcity of groundwater resources exacerbated by unsustainable groundwater use in agricultural activities, climate change which is affecting rainfall and groundwater recharge, and groundwater quality degradation as nitrate pollution and salinization caused by seawater intrusion. Many studies have been conducted to assess the water resource situation in Chtouka region but very few carried out on the ecosystem concept showing the importance of services and goods provided by groundwater-dependent ecosystems as well as their economic value. The only study that investigated the agricultural water valuation was conducted by the Hydraulic Basin Agency of Souss-Massa-Drâa [7] and has assessed the value of irrigation water including its commercial, environmental, and socioeconomic valorization by cultivated crops grown in the Souss-Massa region.

The present study was carried out to complete what has been achieved until now in terms of valuation of ecosystem services. Although previous studies have investigated just the irrigation water value as aquifer good, however, this study suggests the assessment and valuation of the main goods and services of groundwater-dependent ecosystems determining their TEV and thus developing a decision support system in order to help and show the policy makers and managers the importance and the value of ecosystem services.

2 Methodological Approach

Figure 1 shows the methodological approach adopted in this study in order to determine the ecosystem TEV starting with a diagnosis of existing ecosystems and their goods and services.

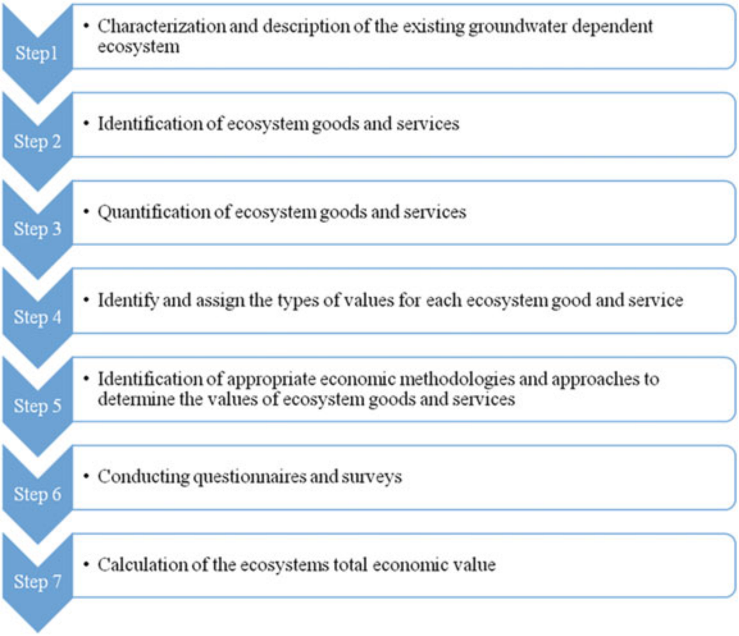

Fig. 1 Methodological approach to study the total economic value (TEV) of groundwater-dependent ecosystem

3 Description of the Groundwater-Dependent Ecosystems in Chtouka Aït Baha Region

3.1 Chtouka Aquifer

The Chtouka aquifer is consisting essentially of Plio-Quaternary deposits, Miocene, and Eocene. They are represented by:

- Dune sandstones and limestone of 20–100 m thick containing intercalated with lake original limestone layer of 2–6 m thick and which can become more or less marl.
- A river-lake formation, made up of marl sand, marl, and limestone. Their thickness varies from 50 m to over 200 m in the southeast region of Agadir. Near Biougra, this formation tends to have coarser deposits (gravels and stones) with thickness that varies from 100 to 150 m.

At the southern edge (toward the Massa river), groundwater flows through Acadian schist land.

In the northern part, the water table level is decreasing since 1971. The decreasing rate is equal to 25 m in Biougra sector and 10–15 m toward the ocean. In the southern part of Chtouka, piezometers record generally small water level variations. A rising of water table is recorded in 1976 (about 8 m between 1975 and 1983). It was due to large-scale irrigation project serving irrigation water to modern public district of Massa, irrigated from the Youssef Ibn Tachfin dam. In Tassila irrigation district, water table level decreased by nearly 4 m between 1998 and 2006 [8].

Analysis of groundwater levels shows that piezometers present a spatiotemporal evolution related to the following reasons:

- Decrease in groundwater recharge due to dry year succession
- Occurrence of some unusually wet years that allowed an improvement of water reserve in certain areas
- Pumping development which recently increased considerably
- The establishment of irrigation megaprojects as the dam construction and irrigation district setup

3.2 The Agroecosystem

The agroecosystem in Chtouka region is characterized by diversity in terms of cultivated crops and their production systems. We can distinguish between three main types of agroecosystems according to their biological, ecological, and agronomic characteristics which are as follows:

- The tree ecosystem, corresponding to fruit trees (citrus, olive, etc.)

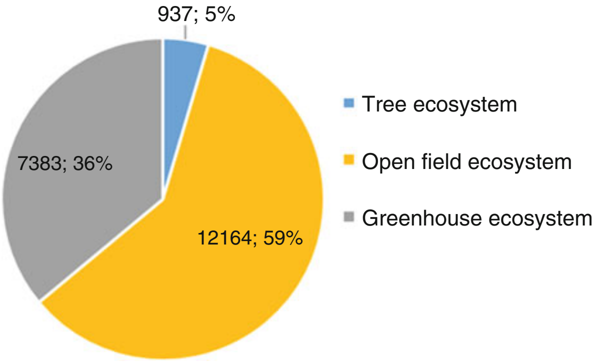

Fig. 2 Average areas (ha) occupied by different agroecosystems. The average areas were calculated using annual data of 5 years (2008–2013) [9]

- Open-field crop ecosystem, corresponding to open-field vegetable crops, forage crops, cereals, and legumes
- The greenhouse ecosystem, corresponding to the crops grown under greenhouses (vegetables, berries, banana, etc.)

These agroecosystems vary according to their biological components, soil use, cropping practices, and use of agricultural inputs. It is well known that the greenhouse agroecosystem is the most consuming in terms of agricultural inputs (fertilizers, pesticides, etc.) and soil. Tree agroecosystem is most affected by weeds and less affecting the soil because its density is relatively lower. Figure 2 shows the average area occupied by the three types of agroecosystems in Chtouka Aït Baha [9].

3.3 *Forest Ecosystem*

The forest ecosystem occupies a major part in Chtouka Aït Baha region, and its estimated area is equal to 100,000 ha. The argan tree covers around 94% of this ecosystem playing a vital role in the ecological, economic, and environmental level. The argan tree ecosystem is dominated by various practices, mainly pastoral and agricultural, which caused a profound alteration of normal and functional structure. Repetitive tree cuts and intensive grazing (goats and camels) have affected greatly the argan forest [10].

We distinguish currently two main types of Argan, namely, the argan orchard and argan forest:

The argan orchard is usually found in lowland areas, with an average density of 100 trees/ha. This type of forest is subject to high degree of agricultural use and very intense grazing. This is the case in the plains of Chtouka and areas surrounding the residential areas.

The argan forest is found in non-cultivable areas of the Atlantic Coast and in the highland parts (mountains of Ait Baha). The density can reach up to 500 trees/ha. Thus, the argan population maintains a relatively specific biological diversity.

3.4 National Park of Souss Massa

The Souss-Massa National Park (NPSM) covers an area of 34,000 ha, between Oued Souss (Agadir) in the North and Sidi Moussa d'Aglou (Tiznit) in the South (29°10 North and 9°37 West). The park has a length of 65 km and an average width of 5 km. This park protects continental and marine environments. It is crossed by Souss and Massa river estuaries. The park administratively is under three provinces: Aït Melloul Inezgane, Chtouka Aït Baha, and Tiznit [11]. The park consists of four areas that are subject to a 5-year development plan and management (Fig. 3):

- Conservation area of natural resources: the lands belong to the state, and farm activities, agriculture, and hunting are prohibited; these areas are reserved for scientific research, environmental education, and ecological tourism; a part of this land is closed and the rest is composed of Euphorbia vegetation.
- Natural resource management areas: these are environments that have been modified by the introduction of some animals and exotic plant species such as eucalyptus and acacia; these plant communities have no economic particular importance, but they stabilize the dunes and provide certain needs of local people for the production of honey and firewood.
- Traditional use areas represent two thirds of the park area with collective and private land property, and the agricultural and pastoral activities are allowed.
- Special use areas with low extension, their objective is to support tourism infrastructure (accommodation, catering, beach activities, etc.).

According to the High Commissariat for Water, Forests, and Fight Against Desertification [13], two animal reserves have been created in the park for acclimatization of four Saharan antelopes (dama gazelle or mhorr gazelle, dorcas gazelle, addax, and oryx) and red-necked ostrich, for their reintroduction into their native habitats in southern Morocco. Nowadays the herds of these animals are important (1,000 Dorcas Gazelles, 600 Addax, 250 Oryx, and 100 ostriches) ready to be reintroduced to Sahara regions (Fig. 4).

According to Harif et al. [11], flora is an essential component of the natural resources of the park. The biogeographical origin of the park's plant species is largely Mediterranean (over 50%) or composed of endemic species (at least 22), Saharian (9 species), and tropical (4 species recorded).

Fig. 3 Map of the National Park of Souss Massa [12]

Fig. 4 Pictures of some animal species protected in the NPSM

3.5 Wetlands

The Souss-Massa National Park hosts two wetlands of international importance (RAMSAR[1]) for migratory water birds being a migration step and suitable habitat for their wintering. Ducks, Waders, Laridae, and others regularly overwinter in these areas. Rare species like Flamingo, Spoonbill, and Avocet are also observed in large numbers. The colony of bald ibis, with 400 birds with 90 pairs having niches in the park, is the last viable population of this species being among the most

[1]The Convention on Wetlands, called the RAMSAR Convention, is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources.

Fig. 5 Souss and Massa river estuaries

Table 1 Inventory of water springs in Chtouka Ait Baha region

Spring name	Commune	X	Y	Flow (l/s)	Served area (ha)
Saymoul	Sidi Wassay	89,200	340,450	8	100
Tighboula	Massa	91,200	343,750	2	14
Aghbalou	Sidi Wassay	86,955	347,812	15	60
Tanalte	Aït Baha	137,200	314,500	13	40
Tamda	Aït Baha	134,700	328,100	25	65
El Henna	Aït Baha	134,693	328,025	10	9
Wintoud	Aït Baha	140,600	322,050	14	17
		Total		87	305

threatened in the world [13]. Both wetlands correspond to Souss and Massa river estuaries (Fig. 5).

3.6 *Water Springs*

Freshwater karst spring ecosystems are dependent on water table because they are fed directly from the aquifer. There are seven water springs in the region of Chtouka Ait Baha that have a variable interannual rate. The total flow of existing spring is equal to 87 l/s, equivalent to 2.7 million m^3/year (Table 1). The waters from all spring are used for irrigating the surrounding land of which the total served area by these springs is equal to 300 ha.

4 Identification of the Groundwater-Dependent Ecosystem Goods and Services

Table 2 presents the main goods and services of the groundwater-dependent ecosystems in Chtouka Aït Baha region:

Table 2 Services and goods of the groundwater-dependent ecosystems in Chtouka Ait Baha region

Ecosystem	Provisioning services	Regulating services	Cultural services	Supporting services
Chtouka aquifer	Irrigation water Potable water Industrial water Livestock watering Nutrients Water spring feeding	Water purification Stabilizing the water temperature	Ablution water (prayer) Scientific research and education	Water storage Stability of living beings including humans
Agroecosystem	Food (fruits and vegetables, forage) Nutrients Wood and fiber (fire, construction)	Pollination Biological control Soil fixation Soil fertility regulation Nutrient recycling Climate regulation (temperature, wind, humidity, etc.) Water regulation (drainage, filtration) Flooding and erosion control	Scientific research and education Medicinal resources Ornamental resources Recreation	Genetic diversity Carbon sequestration (CO_2 fixation) Stability of living beings including humans Soil formation and remediation
Forest ecosystem	Food (argan oil, agricultural products) Wood and fiber (fire, construction) Organic matter Nutrients Grazing	Pollination Biological control Soil fixation Soil fertility regulation Nutrient recycling Climate regulation (temperature, wind, humidity, etc.) Water regulation (drainage, filtration) Flooding and erosion control	Scientific research and education Medicinal resources (herbs) Recreation (ecotourism) Aesthetic resources (argan oil)	Genetic diversity Carbon sequestration (CO_2 fixation) Stability of living beings including humans Argan trees conservation (endemic species)

(continued)

Table 2 (continued)

Ecosystem	Provisioning services	Regulating services	Cultural services	Supporting services
National Park of Souss Massa	Food (argan oil, agricultural products) Wood and fiber (fire, construction) Organic matter Nutrients Grazing (zones with traditional use)	Pollination Biological control Soil fixation Soil fertility regulation Nutrient recycling Climate regulation (temperature, wind, humidity, etc.) Water regulation (drainage, filtration) Flooding and erosion control	Scientific research and education Medicinal resources (herbs) Recreation (ecotourism) Aesthetic resources (argan oil) Religious service (mausoleums)	Genetic diversity Carbon sequestration (CO_2 fixation) Stability of living beings including humans Argan trees conservation (endemic species) Conservation of several rare species (bald ibis, addax, etc.)
Wetlands (Souss and Massa river estuaries)	Food (for migratory birds)	Water treatment Soil fixation Nutrient recycling Climate regulation (temperature, wind, humidity, etc.) Flooding and erosion control Sedimentation control	Scientific research and education Recreation (ecotourism)	Genetic diversity Migratory bird habitats Living environment of many aquatic species
Water springs	Irrigation water Potable water Livestock watering	Stabilizing the water temperature	Medicinal services and treatment of diseases (digestive, skin, etc.) Recreation (ecotourism)	Stability of living beings including humans

5 Total Economic Value

5.1 Use and Nonuse Value

In order to make an assessment of ecosystem services, it is necessary to distinguish the values of use and nonuse values. Use values concern the goods provided by ecosystems as food and wood, services for supporting life or providing regulatory functions such as pollination or water purification, or services providing a healthy living environment and ensuring cultural and religious functions. Nonuse values are

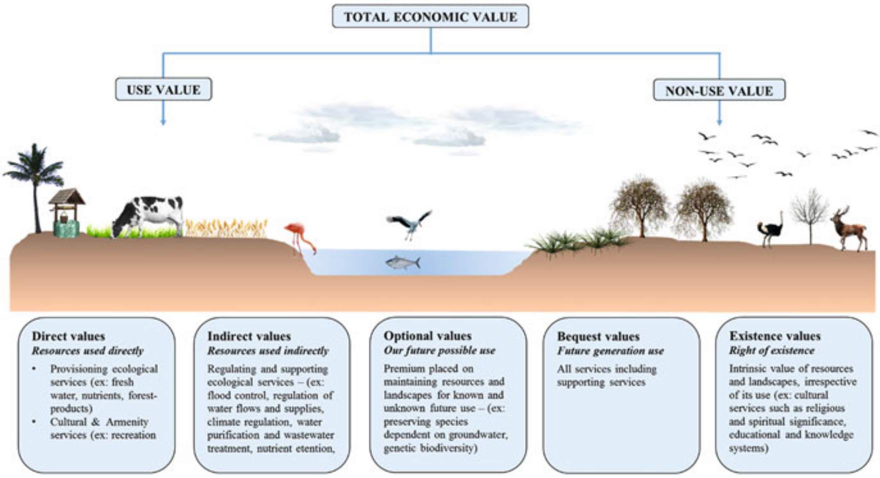

Fig. 6 TEV of ecosystem services

defined as the bequest and existence values of ecosystems. The bequest value is the fact of knowing that the resources will be reserved and transmitted to future generations. Existence value is the nonuse value that people place on simply knowing that something exists, even if they will never see it or use it [14]. Figure 6 presents a detailed classification of ecosystem services according to their value:

6 Methods of Valuation of Ecosystem Services

According to GIZ [15], valuing ecosystem services and incorporating those values into decision-making processes can help in:

- Evaluating the impacts of development policies and policy interventions that alter the condition of an ecosystem and consequently in human well-being
- Comparing the real cost-effectiveness of an investment or project
- Evaluating trade-offs between different ecosystem management options and choosing between competing uses, e.g., of land use
- Assessing liability for damage to the environment
- Creating markets for ecosystem services in order to mobilize financial resources, e.g., global carbon market and payments for ecosystem services
- Awareness building and communication to the public on the overall contribution of ecosystem services to social and economic well-being

A variety of economic valuation approaches have been developed that aim to quantify all or parts of the TEV of an ecosystem service. Each of them includes several methods [4]. A summary is provided in Table 3. The choice of valuation method generally depends on the type of service, availability of resources, and time

Table 3 Ecosystem services valuation methods [4]

Market price	Cost based	Revealed preferences	Stated preferences	Transfer of values
Market price Change in productivity Production cost	Replacement Substitute Avoided damage costs	Travel cost Hedonic price	Contingent valuation Multi-attribute approach	Benefit transfer Function transfer

and data for the study as well as its purpose. Direct use values tend to be the easiest to account for, because they are often part of formal markets. Nonuse values are particularly challenging; they are the most difficult to quantitatively measure and have the greatest uncertainty attached to them [1]. The valuation methodology can be used at three levels of complexity: (1) a full-desktop study, (2) a semi-desktop study requiring stakeholder consultation, and (3) a full-field-based study, according to the time and money available for initial prioritization efforts.

7 Valuation of the Main Groundwater-Dependent Ecosystem Services in Chtouka Aït Baha Region

7.1 Determination of the Economic Value of Water

In Chtouka Aït Baha, water is used under three options:

- Irrigation water: pumped directly from aquifer or dam to irrigate crops grown in the area. Its economic value corresponding to its production cost.
- Drinking water: pumped directly from aquifer or dam for domestic use, industrial use, and livestock watering. The water is generally sold by water utilities (e.g., ONEE) or managed by local associations of drinking water. Its economic value corresponding to its cost of production.
- Spring water: this water usually does not require pumping so actually it has no production costs. Thus its economic value will be equivalent to pumped groundwater production cost.

The ground and surface water used in the Chtouka Aït Baha region is presented in Table 4.

The price of 1 m^3 of agricultural water is the water price at the field in the case where irrigation water is supplied by ORMVASM (Agricultural Development Office) or production cost in the case of pumped water directly from wells to borehole inside the farms. According to ABHSMD [7], the actual production cost of 1 m^3 at farm level in the Chtouka Aït Baha area is equal to 1.4 DH/m^3, and the price of the irrigation coming from the dam serving the irrigated public district is equal to 0.64 DH/m^3.

Table 4 Water use in Chtouka Aït Baha region [16]

Water use	Groundwater	Surface water
Agricultural water in the public irrigation district of Massa	75	28
Agricultural water in the private irrigation district of Massa		56
Agricultural water in Tassila irrigation district	10	
Agricultural water in Oughzifen zone	2	
Agricultural water in Massa mountain	2	
Agricultural water in Anti Atlas/Ait Baha mountains	11	
Domestic and industrial water	7.2	4.07
Spring water	2.2	
Total	109.4	88.07

Table 5 Economic value of water in Chtouka Aït Baha

	Produced quantity (Mm^3)		Production cost (DH/m^3)		Economic value (Million de DH)	
Water use	Groundwater	Surface	Groundwater	Surface	Groundwater	Surface
Agricultural water in the public irrigation district of Massa	75	28	1.14	0.64	85.5	17.9
Agricultural water in the private irrigation district of Massa	–	56	–	0.64	–	35.8
Agricultural water in Tassila irrigation district	10	–	1.14	–	11.4	–
Agricultural water in Oughzifen zone	2	–	1.14	–	2.3	–
Agricultural water in Massa mountain	2	–	1.14	–	2.3	–
Agricultural water in Anti Atlas/Ait Baha mountains	11	–	1.14	–	12.5	–
Domestic and industrial water	7.2	4.07	3.84	3.84	27.6	15.6
Spring water	2.2	–	1.14	–	2.5	–
Total	109.4	88.07	–	–	213.5	

Table 5 shows the economic value of water produced in Chtouka Aït Baha. Results show that the monetary value of the water produced in the Chtouka zone is equal to **213 million DH.**

7.2 Determination of the Economic Value of the Agroecosystem

7.2.1 Agricultural Food

The main agricultural food produced within the agroecosystem in Chtouka Ait Baha corresponds to the following products:

- Horticultural products: fruits and vegetables
- Cereal products: wheat, barley, corn, straw
- Animal products: milk, eggs, meat, honey

Horticultural and Cereals Products

According to statistics from ORMVASM [9], Table 6 shows the average areas and production of horticultural and cereal during 2008–2013 period:

According to ABHSMD [7], the selling price and production cost of the main agricultural products in Chtouka Aït Baha region is presented in Table 7:

Since the agricultural product price is often subject to fluctuations in the market, it is appropriate to use the production cost in order to determine the economic value of agricultural product.

Table 8 shows the TEV of horticultural and cereal products calculated based on production cost rather than market price at local or international market. The economic value of horticultural and cereal production in Chtouka region is so equal to 2,242 DH million/year.

Animal Goods

According to the Statistical Yearbook of Souss-Massa-Drâa [17], the number of livestock heads, slaughter, and the meat quantity produced in Chtouka Aït Baha are presented in Table 9:

The number of exploited hives in Chtouka region and the amount of quantity of produced honey are presented in Table 10 [17]:

The number of poultry and the amount of produced eggs and produced poultry meat are shown in Table 11 [17]:

The economic value of animal products as reported by the High Commission for Planning [17] is presented in Table 12:

7.2.2 Erosion Control

The most used method to evaluate erosion control service of an ecosystem is the avoided damage cost [18]. It is based on the costs incurred to mitigate or avoid some

Table 6 Area and production of main horticultural and cereals crops

Crops	Average during the period 2008–2013	
	Area (ha)	Production (T)
Cereals	**6,208**	**8,501**
Irrigated	**309**	**706**
Tender wheat	124	213
Durum wheat	6	12
Barley	21	32
Maize (grain)	159	449
Rainfed	**5,898**	**7,795**
Tender wheat	5,347	7,285
Durum wheat	12	13
Barley	539	497
Forages	**2,031**	**110,684**
Alfalfa	1,538	87,794
Fodder corn	471	21,953
Vegetables	**105,22**	**960,157**
Primeurs	**8,446**	**879,901**
Greenhouse	**6,597**	**830,527**
Tomato	4,458	676,732
Sweet pepper	593	48,883
Others (melon, cucumber, bean, squash, etc.)	1,547	104,912
Open field	**1,849**	**49,374**
Tomato	19	942
Potato	271	8,064
Others (legumes, squash, etc.)	1,559	40,368
Season	**2,076**	**80,256**
Potato	497	13,599
Watermelon	107	4,488
Others	1,471	62,168
Fruit trees	**837**	**11,794**
Citrus	**694**	**11,735**
Clementine	349	6,410
Navel	47	768
Maroc late	133	2,236
Others	164	2,321
Olive	**143**	**60**
Banana	**786**	**37,056**

words in bold indicate categories and group of cropping systems

environmental risks, such as reforestation cost or planting of new area vulnerable to erosion. People are willing to be involved in these expenses only if the future value of this action exceeds the estimated damage. These data provide an indication of the minimum costs related to environmental risk or minimum benefits of risk mitigation [14].

Table 7 Market price and production cost of main horticultural and cereal products in Chtouka Aït Baha

Product	Market price (DH/Kg)	Production cost (DH/Kg)
Tomato	3	1.83
Carrot	2.5	0.86
Bean	7	6.36
Watermelon	1.1	0.62
Melon	3.6	3.02
Squash	3	2.59
Clementine	3.5	2.5
Sweet Pepper	3	2.29
Banana	5.0	3.50
Oranges	2.7	1.26
Potato	2.8	1.75
Olive	5.5	3.95
Wheat	4	3.76
Peas	7	4.9
Alfalfa		0.46
Fodder corn		0.76

To determine the economic value of this service, the assessment will be based on the cost of the works carried out to control erosion in the region especially those related to reforestation which is the main erosion control strategy practiced by the charged authorities to fight against erosion since soil fixation and erosion control is among the most important roles of vegetation. According to HCEFLCD [20], the unit cost per hectare of reforestation work, soil preparation, and new tree planting carried out in the Souss-Massa region to fight against erosion is equal to 2,500 DH/ha for a period of 30 years (life duration of the project), corresponding to 84 DH/ha/year. The total cultivated area managed by the ORMVASM is equal to 20,487 ha, and subsistence crop cultivated in mountainous area is equal to 16,850 ha, that is a total of 37,337 ha. Thus the TEV of the service "erosion control" is equal to **3.13 million DH/year**.

7.2.3 Climate Regulation and Carbon Sequestration

Climate and wind regulation (sequestration, wind break, etc.) is among the services provided by ecosystems having the flora as a main component in its biota (agroecosystem, forests, wetlands, etc.) [21]. The most used method – according to the TEEB database [18] – to estimate the economic value of climate regulation service and CO_2 sequestration is the benefit transfer method. The approach of this method concerns to transfer the economic values of ecosystem goods and services

Table 8 Economic value of main horticultural and cereal product in Chtouka Ait Baha

Products	Production (T)	Production cost (DH/kg)	Economic value (Million de DH)
Cereals	**8,501**		**18.36**
Irrigated	**706**		**1.99**
Tender wheat	213	3.76	0.80
Durum wheat	12	3.76	0.05
Barley	32	3.76	0.12
Maize (grain)	449	2.28	1.02
Rainfed	**7,795**		**16.37**
Tender wheat	7,285	2.1	15.30
Durum wheat	13	2.1	0.03
Barley	497	2.1	1.04
Forages	**110,684**		**57.07**
Alfalfa	87,794	0.46	40.39
Fodder corn	21,953	0.76	16.68
Vegetables	**960,157**		**2,016.85**
Primeurs	**879,901**		**1,897.02**
Greenhouse	**830,527**		**1,768.96**
Tomato	676,732	1.83	1,238.42
Sweet pepper	48,883	2.29	111.94
Others (melon, cucumber, bean, squash, etc.)	104,912	3.99	418.60
Open field	**49,374**		**128.06**
Tomato	942	1.83	1.72
Potato	8,064	1.75	14.11
Others (legumes, squash, etc.)	40,368	2.78	112.22
Season	**80,256**		**119.83**
Potato	13,599	1.75	23.80
Watermelon	4,488	0.62	2.78
Others	62,168	1.5	93.25
Fruit trees	**11,794**		**149.74**
Citrus	**11,735**		**19.81**
Clementine	6,410	2.5	16.03
Navel	768	1.26	0.97
Maroc late	2,236	1.26	2.82
Olive	**60**	**3.95**	**0.24**
Banana	**37,056**	**3.5**	**129.70**
Total			2,242.024

words in bold indicate categories and group of cropping systems

obtained from previous site investigations to studied site where the current study is elaborated [22]. To ensure a good representation of transferred values, the benefit transfer method requires a rigorous approach.

Table 9 Number of livestock heads, slaughter, and the meat quantity produced in Chtouka Aït Baha

Number of livestock head			Slaughter number			Quantity of produced meat (T)		
Cattle	Sheep	Goats	Cattle	Sheep	Goats	Cattle	Sheep	Goats
41,930	102,040	65,666	11,752	21,250	57,646	1,627	687	466

Table 10 Number of hives and produced honey in Chtouka Aït Baha

Number of hives		Honey production (kg)	
Traditional exploitation	Modern exploitation	Traditional exploitation	Modern exploitation
12,800	5,500	46,524	75,024

Table 11 The number of poultry and the amount of produced eggs and produced poultry meat in Chtouka Aït Baha

Poultry (1,000 heads)	Egg (1,000 unit)	Meat (T)
7,534,000	187,250	13,760

Table 12 Economic value of the main animal product in Chtouka Aït Baha region

Milk production	Red meat	White meat	Honey	Egg	Wool	Manure	Total
192.03	225.6	178.88	8.94	131.07	3.42	4.62	744.56

Inventory of Previous Studies: Using TEEB and GECOSERV Database

Approximately 105 studies reporting the monetary value of climate regulation and CO_2 sequestration service have been identified including 87 in the TEEB database (www.teebweb.org) and 18 in the GECOSERV database (www.gecoserv.org/) (Fig. 7):

Figure 8 shows the different valuation methods used in the identified studies. The most used method is the benefit transfer method:

Meta-Analysis: Multiple Regression

Statistical analysis was carried out using the economic values of different studies with correlation between the economic value of climate regulation and CO_2 sequestration service and several indicators such as study area, gross domestic product, and population density of in the investigated country. The results obtained are shown in Fig. 9. The correlation included 29 countries where one or several studies were conducted.

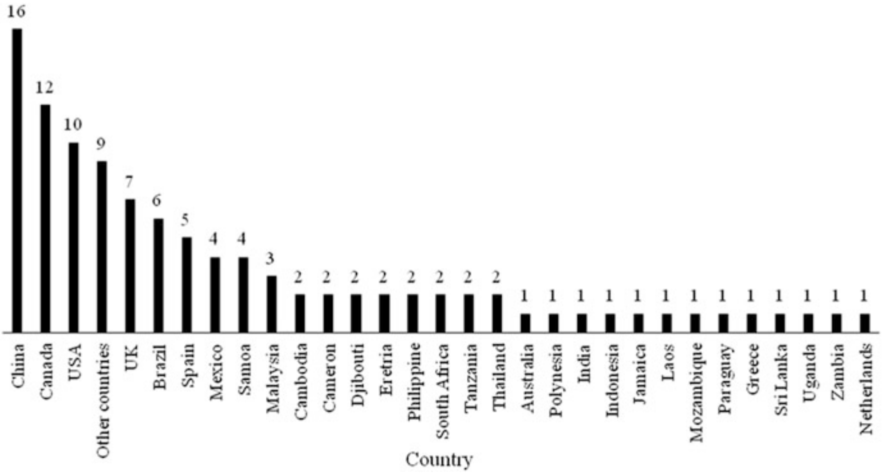

Fig. 7 Number of studies per country valuing the ecosystem service related to climate regulation and CO_2 sequestration

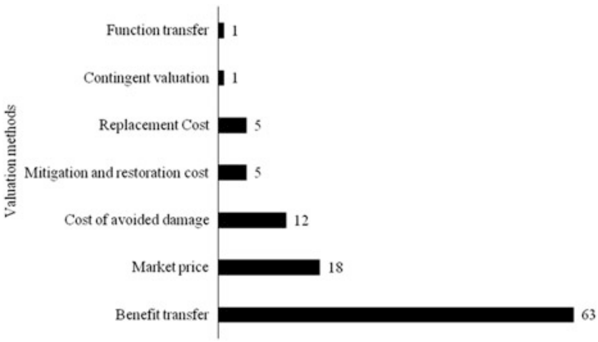

Fig. 8 Valuation methods used in the identified studies for climate regulation and CO_2 sequestration

A multivariable regression was performed using PAST software [23]. The model used is a multivariable linear model:

$$\text{SEV} = \text{Const} + a \times \text{SA} \times b \times \text{GDP} + c \times \text{PD}$$

with:

- SEV: economic value of climate regulation and CO_2 sequestration service (USD/ha)
- Const: regression constant
- *a*, *b*, *c*: coefficients
- SE: study area (ha)
- GDP: gross domestic product (billion USD)
- PD: population density (capita/km^2)

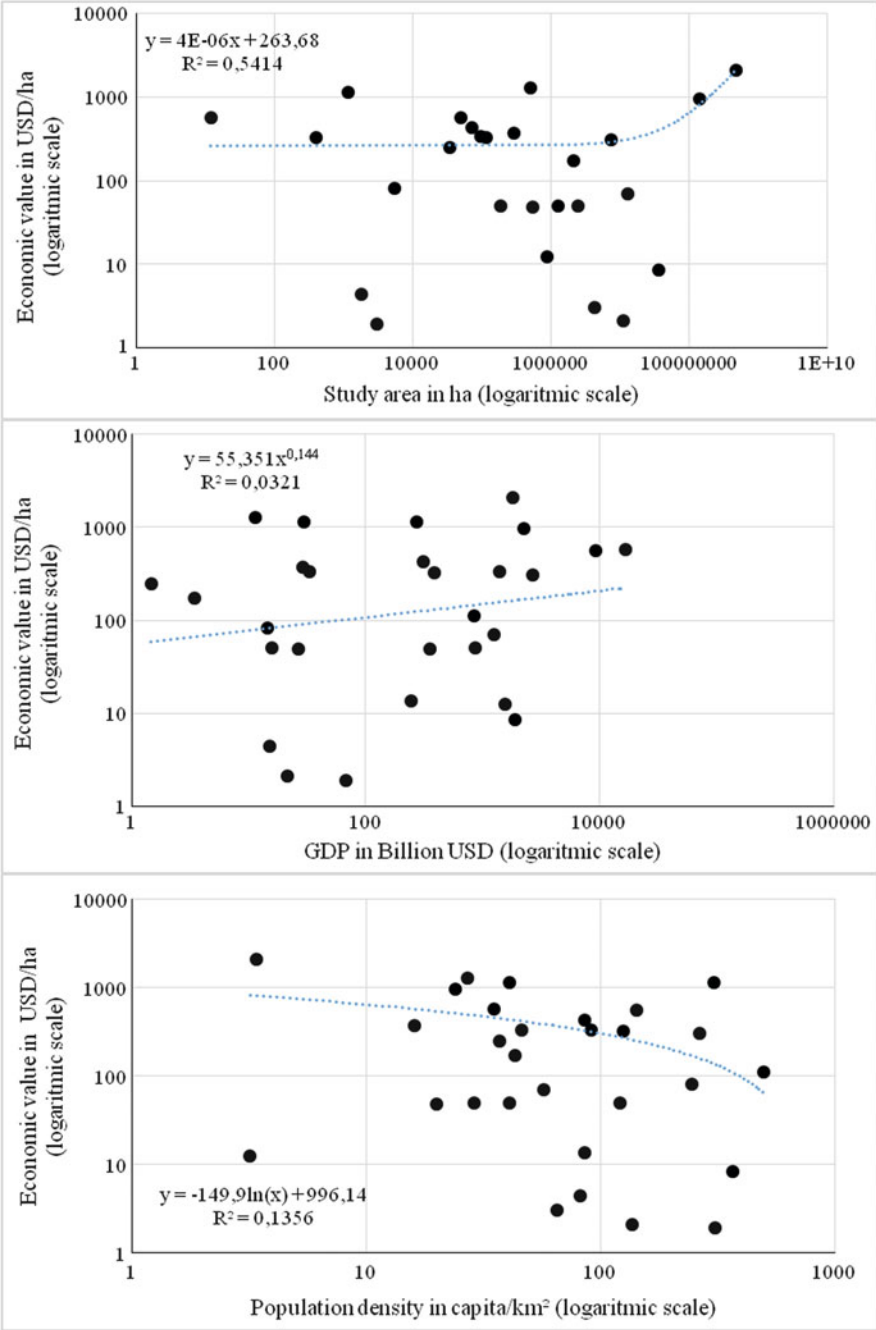

Fig. 9 Correlation of study area, GDP, and population density with the economic value of climate regulation and CO_2 sequestration services

Table 13 Results of multiple regression related to climate regulation and CO_2 sequestration service

Variable	Coefficient	Standard deviation	R^2
Constant	341.85	101.43	0
Study area	0.000003642	0.00000071143	0.54139
GDP	0.020884	0.018491	0.028277
Population density	−1.1117	0.69397	0.11809

The regression results are shown in Table 13:

If we apply the model on the Morocco case with:

- GDP of 104 billion USD[2]
- Population density of 75 capita/km^2.
- The study area concerns the area occupied by vegetation in Chtouka Ait Baha region including cultivated area (37,337 ha) and forests (100,000 ha) which is equal to 137,337 ha.

The economic value of climate regulation and CO_2 sequestration service on is equal to:

$$\begin{aligned}\mathrm{SEV} &= 341.85 + 0.000003642 \times 137,337 + 0.020884 \times 104 - 1.1117 \times 75 \\ &= 261\,\mathrm{USD/ha/year}\end{aligned}$$

Within the agroecosystem, the monetary value of climate regulation and CO_2 sequestration services is equal to 37,337 × 261 = 9.75 million USD = **93 million DH**.

7.3 Determination of the Economic Value of the Forest Ecosystem

The argan forest is a complex ecosystem in which plants and animals live in interdependence, which gives its stability. This ecosystem is organized around the argan tree (*Argania spinosa* (L) Skeels), a tree with a remarkable ability to adapt to water shortages and temperatures that characterize the southwest of Morocco [24]. Argan trees which are the main components of forest ecosystem in the region have traditionally provided with multiple ecosystem goods and services including the provision of fruits from which argan oil is produced, leaves and young shoots eaten by sheep, goats and camels (Fig. 10), and wood for construction and fire. Argan oil has become famous in the last two decades for its cosmetic virtues as a moisturizer and anti-wrinkle treatment and has been exported at prices up to several hundred dollars a liter to Europe, Japan, and the USA [26]. According to HCP [17], the forest in Chtouka Aït Baha consists essentially of argan tree (94%) with an area of about 93,430 ha.

[2]According to World Bank Database (http://data.worldbank.org/country/morocco).

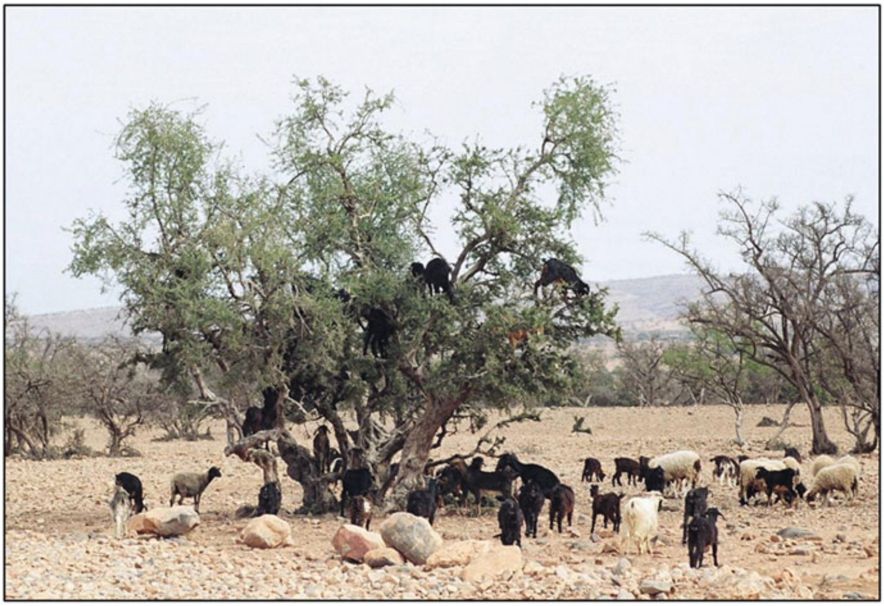

Fig. 10 Argan leaves eaten by goats [25]

7.3.1 Forest Goods

Argan Oil

Fruit production (nuts) of argan trees varies according to their age and density (20–100 kg/tree) with an average of 40 kg/tree/year. If we consider an average density equal to 25 trees per hectare and oil yield equal to 3 l per 100 kg of dry argan nuts, the potential oil production of the whole argan forest is estimated to be 32,000 tones/year [27]. Projection on the area occupied by argan in Chtouka Aït Baha will result in total production of 1,400 tons of argan oil, which is a total value of **280 million DH/year** with an average price of 200 DH/l sold locally or for export as an edible or cosmetic oil.

Livestock Feeding

The average pastoral production of argan tree is estimated to be 200 fodder unit (FU)/ha/year, nearly 174 million fodder units in the whole area of argan forest in Chtouka Aït Baha, which is equivalent to 1.74 million quintals of barley [25]. This production contributes to 40% of the livestock needs which is estimated to be 1.5 million head (65% represented by goats). Argan forests supply about 186,860 equivalent quintals of barley, for a total value of **38 million DH/year** (with barley price equal to 203 DH/quintal).

Wood

According to HCP [17], the quantity of wood produced in the argan forest in Chtouka Aït Baha is estimated to be 4,670 m^3 with a total value of **0.24 million DH/year.**

7.3.2 Erosion Control

Argan tree grows wildly in the arid and semi-arid environment in the southwest of Morocco, where it plays an important role in the ecological balance and biodiversity preservation. Due to its strong root system, it helps maintaining the soil and controlling the erosion which it is threatening most of the region [19]. According to HCEFLCD [20], the unit cost per hectare of reforestation work, soil preparation, and new trees planting carried out in the Souss-Massa region to fight against erosion is equal to 2,500 DH/ha for a period of 30 years (life duration of the project), corresponding to 84 DH/ha/year. For the total area covered by the forest ecosystem in Chtouka Aït Baha (93,430 ha), the economic value of erosion control service is equal to **7.84 million DH/year.**

7.3.3 Climate Regulation and CO_2 Sequestration

The economic value of vegetation in terms of climate regulation and CO_2 sequestration service has been estimated previously equal to 261 USD/ha/year, and for the total area of forest ecosystem in Chtouka Aït Baha region (93,430 ha), the TEV of climate regulation and CO_2 sequestration is equal to **233 million DH/year**.

7.4 Determination of Ecotourism and Recreation Services in Chtouka Aït Baha

Chtouka Aït Baha region has a great potential in terms of ecotourism especially due to its various geomorphological and ecological characteristics (mountains, wetlands, forest, coasts, etc.). According to data reported by Province de Chtouka Aït Baha [28], the tourism market which is corresponding to tourists visiting Agadir consists of a portion of 15% of the visitors who are tourists traveling independently of tourism operators. Those who organized their trip through a tourism operator or agency spend at least one day in the region.

According to Tourism Observatory [29], the region attracted more than 200,000 tourists in 2010. This number concerns only tourists staying in Agadir and visiting the region. The region attracts a total number of tourist days around 267,000 days.

Tourists spent an average of 948 DH/day. Thus the TEV of ecotourism in Chtouka Aït Baha region is equal to **253.12 million DH.**

7.5 Determination of the Economic Value of the National Park of Souss Massa

7.5.1 Wetlands (Souss and Massa River Estuaries)

Recreation Service

To determine the recreational value of the Massa river estuary as wetland, the contingent valuation and travel cost methods were applied by El-Bekkay et al. [30]. The results of 480 surveys conducted in 2010 showed that consumer surplus per person per visit is estimated equal to 490.196 DH and willingness to pay per visitor was about 46.523 DH. Thus, the value of the total consumer surplus is estimated to be **14.7 million dirhams**. According to this economic valuation, any future local development must take into account the possibility that Massa and Souss river estuary provides as a recreational site with high ecotourism potential.

Genetic Resources and Biodiversity

In order to assess the value of ecosystem service related to genetic resources and biodiversity, we have used a meta-analysis of previous studies that have valued this service for coastal wetlands or river estuary. About 37 studies were identified in TEEB and GECOSERV database. Figure 11 shows the distribution of valued ecosystem services by the country.

Figure 12 shows different valuation methods used in the previous identified studies. The most used method is the market price method and benefit transfer.

Statistical analysis was carried out on the economic values of various studies including the correlation between the economic value of genetic resources and biodiversity service and several indicators such as the gross domestic product and population density of the study country. The results obtained are shown in Fig. 13. The correlation concerned 16 countries where one or several studies were conducted.

A multivariable regression was performed using PAST software [23]. The model used is a multivariable linear model:

$$\text{SEV} = \text{Const} + a \times \text{GDP} + b \times \text{PD}$$

with:

- SEV: economic value of genetic resources and biodiversity service (USD/ha)

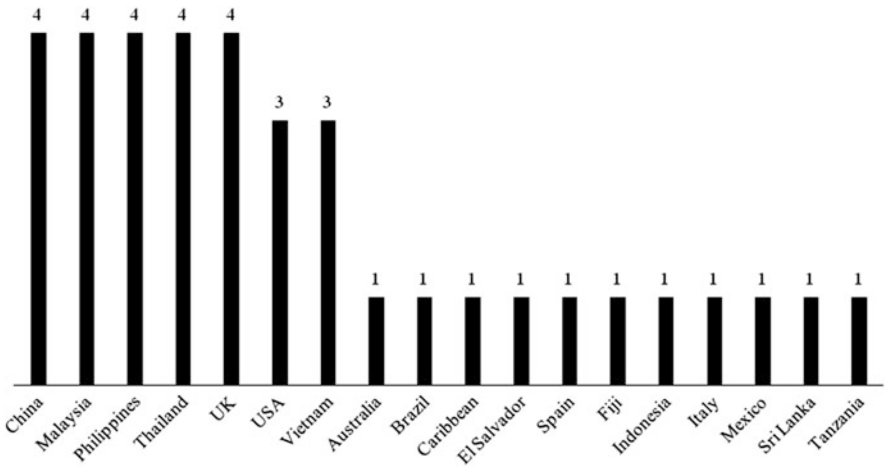

Fig. 11 Distribution of previous studies valuing the ecosystem service related to biodiversity and genetic resources

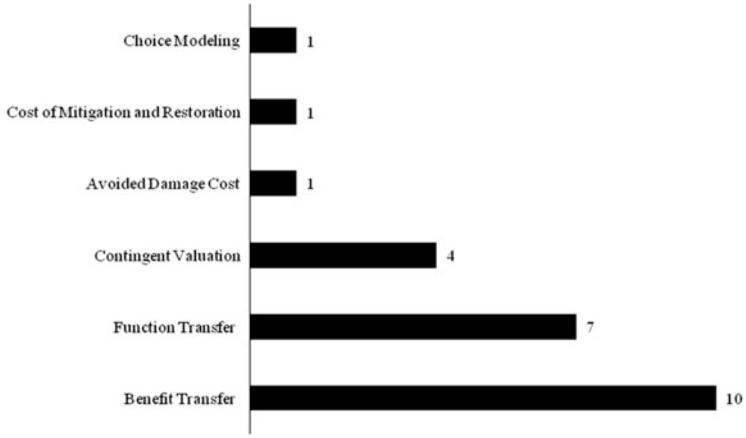

Fig. 12 Distribution of valuation methods used in the previous studies related to biodiversity and genetic resources

- Const: regression constant
- *a*, *b*: coefficients
- GDP: gross domestic product (billion USD)
- PD: population density (capita/km^2)

The regression results are shown in Table 14:
If we apply the model on the Morocco case with:

–GDP of 104 billion USD
–Population density of 75 capita/km2.

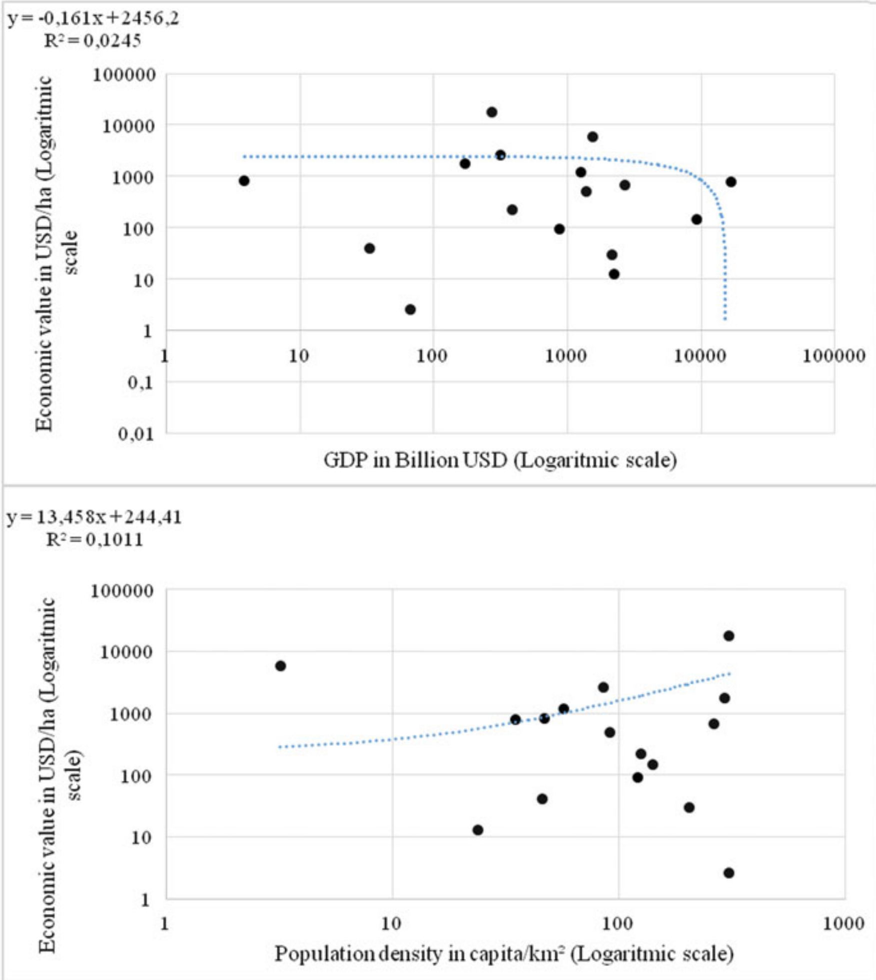

Fig. 13 Correlation between GDP, population density, and the economic value of ecosystem services related to genetic resources and biodiversity

Table 14 Multiple regression results related to genetic resources and biodiversity service

Variable	Coefficient	Standard deviation	R^2
Constant	580.33	2,157.7	0.79218
GDP	−0.08924	0.2771	0.75254
Population density	12.597	11.406	0.28941

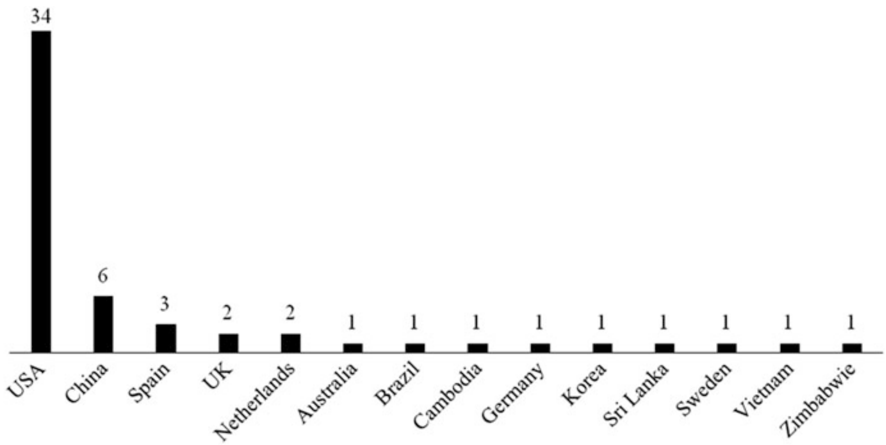

Fig. 14 Distribution of previous studies valuing the ecosystem service related to habitat

The economic value of genetic resources and biodiversity service for the wetlands in Morocco is equal to:

$$\text{SEV} = 580.33 - 0.08924 \times 104 + 12.597 \times 75 = 1{,}515.82 \ \text{USD/ha}$$

The wetland area of Massa and Souss river estuaries is equal to 1,000 ha. So the economic value of service related to genetic resources and biodiversity is equal to 1,516 × 1,000 = 1.516 million USD = **14.25 million DH**.

Habitat

Similar to the ecosystem service related to genetic resources and biodiversity, we have used a meta-analysis of previous studies that have valued habitat service for coastal wetlands or river estuary. About 56 studies were identified in TEEB and GECOSERV database. Figure 14 shows the distribution of valued ecosystem services by country:

Statistical analysis was carried out on the economic values of various studies including the correlation between the economic value of habitat service and indicators such as the gross domestic product and population density of the study country. The results obtained are shown in Fig. 15. The correlation concerned 14 countries where one or several studies were conducted:

A multivariable regression was performed using PAST software [23]. The model used is a multivariable linear model:

$$\text{SEV} = \text{Const} + a \times \text{GDP} + b \times \text{PD}$$

with:

- SEV: economic value of genetic resources and biodiversity service (USD/ha)
- Const: regression constant

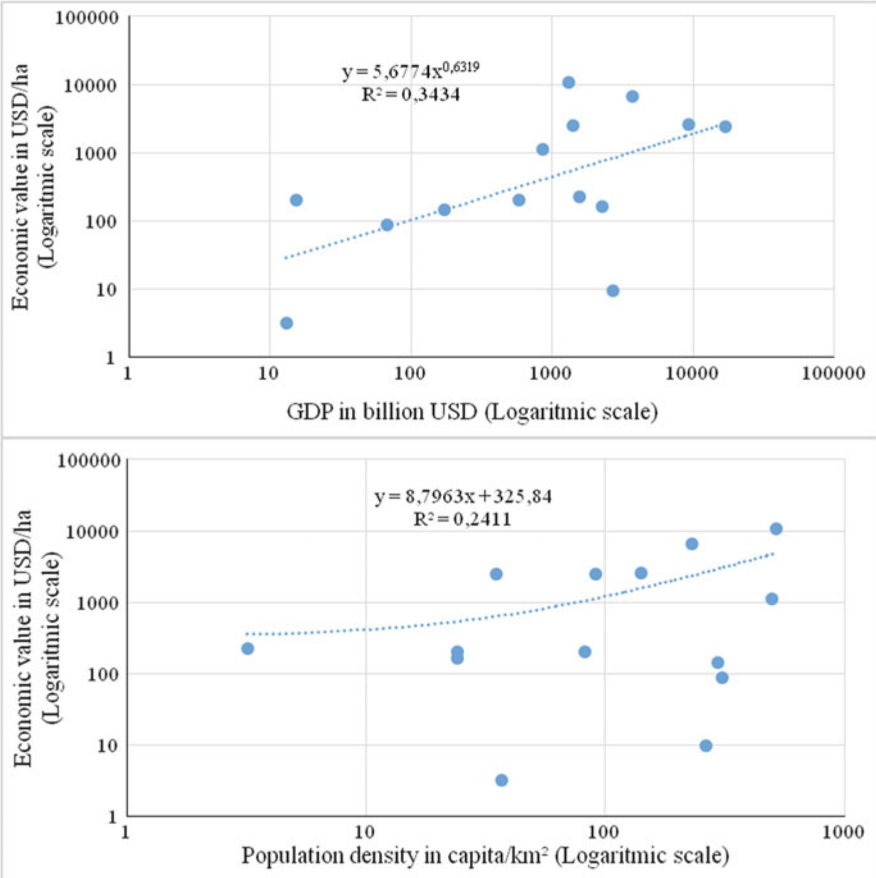

Fig. 15 Correlation between GDP, population density and the economic value of ecosystem services related to habitat

- *a*, *b*: coefficients
- GDP: gross domestic product (billion USD)
- PD: population density (capita/km^2)

The regression results are shown in Table 15:
If we apply the model on the Morocco case with:

–GDP of 104 billion USD
–Population density of 75 capita/km2.

The economic value of genetic resources and biodiversity service for the wetlands in Morocco is equal to:

$$\mathrm{SEV} = -488.84 + 0.19936 \times 104 + 10.093 \times 75 = 288\,\mathrm{USD/ha}$$

Table 15 Multiple regression results related to habitat service

Variable	Coefficient	Standard deviation	R^2
Constant	−488.87	1,302.8	0.71462
GDP	0.19936	0.17102	0.26839
Population density	10.093	4.5769	0.049629

Table 16 Summary of the total economic value of Chtouka Aït Baha ecosystems (million DH)

Ecosystem	Services	Monetary value
Aquifer	Water	213.5
Agroecosystem	Horticultural and cereals products	2,242
	Animal goods	744.56
	Erosion control	3.13
	Climate regulation and carbon sequestration	93
Forest ecosystem	Forest goods – argan oil	280
	Forest goods – livestock feeding	38
	Forest goods – wood	0.24
	Erosion control	7.84
	Climate regulation and carbon sequestration	233
National Park of Souss Massa	Recreation	14.7
	Genetic resources and biodiversity	14.25
	Habitat	2.73
All ecosystems	Recreation and ecotourism	253.12
Total economic value of Chtouka Aït Baha ecosystems		4,140.07

The wetland area of Massa and Souss river estuaries is equal to 1,000 ha. So the economic value of service related to habitat is equal to $288 \times 1{,}000 = 0.288$ million USD = **2.73 million DH.**

7.6 Summary of the Total Economic Value of Chtouka Aït Baha Ecosystems

Table 16 presents a summary of the main valued services in the region where the agroecosystem contributes by more than 74% in the TEV of the whole ecosystem. This percentage shows the important development of the agricultural sector in the region especially this region is the most productive region in Souss-Massa region as well as Morocco. The forest ecosystem who contributes by more than 13% in the TEV has more regulating services rather than provisioning services compared to agroecosystem where climate regulation and CO_2 sequestration and erosion control services contribute by more than 43% of the TEV of this ecosystem compared to agroecosystem where regulating services contribute only by 3% in the TEV of the ecosystem. Recreation and ecotourism represents about 6% in the TEV of the whole ecosystem of the region which reflects its importance in the ecological and socio-economic development of the region. Groundwater or aquifer ecosystem contributes by 5%; however, it is the most important ecosystem on which the whole ecosystem is depending for its continuity; thus an integrated management of groundwater resources taking into consideration the links between groundwater and other ecosystems should be improved and implemented in water management strategies and policies.

8 Conclusion

Groundwater-dependent ecosystems provide valuable services for humans and other species. These systems are typically of high value as they support high biodiversity and provide the habitat for several endangered species. Some of these ecosystems and related water bodies have been protected to a certain extent by international conventions such as the RAMSAR Convention. Recently strong social pressures are likely to arise for further agricultural and urban development, which are likely to impact groundwater-related ecosystems either directly (through increased groundwater extraction) or indirectly (through increased groundwater contaminant load). Thus an important issue in relation to the implementation of groundwater management to protect groundwater-dependent ecosystems is who should be the stakeholder representing the interests of a given ecosystem.

It was shown through this study that the agroecosystem is the main productive ecosystem contributing by more 74% in the TEV of the whole ecosystem of Chtouka Aït Baha. This ecosystem has a great impact on the socioeconomic development of the region compared to other ecosystems. Although the economic value of many other ecosystem services is not determined in this report, we tried to focus on the main services that have a direct impact on the ecological, socioeconomic, and cultural development of the region. However further works and field surveys should be undertaken to determine other services' economic value and taken into consideration in decision-making and project implementation and management. To avoid unnecessary damage to groundwater-dependent ecosystem services (GDEs), water managers and policy makers should be provided with updated information about the occurrence and status of GDEs. As these systems vary locally, depending on hydrogeology and climate, both local and regional studies are needed. To date, little information is available on the correct scale to understand these systems. National monitoring efforts should be conducted on the most typical ecosystems. Research is needed to better understand groundwater catchment areas of GDEs so that measures can be set correctly.

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Environmental Risk Assessment of the Reuse of Treated Wastewaters in the Souss-Massa River Basin

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Abstract Souss-Massa watershed is suffering more and more from hydraulic deficit and the use of treated wastewater represents an alternative for water conservation, and sustainable economic growth of the region. The Agadir region is known for its agriculture and its tourist attraction, which puts a lot of pressure on water resources, and at the same time the potential of treated wastewater is around 50 million m^3/year. The use of municipal wastewater (treated and untreated) in agriculture is becoming a routine practice in many (semi-) arid countries of the world. Wastewater and its nutrient content can be used extensively for irrigation and other ecosystem services, cutting on groundwater and freshwater consumption. Wastewater also offers environmental and socioeconomic benefits such as reduction in effluent disposal problems, supply of nutrients as fertilizer, and improvement in crop production during the dry season. Its reuse can deliver positive benefits (save freshwater, save fertilizer, and prevent pollution) to the farming community, society, and municipalities. Despite these advantages, wastewater applicability for irrigation depends on its physical, chemical, and microbiological quality. In fact, a continuous use of wastewater may cause serious health problems for humans and animals because of the possible heavy metal content. Therefore, it is of paramount importance to continue thorough investigations to evaluate the effects of wastewater irrigation on crops, grasses, soil, and environment before recommending it for long-term use.

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This chapter provides insights on wastewater use practices in Souss Massa, where water scarcity is always the major consideration. It also provides an understanding of the constraints and limitations of such an assessment, and the importance of developing a clear strategy for future assessments. It also highlights the potential of wastewater reuse in the Souss-Massa region. The analysis shows that a variety of constraints inhibit formal reuse of wastewater in the region, including the cost of reuse, low demand for reclaimed wastewater, the widespread lack of effective price signals and cost recovery in the water sector, and challenges in structuring the financing of reuse.

Keywords Effluent quality, Reuse, Socioeconomical aspects, Souss Massa, Treated wastewater, Treatment plants

Contents

1 Introduction

Water resources scarcity, accessibility, and environmental degradation are the major challenges facing the Souss Massa region. This region is facing a chronic water deficit, and some area, is unable to meet the agriculture requirements through the available water resources.

Treated and reused sewage water is becoming a common source for additional water in the region and it is included in the water resources management within the master plan. Water recycling by reusing treated wastewater has several beneficial purposes such as agricultural and landscape irrigation, industrial processes, and replenishing a groundwater basin (referred to as groundwater recharge).

Wastewater treatment can be tailored to meet the water quality requirements of a planned reuse. Recycled water for landscape irrigation requires less treatment than recycled water for drinking water.

The Environmental Risk Assessment of the reuse of treated wastewaters in the Souss-Massa River Basin is part of a comprehensive assessment of water management in agriculture. Within the Sanitary National Plan, Morocco is predicted to reuse 300 Mm^3 by the year 2025 for irrigation but at present there is a gap in knowledge about global estimates, the possible trade-offs between health and environmental impacts, and the benefits related to the livelihoods of those using wastewater.

2 Wastewater Treatment at Greater Agadir

Faced with increasing water scarcity, policy-makers in the Souss Massa region are increasingly interested in tapping non-conventional water resources, such as recycled wastewater, to meet demands for water. Treated wastewater in the region of Souss Massa is mostly domestic treated sewage and can be reused primarily for agricultural, landscaping, and golf courses irrigation [1]. Treatment level as related to the purpose and location of reuse is of special concern [2]. The nutrients contained in the treated wastewater are beneficial for agricultural use [3]. Current efforts of wastewater reclamation focus on removal of pathogens.

Actually, several treatment plants are treating a total volume of 53 000 m^3/day, using the sand infiltration and lagoon system technologies (Table 1), and almost less than 10% volume is recycled due to lack of institutional framework use this treated wastewater in agriculture, landscaping and golf course irrigation.

In the region of Agadir, farmers whose products are exported to foreign markets are very reticent to use treated wastewater as a precaution to compromise their markets, and within the region, there is still natural hesitation to consume fruits and vegetables irrigated with used water.

2.1 Wastewater Treatment Situation

Actually, there are about ten treatment plants within the region of Souss Massa. The predominant technology used is the stabilization ponds which does not require electricity, and its lower operating costs make it less vulnerable to disruptions in the case of strained operating budgets. We also have two activated sludge plants (airport Al Massira, Taghazout Bay) and a few trickling filter plants (Great Agadir, Bensergao, and Drarga).

Table 1 Wastewater treatment plant technologies in the Souss Massa region

UWWTP station	Treatment system	Starting year and treatment capacity
Bensergao	Anaerobic lagoon and infiltration–percolation and agriculture use	November 1989, 750 m^3/day
Drargua	Anaerobic lagoon and infiltration–percolation with denitrification and reed bed for tertiary treatment and agriculture use	October 2000. 1,200 m^3/day
Great Agadir Lamzar[a]	Anaerobic lagoon and infiltration–percolation and UV treatment for tertiary treatment landscape, and golf courses use	November 2002: anaerobic lagoon for 50,000 m^3/day. June 2005: infiltration–percolation for 30,000 m^3/day
Biogra	Lagoons system and groundwater recharge	July 2006 for 12,000 m^3/day
Oulad Teima	Lagoons system and agriculture use	
Tiznit	Lagoons system and agriculture use to irrigate cereals, olives, and vegetables	2006 for 6,000 m^3/day
Taghazout Bay	Activated sludge and golf course use	Under construction

[a]Emissary of 700 m long, rejects wastewater primary treated to the sea

The sequence of urban wastewater treatment includes several processes:

Step 1: Primary treatment (anaerobic basins)
Step 2: Secondary treatment (filters with sand)
Those steps are used in Ben Sergao, Drarga, and Lemzar wastewater treatment plants.
Step 3: Tertiary treatment (only for Drarga). This step of treatment is followed by:

1. A drying-bed for the treatment of sewage sludge is connected to the anaerobic basin
2. A storage basin filled with a 1-meter layer of gravel for treating wastewater using reeds beds.

2.2 *Treatment Efficiency*

The qualities of the treated wastewater comply with the norms of WHO regulation to be used without restriction in agriculture irrigation. The treatment efficiency is high enough to produce effluent quality corresponding to WHO value limits (see Table 2) indicate the reliability of these technologies and respond the socioeconomical condition of this region [4].

The potential of using this treated wastewater for irrigating agricultural crops and the greening of the city has been established in the demonstration pilot station of the ORMVA Souss-Massa. The results confirmed that these conventional systems:

Table 2 Treatment efficiency of the different wastewater plants in Souss Massa Region

Parameters	Bensergao	Great Agadir	Drarga	Tiznit	Oulad Teima	Limits CEE (1991)	Limit values
DBO_5(mg O_2/l)	98.40	99.40	98.4	99.4	99.4	79–90	30
COD (mg O_2/l)	95.75	97.29	96	94.0	9	75	–
MES (mg/l)	99.50	99.00	99.00	90	90	90	30
NTK(mg N/l)	92.04	94.81	97.0	93.8		70–80	
Fecal coliforme (germs/100 ml)	99.9	99.9	99.9	99.999	99.99	99.99	Less than 1,000
Eggs (helminths) (number/l)	100	100	100	100	100	100	0

- These conventional systems offer several advantages as a reliable wastewater treatment plant (lower construction and operating, no energy requirement, easy maintenance, higher quality recycling of water and nutrients for irrigation, and aquifer recharge)
- The sanitary quality of treated wastewater corresponds to category A of the WHO recommendations for irrigation of products for raw consumption (the results are given in the table above): less than 1,000 fecal coliform, less than 30 mg/l of suspended matter and free of helminth eggs
- The concentrations of major fertilizing elements of treated wastewater reduce the input cost of fertilizer for horticultural crops
- For the open field and protect crops, the quantity and quality of yields obtained using treated wastewater irrigation and complementary fertilization are generally higher than those obtained with irrigation using groundwater and classic fertilization (explained by the availability of fertilizing elements in wastewater including microelements and humic-acids)
- Concerning parasitological and bacteriological quality of the products: no contamination detected. There was no significant difference between tomatoes and melon irrigated with the two water qualities as far as fecal coliform.

3 The Options of Reusing Recycled Water

Compared to the overall water use in the Souss Massa valleys, reclaimed water can only provide a fraction of the region's increasing water needs. Furthermore, there is no regulatory framework for water reuse and no established system to recover the costs for reclaimed water from users.

3.1 Golf Courses and Landscaping Uses

In 2009, a large reuse project was planned in Agadir to irrigate a golf course and municipal gardens with 50,000 m^3/day with 30 000 m^3/day at the tertiary level. This allows a saving of about 30,000 m^3/day of ground freshwater. In Agadir city, there is about 500 ha of golf course where a quantity of 20 mm^3/year of the treated wastewater can be valorized, currently only the Golf de l'Océan (90 ha) which is using treated wastewater as source of irrigation water. There is also about 576 ha of landscapes for which 8 mm^3 of treated wastewater could be supplied [5]. The major constraint for reusing treated wastewater in landscaping and golf courses is mainly due to high salinity of the effluent (3.5–4.5 dS/m) and the level of nitrate (over 300 mg/l). The water district in charge of the wastewater treatment RAMSA has a program to reduce the salinity of the effluent by developing a pretreatment of the wastewater of the fishery industry at the source level. The reuse should be oriented to demand-driven planning of reuse projects, and commitment to the reuse. A good example is illustrated by the partnership between the water distributor agency of Marrakech (RADEEMA), the state of Morocco, and the 24 golf owners. The agency will contribute up to 46.7 million US dollars, the golf course owners with 36.7 million US dollars, and the state with a subsidy of 16.1 million US dollars. The plant will allow the production of 24 mm^3 of tertiary treated wastewater to be used for the irrigation of these golf courses [6].

3.2 Agricultural Land Use

The region of Tiznit suffers from a water stress. The average rainfall is 150 mm per year. In this context of scarcity, the major concern for the region, in fact, protecting resources and conserving water is also major concern for the region. Treatment and reuse of treated wastewater in agriculture is thus presented as a key solution. This allows exploiting a resource with additional water available at all times. Reducing operating costs by minimizing chemical fertilizer is also to consider.

Among the strengths of Tiznit project, the position of the wastewater treatment at the periphery of the city located between the urban area and the rural area suitable for agriculture irrigation. In addition, the seasonal peak water production with the return of Moroccan workers from Europe coincides with rising water needs of crops. It should also be noted that the station can operate year-round without the need for a storage, as the rainfall is low and the temperatures are high. In addition, the water quality fully meets the rotation proposed by the local cropping systems.

For the implementation of this project on the treated wastewater in Tiznit, several steps have been taken. A monitoring committee was first created. It is led by the Provincial Delegation of Agriculture (DPA). An agreement between all stakeholders, including health delegation department, was developed with well-defined responsibilities. Also, most of the farmers will use drip irrigation as a suitable technique to irrigate their crops, because of the water quality and low volume of water available, as well as the government will subsidize 100% of the investment for choosing this irrigation system. Therefore, it is possible to double the surface to be irrigated with treated wastewater by the year 2018. Nine million DH (about one million US dollars) was invested in the reuse implantation project to pump the effluent to the irrigated areas and install the irrigation network. The hydro-agricultural development is funded by the Agricultural Development Fund.

The wastewater treatment is located in the West side of the city of Tiznit, in the southern part of Morocco. It occupies a surface area of 39 ha, and it was first operated in the year 2006. The total cost of the plant was 41 million dirham (3.8 million euros). Part of the cost (70%) was supported by ONEP through a German cooperation (KFW) and the rest was paid by the municipality which offered the land (Daoudi 2011).

Based on the WHO guidelines, these lagoon systems under arid condition allow reaching a quality of treated effluent to be used with no restriction for irrigation. The fecal coliform was always less than 200 units per 100 ml, and there were no helminths eggs after the maturation pond. The salinity of the effluent was less than 2 dS/m, rich in nitrogen and phosphor, and reduces the cost of fertilizers for the farmers.

Two zone areas are using the treated wastewater of Tiznit plant. One is located downstream of the plant (Attbane) and treated wastewater could be conveyed by gravity, and the second zone in the upstream (Doutourga) and the effluents are pumped using a pumping station. A third zone that could be also irrigated in the future by 2015 (Targa N'Zit) is located close to the second zone. The two farmers associations of these zones (Attbane and Doutourga) built a pumping station with the financial help of the state authority of the city of Tiznit, which help them to distribute the treated effluent to each farmer, install the drip irrigation system and save water. Each farmer has a water meter and pays the association a fee at the end of the month at a rate of 0.7 Dh/m^3. These revenues allow the association to pay for the electricity and the operation and maintenances of the pumping station.

The farmers of the areas of Attbane and Doutourga were organized in agricultural irrigation association in order to facilitate awareness programs on the best practices for reusing treated wastewater. The total of the farmers plots were 665 with average size of 0.65 ha [5].

The cropping system is based on fruit crops (olives and palm trees), cereals (wheat and barley), and vegetable crops and forage crops (beans, cauliflower, artichoke, and alfalfa).

Thus far, socioeconomic indicators point to the positive impact of this pioneering project and its success, most evidently portrayed by increased income per family, and elevated standards of living of the local community and farmers. Hence, it can be stated that, in terms of financial viability, these projects have proved to be successful and sustainable, where revenues from fodder and fruit tree crops are high enough to cover the direct production costs and to provide an attractive income. This water reuse project for agriculture has created the opportunity for the local community groups to take responsibility for water management, while improving general efficiency and system performance and reducing costs for the farmers and the Government. The farmers worked toward solutions to increase their income and raise their standards of living, with great transparency within their local community.

This successful best practice could be replicated and a considerable potential for other regions of Morocco, as well as other Mediterranean countries, as they have similar climates and food security needs. Another very important lesson learned is related to the operational performance, and good public communication which are fundamental to the success of any water reuse project. It can only realistically be promoted where investments in wastewater collection and treatment systems have already or are soon to be made. Also, one of the most important lessons learned is that, to enable the Moroccan people to feel confident with reused water for irrigation, it was imperative to establish trusted institutions to ensure the highest standards of health and safety.

(1) This project contributes to fresh water saving, and provides food (cereals and vegetables) to the city, (2) it is cost effective and production is less costly, (3) it provides employment to the poor, (4) it creates a buffer between urban and rural area, (5) it provides oxygen in the environment, and (6) it restores biodiversity.

In the Drarga city (Agadir region), the treated wastewater is used to irrigate about 16 ha of some cereals, forage, and vegetable crops using the drip irrigation system. This practice allows a saving of about 120–361 euros/ha in terms of fertilizer and 61–150 euros/ha in terms of water use. Generally, the yield of irrigated crop was doubled. This indicates that the use of unconventional water allowed getting higher water use efficiency without decrease in yield. As matter of fact, yields were higher for plants irrigated with treated wastewater. The increase of yield for plants receiving 20% more water is mainly due to more supply of nitrogen and lower salinity in the roots zone. The water use efficiency was significantly different between treated wastewater and saline well water. Water use efficiency was the highest for the plants receiving treated wastewater at 120% ETM [7].

3.3 Artificial Recharge of the Aquifer

Within the region of Chtouka, water deficit is reaching 60 mm^3/year in order to cope with the seawater intrusion due to overexploitation of groundwater [8]. In Agadir city, the treated wastewater in Biogra station is used for the artificial recharge of the aquifer using an amount of about 10 mm^3/year through filtration basing [5]. There is little success in this artificial recharge of the aquifer as the level of the treatment is only secondary level and there is a risk for groundwater contamination with both nitrate and coliforms.

3.4 Sylviculture

In the Ait Melloul city (Agadir region), there is a possibility to irrigate 400 ha of Argania forest using about 4 mm^3/year of treated wastewater generated by the M'zar station [5]. Along the coastal area between Agadir and Tiznit, there is a potential to use treated wastewater to grow and to irrigate trees (eucalyptus) and local bushes (*Tamarix* sp.) to establish a coastal forest in order to fix the dunes preventing wind erosion and produce wood.

4 Environmental Risk from Treated Wastewater Irrigation

Wastewater irrigation poses several threats to agricultural sustainability. Nitrogen in high concentrations, while usually beneficial to crops through its fertilizing properties [7], can also limit plant growth and crop yield [9]. Salinity and sodicity, however, are by far the most important sustainability constraints [4] and will be the focus of the following discussion. The properties of wastewater clearly depend on its origin, but most wastewaters are higher in salts than traditional irrigation waters, with electrical conductivity roughly ranging from 2 to 3.5 dS/m [10, 11]. Salts can affect plants either through causing osmotic stress or via direct toxicity. High concentrations of salt in the root zone lead to a decrease in the osmotic potential of the soil–water solution, thus retarding the water uptake rate of the plant. The plant expends considerable energy trying to osmotically adjust, by accumulating ions, and this is typically at the expense of yield. Toxicity occurs when salt ions enter the plant and interfere with cellular processes. Most horticultural crops uptake salts more readily through the leaves than through the roots. Therefore, through substituting overhead irrigation with drip, furrow, or sub-subsurface methods, the toxic effects of salinity can be easily remedied, but not the osmotic effect.

In the case of Ben Sergao (Agadir, Morocco), the use of the treated wastewater for irrigation adds to the soil a large amount of nitrate nitrogen, which exceed the crops requirements, and lead in consequence to nitrate lixiviation toward underground water. This will present on a long-term basis a high risk to deteriorate seriously the quality of the water resources. This is already happening in certain localities due to abuse nitrogen fertilization program of several plastic house crops as well as in the villages along the Souss river area where no sewerage is existing.

4.1 Groundwater and Surface-Water Contamination

Leaching of nitrates poses one of the greatest threats to groundwater health arising from wastewater irrigation [6]. The risk of groundwater contamination with nitrate can be markedly reduced through appropriately matching plant production systems to effluent characteristics [12]. In Drarga, trials showed that the irrigation volumes used for each crop generated nitrate nitrogen supply evaluated up to 2,114 kg of NO_3/ha and 2,397 kg of NO_3/ha, respectively, for melon and carnation. These values correspond, respectively, to 477 and 541 unit of nitrogen fertilizer. The quantity of nitrogen taken up, respectively, by melon and carnation are 260 and 357 kg N/ha. These amounts represent 54.5 and 66% of nitrogen added by irrigation water of melon and carnation, respectively. We then conclude that the amount of nitrogen lost to the underground water are 346 and 343 kg of N/ha, respectively, for melon and carnation, considering all the components related to nitrogen budge. High-yielding crops with large amounts of nitrogen in their biomass would be more effective than tree plantations at reducing nitrate leaching. Water bodies located near densely built-up areas have a high recreation value. Constructed wetlands may offer the additional benefit of improving water quality by assimilating and transforming organic, inorganic, and toxic constituents through the processes such as adsorption, settling, sedimentation, and biodegradation [13]. Constructed wetlands are ideal, low-cost, wastewater treatment systems; they provide an efficient and an easily operated alternative to conventional treatment systems. In addition to treating pollutants and waste, they may also provide important wildlife and recreational benefits commonly associated with natural wetlands [14].

4.2 Health Risk

Reusing raw wastewater is likely to imperil human health and to contaminate the environment. Indeed, wastewater can transport many pathogenic germs (parasitic, bacteria, viruses, and fungi) that possess high resistance to the medium and can harm humans. Wastewater is therefore a significant transmitter of biological and chemical agents resulting from human and/or industrial activities. Agriculture that is irrigated with wastewater concentrates many infectious and toxic agents. In addition, it represents a medium for the proliferation of certain pathogenic agents emitted in human or animal waste. In addition, wastewater resulting from hospital discharge or other infected mediums may be a dangerous source of contamination [12].

4.3 Pollution of Receiving Waters and Associated Habitats

The other major environmental benefit to be garnered from reusing wastewater is diminution in pollution of waters receiving discharge of sewage. Most of Souss Massa's large sewage treatment plants employ primary and secondary treatment. While clearly preferable to the release of raw sewage, the discharge of secondary-treated effluents can nonetheless have substantial adverse bearing on the ecology of aquatic ecosystems. Of particular concern is the potential for eutrophication of receiving waters. Nitrogen and phosphorus are the prime causative agents of eutrophication, the former tending to be more problematic in the marine environment, and the latter in freshwater systems. Adverse environmental impacts upon receiving waters, fresh and marine, are numerous. An extensive 4-year study found that most of the nitrogen entering the Bay stayed there and is assimilated there. Consequently, the report recommended a precautionary of at least a primary treatment, which allows a reduction of 50% nitrogen load. In short, huge amounts of pollutant-laden wastewater are being discharged to water bodies in most inhabited parts of the world. Reducing the volume of this discharge is a powerful driver for wastewater reuse.

4.4 Pollution Risk Mitigation

It should rely on the following good practices:

- It is important to establish with high precision the water balance in the soil plant system, by quantifying the inputs (rainfall and irrigation volume) and the outputs (crop uptakes and evaporation).
- Analyze the nutrient contents, in particular treated wastewater nitrogen. This will allow quantifying the amount of added nitrogen in the applied irrigation considering the yield level to be achieved in order to evaluate the nutrients uptakes.
- Based on the soil analysis, consider the balance mineral nitrogen remaining in the soil.
- The irrigation dose is an important factor that conditions the nitrate leaching. Therefore, in light sandy soils, it is recommended to reduce the amount of water applied and increase the frequency. At this level, it is recommended to consider the importance to optimize the rate of nitrogen and the irrigation water depth on the basis of crop water and nitrogen requirements for the different stages.
- Choose crops with high nitrogen uptake, and/or assure maximum soil crop cover.
- Mix rich nitrogen waters and low nitrogen waters or alternate these two types of waters.

The knowledge of the amount and the form of the mineral nitrogen in the treated wastewater is of prime importance. In fact, depending on the adopted treatment process, this water would contain ammonium (lagoon) or nitrate (infiltration–percolation). It the first case, it is recommended to use nitrification inhibitors, and in the second case, two possibilities are to be considered: add a denitrification system at the plant level or mix the treated wastewater with a proportion of surface or underground water to reduce the level of nitrates.

It is also strongly recommended to establish a nitrogen mass balance, coupled with a water balance in order to protect the aquifer against nitrate contamination.

The objectives are to keep the nitrate concentration in the water below 50 mg/l or assure 0% annual increment rate in case the nitrate concentrations exceed 50 mg/l.

5 Institutions for Wastewater Management

Although a series of legislation and decrees emphasizing the State's commitment and outlining the responsibilities for water resources protection and management exists, there is no single fully constituted entity responsible for wastewater management per se in Souss Massa.

Prevention and mitigation of negative impacts on the environment are regulated by environmental legislation under the Ministry of Environment. At the provincial and city level, the regional service of the Department of Environment reports to the Provincial Committee responsible for environmental protection and management.

Operation and management of city sewerage systems is under the authority Water District Company (RAMSA) in the region of the great Agadir. The RAMSA is supervised by the Department of Interior and the Ministry of Finance. In the rest of the region, the distribution of water and the treatment of wastewater is under the authority of ONEE-section water.

The required standards and the legislation are provided by the Law 10-95 under the supervision of the department of water which is locally is represented by the River basin agency of Souss Massa.

This old legislation ceased to correspond to the country's modern organization and could no longer meet the needs for its socioeconomic development, which required the creation of a modern regulation of water through the adoption of law No: 1-95-154 of 18 Rabii I 1416 (corresponding to 16 August 1995) and promulgation of the law No. 10-95 on water. This Law aims at the elaboration of a national water policy based on a forward vision that takes account of the evolution of resources and of national water needs.

In the field of wastewater, this new Law 10-95 on water, in its chapter VI, regulates the reuse of wastewater and its texts constitute the legal basis of the institutional framework for reuse, in particular articles 51, 52, 56, 57, 59, and 84 [4].

5.1 Social Livelihoods and Political Aspects

There are reservations related to the use of the treated wastewater (which is often perceived as unclean). This is paradoxical when one considers the quantities of wastewater reused in its raw state. Wastewater goes through a treatment station where the influx of raw wastewater is clearly visible. The origin of used water is thus known. There is therefore natural hesitation to consume fruits and vegetables irrigated with used water. In the region of Agadir, farmers whose products are exported to foreign markets are very reticent to use treated wastewater lest this compromises their markets [4].

Data availability was sketchy at this level of assessment, and it was understood that more detailed studies on the livelihoods dimension of wastewater use were needed. In the context of this study, livelihoods reflect the number of persons' dependent or engaged in wastewater agriculture, using it either as a main or as a secondary source of income.

Water recycling has proven to be effective and successful in creating a new and reliable water supply without compromising public health. Nonpotable reuse is a widely accepted practice that will continue to grow. However, in many parts of the USA, the uses of recycled water are expanding in order to accommodate the needs of the environment and growing water supply demands. Advances in wastewater treatment technology and health studies of indirect potable reuse have led many to predict that planned indirect potable reuse will soon become more common. Recycling waste and gray water requires far less energy than treating salt water using a desalination system. On the other hand, there are concomitant environmental risks with wastewater reuse. Ultimately, the challenge facing wastewater reuse is to minimize such risks so as to maximize the net environmental gain.

While water recycling is a sustainable approach and can be cost effective in the long term, the treatment of wastewater for reuse and the installation of distribution systems at centralized facilities can be initially expensive compared to such water supply alternatives as imported water, groundwater, or the use of gray water onsite from homes. Institutional barriers, as well as varying agency priorities and public misperception, can make it difficult to implement water recycling projects. Finally, early in the planning process, agencies must reach out to the public to address any concerns and to keep the public informed and involved in the planning process. Local communities and businesses are working together to meet water resource needs locally in ways that expand resources, support the environment, and strengthen the economy.

6 Conclusion

The use of urban wastewater in agriculture is a common practice all over the world and for diverse reasons, not least of which are water scarcity, fertilizer value, and lack of an alternative source of water. However, it is necessary to have a clear understanding of wastewater's importance and significance in terms of extent, agricultural production, landscaping uses, and livelihood impacts before appropriate policies, strategies, and guidelines for its use in an integrated water management framework are developed.

Use of wastewater of municipal sewage treatment plant for irrigation of agricultural crops, golf course grasses, or landscape bushes and trees requires accurate analysis. Determining the factors influencing the health risks of using wastewater in crop irrigation for humans and plants is very difficult. But today, due to lack of water and the unavailability of it, urban wastewater for agriculture and landscaping is being used in developing countries. However, determining the level of risk factors in soil quality and products is essential. In fact, if any of the factors in the production of agricultural products violates the standard, that indicates poor conditions and inappropriate sewage to be used in agriculture and landscaping.

In this study, the risk level of several parameters in urban wastewater treatment plant to be used in agricultural production in Ardebil region was determined that these factors including total coliform, coliform gastrointestinal, helminth eggs parasites, lead, copper, cadmium, zinc, total dissolved solids, nitrate, phosphate, sodium, potassium, calcium, magnesium, sulfate, chloride, and the electrical conductivity. Our results showed that that sodium, chloride, bicarbonate, calcium, and nitrate had the highest risk. If the amount of this substances is higher than the standard limit for groundwater and accumulation in plant tissues, it could have dangerous effects for plants and humans. Therefore, the results suggest that in using sewage for agriculture, important values such as specific salts, nitrates, and biological parameters should be carefully considered.

This additional water resource is considered somewhat attractive, being renewable and accessible in peri-urban areas, cheap source that be disposed-off, its quantity grows with the expansion of sanitation networks installed for urban or rural communities, and being not affected by the climate change. The current overall contribution of treated wastewater to agriculture in the Souss Massa could hardly exceed 0.5% of this sector demand of freshwater, knowing that the potential of treated wastewater is around 5%. This small percentage, however, should be reckoned with when drafting water master plans, not only for satisfying some irrigation requirements but also for the fact that reuse of treated effluent is safe, feasible, and environmentally sound method of wastewater disposal.

Domestic WWTR is a tool to address the food and water insecurity facing many countries suffering from water scarcity. In coming years, in most arid countries, valuable freshwater will have to be preserved solely for drinking, very high value industrial purposes, and for high value fresh vegetables crops consumed raw. Where feasible, most crops in arid countries will have to be grown increasingly, and eventually solely, with treated wastewater. The economic, social, and environmental benefits of such an approach are clear. To help the gradual and coherent introduction of such a policy, which protects the environment and public health, governments shall have to adapt an Integrated Water Management approach, facilitate public participation, disseminate existing knowledge, and generate new knowledge, and monitor and enforce standards.

To ensure the sustainability of the system, a cost recovery analysis should not be neglected. With the low income of most farmers, it is not realistic to expect farmers to pay any portion of the treatment cost, but tariffs should cover the cost of transferring and distribution of the reclaimed water.

On the technology side, small-scale decentralized sanitation technologies, such as lagoons, sand filters, constructed wetland, and even septic tanks combined with small-bore sewers, offer great potential in small rural areas. As far as irrigation technologies are concerned, drip and bubbler irrigation may be considered the preferred method of application particularly for tree crops. It provides some water savings, and also provides some degree of protection against clogging and contamination exposure.

In addition, we should emphasize that coordination of actors or key stakeholders and their activities at different levels of society is ineffective and is a major challenge in transforming the sanitation sector and translating the reuse of treated wastewater policies into practice in Souss Massa. There is, however, an increasing understanding of the above challenges and efforts are being made at the regional level to clarify, redefine, and reassign roles and responsibilities, and improve coordination in the sector.

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Contribution of Seawater Desalination to Cope with Water Scarcity in Souss-Massa Region in Southern Morocco

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Abstract Souss-Massa region is characterized by a high value in terms of horticultural production, mainly in greenhouse crops, which contributes to the socio-economic development of the region. Since the early 2000s, the region is subject to increasing pressure on water resources, resulting in exploitation of groundwater beyond its renewable potential leading to a continuous decline in its piezometric level and threatening the agricultural development as well as all groundwater dependent ecosystems. In order to cope with water scarcity, the government decided to setup a project for groundwater safeguarding by implementing a seawater desalination plant for greenhouse crops irrigation in Chtouka zone with final capacity of 167,000 m^3/day feeding irrigation network covering about 13,600 ha. The project aims as well to substitute some of the groundwater uptake and further more contributes to groundwater recharge by irrigation water leaching to the aquifer. The Government has established an agreement with representative agricultural organizations and stakeholders focusing on the implementation of collective management of water resources in Chtouka region particularly through the introduction of a quota system of groundwater withdrawals to limit the groundwater overexploitation and commitment of high cash crops producers to use a desalinated

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water volume of 3,600–4,000 m^3 per hectare per year. The project will have a positive impact on the environment as it will contribute significantly in the reduction of the aquifer overexploitation and consequently will achieve an equilibrium in terms of groundwater balance as well as sustainable use of the aquifer in the Chtouka zone. Through this project the region will avoid a loss of nearly 9 billion DH as added value and 3 billion DH as capital in the horizon of 2035. The project will allow to increase the agricultural added value by 21.9% and preserve more than 2,830 permanent jobs.

Keywords Aquifer, Chtouka, Institutional framework, Vegetables, Water balance

Contents

1 Introduction

To deal with the increasing global water crisis, desalination plants have become the latest vogue, providing alternative freshwater sources. There were about 14,500 facilities in 2010 and approximately another 240 units under construction in the world but the highest desalination capacity is located in the Middle East. The global number of desalination plants is expected to continue to rise for the foreseeable future [1]. Desalination processes can be undertaken with several technologies. The most common are units based on multistage flash (MSF) distillation, which uses steam, and processes using reverse osmosis (RO), which is a membrane technology driven by electric pumps [2]. MSF desalination technology is mainly used across the Middle East. However, in recent years RO seawater desalination plants have become more popular, because of their sustainability, cost effectiveness, and simplicity, achieved by technological improvement [1].

In spite of desalination technologies development, the costs of desalinated water are still too high for the full use of this resource in irrigated agriculture, with the exception of intensive horticulture for high-value cash crops, such as vegetables and berries (mainly in greenhouses), grown in coastal areas (where safe disposal is easier than in inland areas) [3]. For agricultural uses, RO is the preferred desalination technology because of the cost reductions driven by improvements in membranes in recent years. Many people think that this application is not feasible for irrigation due to the high water costs, but the reality is that it has been used in many countries with success for years such as Spain and some GCC countries providing a significant example of application of desalinated water inirrigation. For example, Spain has more than 300 treatment plants, about 40% of the total number of existing plants and 22.4% of the total desalinated water is used for agriculture. Most of these plants process brackish water (only 10% of the total desalinated water for agriculture originates from seawater) and are located in coastal areas or within 60 km from the sea. In this country, small- and medium-sized brackish-water desalination plants, with a capacity of less than 1,000 m^3/day (11.6 l/s), are common because they adapt better to individual farmer requirements and to the existing hydraulic structures [4].

Souss-Massa region in the south of Morocco is considered the most productive in terms of horticultural products especially destined for export. The part of the region in exportation of fruit and vegetable is about 90% at national level. The greenhouse cropping system is the most common with more than 15,000 ha of crops grown under greenhouses. However, this region suffers from a serious problem of water scarcity, where the annual rainfall does not exceed 200 mm, and the water deficit is more than 280 Mm^3. Furthermore agriculture, in this region, consumes about 90% of the water resources. Overpumping of groundwater is among the practices aggravating the situation by lowering the water table and consequently increasing pumping costs and groundwater salinization due to seawater intrusion, especially in the coastal areas. Using desalination of seawater for irrigation of cash crops as tomato and berries and other vegetables crops could be a judicious solution to maintain a sustainable horticultural production and water saving [5].

This paper provides a review about water resources situation and management in Chtouka region as well as a technical description of the public–private partnership (PPP) desalination project destined to irrigation focusing on its impacts, benefits, and institutional aspects.

2 Current Situation of Water Resources in Souss-Massa Basin

The Souss-Massa river basin, which is bounded on the north by the High Atlas mountains and on the south and east by the Anti-Atlas mountains, covers approximately 27,000 km^2. The Souss-Massa region is characterized by an arid climate with low precipitations (<200 mm/year). The annual rainfall is very variable; precipitations of the humid year sometimes reach 3 times of the average year and 15 times of the dry year. Surface water is collected and stored behind seven dams that have a combined total capacity of approximately 800 Mm^3 [6]. The total water

Table 1 Water balance in Souss and Chtouka aquifer

Aquifer recharge (Mm^3)	Souss aquifer	Chtouka aquifer
Rainfall water infiltration	31	3.5
River and flooding water infiltration	160	2
Return of irrigation water (surface water)	4.5	15.7
Artificial recharge	9	–
Upward drainage from deep aquifers	3	10
Flows from next aquifers	60	1.7
Total input	268	33
Water withdrawal (Mm^3)		
Underground flow to the sea	4	3
Drainage to drains and rivers	0	2.2
Irrigation water uptake	521	78
Drinking and industrial water uptake	26	7.2
Total output	551	90
Balance	−284	−58

use in the basin is approximately 1,034 Mm^3/year, 36% from surface water and 64% from aquifers, 95% of this quantity is used mainly in agriculture, and 5% as drinking and industrial water [7]. Overall, demand for water exceeds the sustainable supply, with the deficit being made up by groundwater overexploitation. Overpumping of the alluvial aquifer exceeds an average of 284 Mm^3/year in Souss aquifer and 58 Mm^3/year in Chtouka aquifer (Table 1), which has resulted in water level declines ranging from 0.5 to 2.5 m per year during the past three decades. According to ABHSMD [8], the piezometric level analysis in the Souss-Massa aquifers between 1968 and 2003 shows a reduction in water table level of about 15 m in the Souss upstream, more than 30 m in the middle Souss, and 20 m in the Souss downstream. While in the Chtouka aquifer, the piezometric level was reduced by more than 20 m.

The deterioration of water quality is observed in many zones marked by an increase of TDS and nitrate contents. The interannual monitoring shows that Souss downstream groundwater present a low quality while in medium and Souss upstream, the quality is generally good as well as in Chtouka where the water quality is mainly suitable. Recently, several hydrochemical and isotopic studies were carried out in order to assess the recharge and the quality of groundwater, to define the sources of groundwater salinization, and to find out the impacts of agricultural activities as irrigation and fertilization on groundwater quality [9–12]. Therefore, the overall quality of groundwater in the Souss-Massa aquifers shows a deterioration from east to west in Souss plain and from north to south in Chtouka plain. According to Tagma et al. [12], the Souss and Chtouka aquifer are the most contaminated aquifers in the regions, 36% of wells exceed the regulatory threshold of drinking water which is equal to 50 mg/l of nitrates. In the Souss region, it is relatively less affected; 7% of wells presented nitrate concentration more than 50 mg/l with an average of 22 mg/l. The irrigated areas seem to be the most affected by nitrate pollution. The overall degradation of Souss and Chtouka aquifer is mainly due to geological origin (evaporates) and anthropogenic activities (fertilizers and wastewater).

3 Economic Importance of Agriculture in Souss-Massa Region

Agriculture constitutes an economic pillar for Souss-Massa region where it contributes by 13% of the regional GDP (Gross Domestic Product). According to the Ministry of Agriculture and Fishery [13], the production of agricultural sector should know an increasing from 11,838 Million DH in 2010 to 17,669 Million DH in 2020. The created working days increased from 30,804 working days in 2010 to 36,845 working days in the horizon of 2020. Table 2 shows the agricultural production and the national part of the Souss-Massa region. Data indicate that the region produces 77% of vegetables and 40% of citrus fruits. Those crops require very high water requirements. However the available water quantity could not satisfy the increased development in the agricultural sector. Thus the need for new water resources becomes a priority of all agricultural producers and users as well as water authorities.

4 Water Resources Management Scenarios in Souss-Massa Region

According to the current situation of water resources management in Souss-Massa region, we can distinguish between 2 management scenarios which likely to be occurred in the future. The catastrophe scenario which is the pessimistic scenario under which the current management of water resources and their misuse will continue without any measures of preservation. The safeguarding scenario under which many water preservation strategies and measures will be adopted by the managers and water users [14].

Table 2 Cereals and horticultural production (×1000 T) in the Souss-Massa region [13]

Product	2010	National part (%)	2013	2020
Cereals	385	5%	283	287
Vegetables	1,480	77%	1,778	2,140
Olive	27	2%	28	43
Citrus	646	39%	893	1,070
Fruits	562	18%	571	677

4.1 Catastrophe Scenario

This scenario is characterized by an overexploitation of water resources without any measures to be taken by water users and decision makers. Prediction results of the groundwater level in Chtouka aquifer are presented in Fig. 1:

Figure 1 shows clearly that during the last decades groundwater level decreased by more than 30 m. This reduction will result in a second time a salt accumulation in the soil and groundwater quality degradation due to misuse of fertilizers and seawater intrusion. Consequently this increase in salinity may lead to the installation of desalination individual units in larger farms. In 2010, some farmers have already installed this technology. However, this advanced technique would only be a step in the tragedy since brines issued from desalination will be discharged directly into the aquifer which lead certainly to groundwater salinity increase.

Losses associated with this scenario can be summarized as follows:

- Capital losses on all greenhouses, borehole, wells, and associated packaging houses. It is clear that the value of a borehole or well after saline intrusion is zero due to the fact that these installations cannot be moved
- Loss in value of the total production using groundwater from Chtouka aquifer
- Job losses for labor used in production and packaging
- Job losses in inputs and services suppliers related to agricultural sector

The economic impact of the catastrophe scenario was estimated using a model based on representative farms samples associated with a packaging station. This representative model defines the added value per hectare, the number of agricultural jobs, packaging, and the capital invested per hectare. Table 3 summarizes the results obtained according to the nature of the losses:

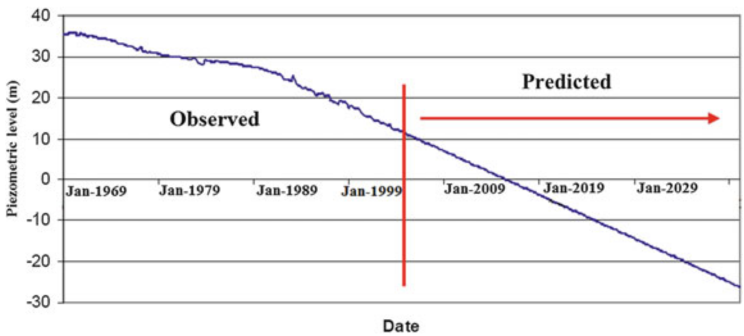

Fig. 1 Piezometric level evolution in the Chtouka aquifer

Table 3 Total losses of the catastrophe scenario in the horizon of 2035 [14]

Updated value of capital losses (Million DH)	3,065
Updated value of added value losses (Million DH)	8,903
Permanent job losses (equivalent)	2,834

4.2 *Safeguarding Scenario*

Water managers in the Souss-Massa region propose a preservation scenario to limit the imbalances in water resources by an active policy of mobilizing additional resources. This scenario is based on a political offer engaging all water users and stakeholders and aims to increase water offer to cope with existing water deficit. Several preservation measures are adopted in this scenario, some of them have already taken place and others are planned in the future:

4.2.1 Water Supply Management Strategies

- Construction of dams planned in the PDAIRE (Master Plan of Integrated Development of Water Resources)
- Rainwater harvesting
- Seawater desalination
- Wastewater reuse
- Artificial recharge
- Water transfer from north basins
- Interconnection of hydraulic systems
- Saline water demineralization
- Use of saline water

4.2.2 Water Demand Management Strategies

- Adaptation of less water consumer crops
- Infrastructure rehabilitation
- Cropping adaptation technique to save water (hydroponics)
- Conversion to drip irrigation (facilitation of procedures for water users associations and small farmers, extension services): already 30,000 ha have been converted
- Control of water withdrawal and pumping

4.2.3 Transversal Actions

- Revision of water pricing
- Water governance (groundwater contract, implementation, and strengthening of water users associations)

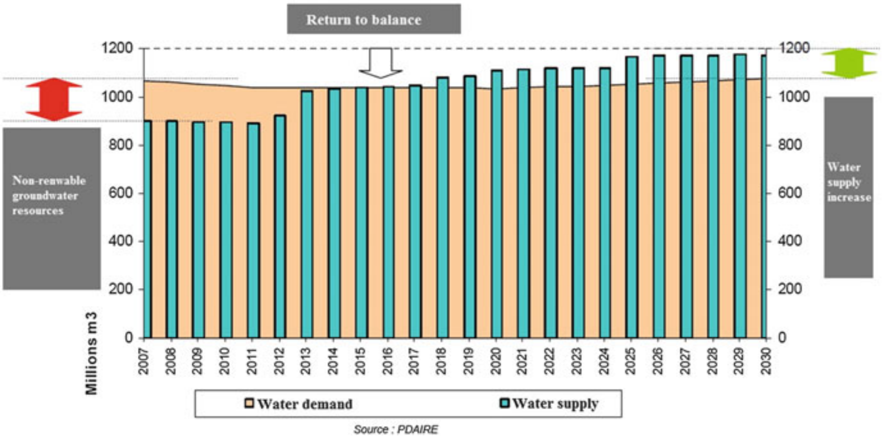

Fig. 2 Evolution of water balance under the safeguarding scenario towards 2030 [14]

- Public–private partnership
- Encourage scientific research
- Capacity building
- Improve groundwater monitoring
- Improve hydrological monitoring
- Improve water withdrawal monitoring (remote sensing)
- Monitoring and evaluation of projects
- Encourage transnational cooperation
- Encourage the data exchange between stakeholders

In the horizon of 2030, water supply will be increased by almost 20%, from 901 to 1,171 Mm^3/year if the safeguarding scenario has occurred (Fig. 2). This increase in supply should lead to a return to the groundwater balance and satisfaction of growing demand. The safeguarding scenario balance even exceeds the water demand and allows a surplus of 100 Mm^3/year.

5 Seawater Desalination Public–Private Partnership Project for Irrigation

The Ministry of Agriculture and Fishery was engaged in irrigation project using desalinated seawater in the Chtouka zone in the Souss-Massa region. This project has a particular importance in Morocco as it is implemented within the frame of the National Green Plan as a PPP (Public–Private Partnership) project. The project will support the agricultural development in the Souss-Massa region as it is the first region in terms of production and export of agricultural products with high added value. This project will respond to vegetables and fruits producers needs in the Chtouka zone.

5.1 Willingness to Pay for Desalinated Water: Farmers Survey

The Agrotech[1] association has carried out in collaboration with the ORMVASM[2] (agricultural development office) surveys covering most of greenhouse producers in the Chtouka zone. The objectives of this survey are:

- To identify the area equipped by greenhouses determining the spatial distribution of greenhouses
- To determine the total water volume used by the farmers and the potential desalinated water volume that will be required
- To know the farmers opinion about the use of desalinated water for irrigation and their interest to be part of the project

The survey covered 847 greenhouses farms with a total area of 12,770 ha. The obtained results are presented in Tables 4, 5, and 6 [15].

Table 4 Characteristics of the surveyed area

Number of surveyed farms	847
Number of farms willing to join the project	782
Percentage (%)	92%
Total surveyed greenhouses area (ha)	12,770
Actual greenhouse covered area (ha)	7,986
Consumed water volume (m^3)	54,729,087
Total area adhered to the project (ha)	12,186
Actual greenhouse covered area adhered to the project (ha)	7,555
Required water volume (m^3)	31,722,349

[1]The Agrotech association of the Souss-Massa-Drâa (Agrotech SMD) is an association of institutions created in 2006 in order to create an activity advanced center in the agro-technology field in the Souss-Massa-Drâa region, to help companies and institutions in the field of research and development of food biotechnology. The association is public and based in the Agronomic and Veterinary Medicine Hassan II Institute, Complex of Horticulture in Ait Melloul city.

[2]Office de Mise en Valeur Agricole de Souss-Massa.

Table 5 Survey results in terms of area and volume

	%	Required volume (m^3)	Greenhouse area (ha)
Percentage of project membership	95	31,672,549	7,555.10
Participation in the investment	67	23,724,146	5,350.39
Pay 5–7 DH/m^3 (0.51–0.71$[a]/$m^3$)	50	17,459,891	3,996.30
Pay ≥ 8 DH/m^3 (≥0.82$/$m^3$)	20	6,183,842	1,581.71
Pay ≥ 10 DH/m^3 (≥1.02$/$m^3$)	6	1,419,055	497.10

[a]Currency conversion was based on Google currency converter; conversion was made in 28/09/2015

Table 6 Survey results in terms of farm number and volume

	%	Required volume (m^3)	Number of farms
Percentage of project membership	92	31,672,549	782
Participation in the investment	61	23,724,146	515
Pay 5–7 DH/m^3 (0.51–0.71$/$m^3$)	42	17,459,891	354
Pay ≥ 8 DH/m^3 (≥0.82$/$m^3$)	15	6,183,842	127
Pay ≥ 10 DH/m^3 (≥1.02$/$m^3$)	4	1,419,055	36

5.2 Description of the Seawater Desalination Project

The technical characteristics of the project are:

- The concerned area: 9,000 ha (at the beginning of the project run) and 13,600 ha (in the horizon of 2035)
- Required desalinated water: 55 Mm^3/year (the aquifer water pumping should not exceed 25 Mm^3/year within the limits of renewable groundwater)
- 2,500 beneficiaries
- Water price: 6 DH/m^3, 0.61 $
- Desalination plant
  - Location: coastal site in the National Park of Souss-Massa (between Tifnit and Douira)
  - Capacity: 111,000 m^3/day in the beginning of the project run and 166,500 m^3/day in the horizon of 2035
  - Desalination technique: reverse osmosis with double pass
  - Modular and advanced plant to follow the progressive development of the project
  - Electrical powers: 34 MW
- Infrastructures of pumping and distribution of desalinated water for irrigation
  - Pumping station to pump the desalinated water into a regulation and control basin
  - Pumping from the regulation basin to mean distribution network
  - Mean distribution network of 290 km
  - Pressuring station
  - 1360 hydrants

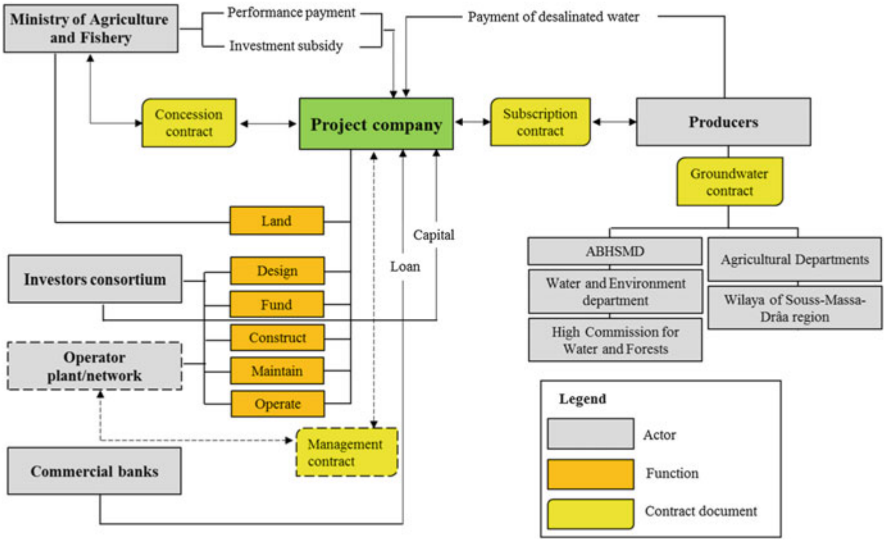

Fig. 3 Institutional framework of the project

The project will be built within the frame of public service delegation to a private operator (PPP) who will be charged to build, design, and manage all infrastructures related to the seawater desalination and irrigation especially after the success of the El Guerdane irrigation PPP project.[3] All the concerned parts by the delegated management convention (state, regional consul, banks, and users) will provide a financial contribution in the initial investment. The users contribution will be related to membership fees (Fig. 3). Users will pay membership fees to the operator in charge to use the desalinated water for irrigation [16].

5.3 *Impacts of the Seawater Desalination Project*

The project will have a positive impact in the environment as it will contribute significantly in the reduction of the aquifer overexploitation and consequently the project will achieve an equilibrium in terms of groundwater balance as well as

[3]The El Guerdane project was initiated by the Moroccan authorities in 1995 to address the problem of decreasing water availability and its effects on local livelihoods and high water demand. The project was aimed at delivering water from a complex of two dams (Aoulouz, inaugurated in 1991 and Mokhtar Soussi, inaugurated in 2002) located in the upper Souss Valley to an area of private citrus fruit exploitations near the locality of Sebt El Guerdane a hundred kilometers south. This irrigation system sees 45 Mm^3 of water per annum transferred through 90 km of pipeline, and a 300 km gravity-pressurized network distributes this water in the El Guerdane irrigation scheme. The project has been operational since the end of 2009, supplying 597 citrus fruit exploitations totalling 9,600 ha spread over an area of 30,000 ha with 4,000 m^3 of water per hectare and year.

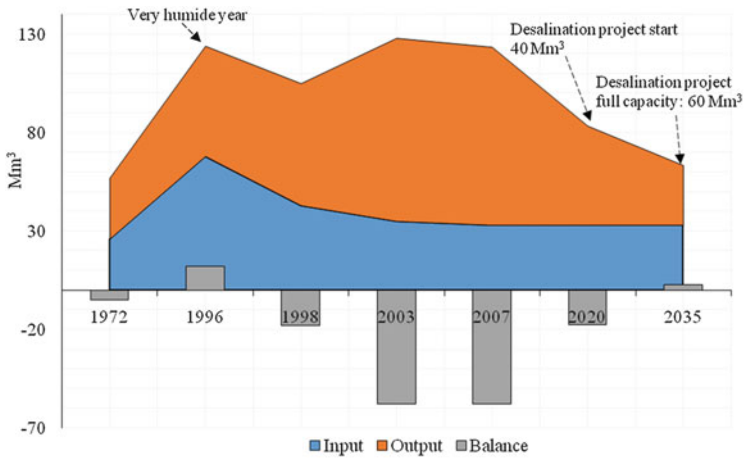

Fig. 4 Projection of water balance in Chtouka region, note the impact of desalination project in decreasing the aquifer output and increasing water supply

sustainable use of the aquifer in Chtouka zone and preservation of groundwater dependent ecosystems (forests, wild parks, etc.). Through this project the region will avoid a loss of nearly 9 billion DH as added value and 3 billion DH as capital in the horizon of 2035. The project will allow to increase the agricultural added value by 21.9% and preserve more than 2,830 permanent jobs and even reach over 4,275. Consequently the project will preserve a great horticultural expertize and export markets (Fig. 4).

The implementation site has been chosen to allow a zero impact especially on the bald ibis birds protected under the national park of Souss-Massa where the project will be installed. The infrastructures have been designed to control the brines disposal through the use of modern technology. A marine cartography and mapping will be performed in order to minimize the impacts and risks as maximum as possible [5]. A major environmental problem of water desalination is the production of a flow of brine containing the salts removed from the intake water and that needs to be disposed. In addition, this brine may be polluted. This brine represents a significant fraction of the intake water flow. Seawater desalination typically yields a brine flow of 50–65% of the intake water flow, with about twice the initial concentration [17]. As the project will be implemented in coastal area, the brine will be safely disposed in the Atlantic Ocean without any significant impacts on the coastal ecosystems.

6 Conclusion

There are a number of benefits for desalinated water use in the agricultural activity in Chtouka region. The most obvious one is that the technology produces an additional water resource to cope with increasing water deficit, but additionally, there is an increase in crop productivity and quality. However, costs are a major limitation and less expensive options are likely to be more attractive for agriculture. The desalination project in Chtouka aims to increase the water availability for greenhouse producers, to maintain their socioeconomic activities and to contribute to regional and national economy. Using desalination water for irrigation is much suitable for high cash crops destined to export as tomato, berries, green beans, salads, etc., where the cost of water can be compensated by the high selling price. Situation without desalination project is seen to be worst in the future especially numbers about economic added values losses are indicating that Souss-Massa region which is depending widely on groundwater will be subjected to catastrophic scenario.

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SALTMED Model and Its Application on Field Crops, Different Water and Field Management and Under Current and Future Climate Change

R. Ragab, R. Choukr-Allah, A. Nghira, and A. Hirich

Abstract Models can be very useful tools in agriculture water management. They could help in irrigation scheduling and crop water requirement estimation and to predict yields and soil salinization. SALTMED model is a generic model that can be used for a variety of irrigation systems, soil types, crops and trees, water application strategies and different water qualities. The early version was successfully tested against field experimental data. The current version, SALTMED 2015, includes additional sub-models, crop growth according to heat units/degree days, crop rotations, nitrogen dynamics, soil temperature, dry matter and yield, subsurface irrigation, deficit irrigation including the Partial Root Drying, PRD, drainage flow to tile or open drains systems, presence of shallow groundwater, evapotranspiration (ET) using Penman–Monteith equation, with different options to obtain the canopy conductance. The current version allows up to 20 fields or treatments to run simultaneously.

The model was applied on field experiments in Agadir in the Souss-Massa river basin. These experiments included several crops, such as quinoa, sweetcorn and chickpea; different water qualities, such as saline water, treated waste water and fresh water; different irrigation strategies, such as deficit irrigation (applying less water than the total crop water requirement) and applied water stress during certain growth stages. The model was successful in predicting the soil moisture, yield and dry matter for all the crops under different water qualities and all the water application strategies. The results showed that quinoa is the most drought and salt tolerant cereal crop. The results also showed the possibility of significant fresh

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water saving when using treated waste water and applying moderate water deficit/stress especially during the non-sensitive growth stages.

The SALTMED model, for three growing seasons, supplied "baseline data" for sweetcorn. The SALTMED model was run in forecasting mode to obtain future projections of crop ET and crop productivity under changing climate. The results suggested that, with increasing temperature, the crop ET is expected to increase by 15% while crop water requirement is expected to decrease by 13%, due to the shortening growth season of corn. The results also show that the crop harvest is expected to be 20 days earlier. Crop productivity in terms of dry matter and yield could exhibit a reduction of 2.5% towards the end of the twenty-first century. This study was applied on corn but it is likely that a similar trend could be found for other crops grown in the Souss region. These results indicate that climate change could have a negative impact on water availability in this water poor region and subsequently may pose a serious threat to the region's food security.

Keywords Agadir, Agricultural water management, Climate change impact on yield and crop water requirement, Modelling, SALTMED model, Souss-Massa basin, Yield

Contents

1 Introduction

Semi-arid regions frequently suffer from years of below-average rainfall and severe drought. Even in humid regions, drought events became very frequent and the rainfed agriculture is frequently supported by supplemental irrigation during the water shortage periods. Deficit irrigation is now in practice and drought tolerant varieties are sown to cope with the water scarcity. A truly integrated approach is essential to encourage the increased use of poor quality water for irrigation, in order to both minimize drainage disposal problems and maximize the beneficial use of multiple water sources.

At present, there is a competition among several sectors for fresh water. As a result, the agriculture sector in different parts of the world searched for alternative water resources sometimes known as non-conventional water resources, e.g. re-use of agriculture drainage water, use of brackish water (groundwater), use of seawater, desalinated saline water or treated waste water. In applying these non-conventional methods, a great deal of care should be exercised in order not to harm the environment or cause soil degradation [1–7]. In addition, the concept of deficit irrigation (applying less water than the crop water requirement) by subjecting the plant to mild stress in the growth stages less sensitive to water stress is being adopted in different parts of the world.

The impact of using poor quality water on soil and the environment is a slow long-term process and therefore short-term experiments are unable to show the impact. For that reason, models to predict the long-term effect on soil and environment, crop yield, soil water and salinity under different strategies of water management (deficit irrigation and alternative use of fresh and poor quality waters), and leaching requirements have been developed in parallel with the field and greenhouse experiments.

Models can be very useful tools in agriculture water management. Not only could they help in irrigation scheduling and estimating crop water requirements calculation but they could also be used to predict dry matter and yields, soil moisture deficit, soil salinity and soil nutrient status. SALTMED model has been developed for generic applications. It accounts for different irrigation systems, irrigation strategies (deficit irrigation, Partial Root drying, PRD), presence of drainage systems and shallow groundwater, crop and soil types and N-fertilizer applications. The SALTMED model [8–10] was developed to predict dry matter and yield, soil salinity and soil moisture profiles, salinity leaching requirements and soil nitrogen dynamics and nitrate leaching, soil temperature, plant water uptake and evapotranspiration (ET). The model is friendly and easy to use benefiting from the Windows™ environment; however, it is a physically based model using the well-known water and solute transport, ET, and water uptake equations.

In this chapter, the SALTMED model processes will be briefly described. This will be followed by example of model application on field experiments carried out in Agadir, Souss-Massa river basin.

2 Brief Description of the Main Processes in the SALTMED Model

The SALTMED model includes the following key processes: ET, plant water uptake, water and solute transport under different irrigation systems, nitrogen dynamics and dry matter and biomass production. A brief description of the above-mentioned processes will be given in the following sections.

2.1 Evapotranspiration

Evapotranspiration has been calculated using the Penman–Monteith equation according to the modified version of Allen et al. [11] in the following form:

$$\mathrm{ET}_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_S - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \tag{1a}$$

where ET_o is the reference evapotranspiration (mm day^{-1}), R_n is the net radiation (MJ m^{-2} day^{-1}), G is the soil heat flux density (MJ m^{-2} day^{-1}), T is the mean daily air temperature at 2 m height (°C), Δ is the slope of the saturated vapour pressure curve (kPa °C^{-1}), γ is the psychrometric constant, 66 Pa °C^{-1}, e_s is the saturated vapour pressure at air temperature (kPa), e_a is the prevailing vapour pressure (kPa) and U_2 is the wind speed at 2 m height (m s^{-1}). The calculated ET_o here is for short well-watered green grass. In this formula, a hypothetical reference crop with an assumed height of 0.12 m, a fixed surface resistance of 70 s m^{-1} and an albedo of 0.23 was considered.

In the presence of stomata/canopy surface resistance data, one could use the widely used equation of Penman–Monteith [12] in the following form:

$$\lambda E_p = \frac{\Delta R_n + \rho C_p\frac{(e_s - e)}{r_a}}{\Delta + \gamma\frac{(1 + r_s)}{r_a}} \tag{1b}$$

where "r_s" and "r_a" are the bulk surface and aerodynamic resistances (s m^{-1}), respectively.

The r_s can be measured or calculated from environmental and meteorological parameter or from the leaf water potential and Abscisic Acid, ABA.

In the absence of meteorological data (temperature, radiation, wind speed, etc.) and if Class A pan evaporation data are available, the SALTMED model can use these data to calculate ET_o according to the FAO procedure [11]. The model can also calculate the net radiation from solar radiation according to the FAO (1998) procedure if net radiation data are not available. The crop evapotranspiration ET_c is calculated as:

$$ET_c = ET_o(K_{cb} + K_e) \tag{2}$$

where K_{cb} is the crop transpiration coefficient (known also as basal crop coefficient) and K_e is the soil evaporation coefficient. The values of K_{cb} and K_c (the crop coefficient) for each growth stage and the duration of each growth stage for different crops are available in the model's database. These data can be used in the absence of measured values. K_e is calculated according to FAO [11]. K_{cb} and K_c are adjusted according to FAO [11] for wind speed and relative humidity if different from 2 m s^{-1} and 45%, respectively. The SALTMED model runs with a daily time step and uses K_{cb} and K_e. These parameter values are not universal and their values differ according to climatic conditions and other factors.

2.2 *Plant Water Uptake in the Presence of Saline Water*

2.2.1 The Actual Water Uptake Rate

The formula adopted in the SALTMED model is that suggested by Cardon and Letey [13], which determines the water uptake S (d^{-1}) as:

$$S(z,t) = \left[\frac{S_{\max}(t)}{1 + \left(\frac{a(t)h + \pi}{\pi_{50}(t)} \right)^3} \right] \lambda(z,t) \tag{3}$$

where $S_{\max}(t)$ is the maximum potential root water uptake at the time t; z is the vertical depth taken positive downwards; $\lambda(z,t)$ is the depth- and time-dependent fraction of total root mass; h is the matric pressure head; π is the osmotic pressure head; $\pi_{50}(t)$ is the time-dependent value of the osmotic pressure at which $S_{\max}(t)$ is reduced by 50% and $a(t)$ is a weighing coefficient that accounts for the differential response of a crop to matric and solute pressure. The coefficient $a(t)$ equals $\pi_{50}(t)/h_{50}(t)$ where $h_{50}(t)$ is the matric pressure at which $S_{\max}(t)$ is reduced by 50%.

The maximum water uptake $S_{\max}(t)$ is calculated as:

$$S_{\max}(t) = \mathrm{ET}_o(t) \times K_{cb}(t) \tag{4}$$

The values of h_{50} and π_{50} can be obtained from experiments or from the literature [14].

2.3 The Relative Crop Yield, RY

Due to the unique and strong relationship between water uptake and biomass production, and hence the final yield, the relative crop yield RY is estimated as the sum of the actual water uptake over the season divided by the sum of the potential water uptake (under no water and salinity stress conditions) as:

$$\mathrm{RY} = \frac{\sum S(x, z, t)}{\sum S_{\max}(x, z, t)} \tag{5}$$

where x, z are the horizontal and vertical coordinates of each grid cell that contains roots, respectively.

The actual yield, AY

The actual yield, AY, is simply obtainable by:

$$\mathrm{AY} = \mathrm{RY} \times Y_{\max} \tag{6}$$

where $Y_{\max}$ is the maximum yield obtainable in a given region under optimum and stress-free condition. This option assumes that salinity and water are the only stressors and all other factors are at optimum level. It is also used for quick answers when one needs to run several “what if” scenarios. The other option to obtain the actual yield is by calculating the daily biomass production and obtaining the actual yield from the harvest index times the total dry matter as given hereunder.

2.4 Crop Growth, Biomass Production and Yield

The crop growth, biomass, dry matter production and yield have been calculated based on: radiation, photosynthetic efficiency, water uptake, air temperature, leaf nitrogen content, leaf area index (LAI), respiration losses and the harvest index.

The approach used is very much based on the work of Eckersten and Jansson [15].

$$\text{The assimilation rate "}A\text{" per unit of area} \\ = E \times I \times f(\text{Temp}) \times f(T) \times f(\text{Leaf} - N) \quad (7)$$

where E is the photosynthetic efficiency (g dry matter MJ^{-1}), I is the radiation input: = Rs ($1 - e^{-k \times \text{LAI}}$), Rs is global radiation (MJ m^{-2} day^{-1}), k is extinction coefficient and LAI is the leaf area index (m^2 m^{-2}). Rs is given in climate data, LAI is interpolated in SALTMED assimilation rate, "A", per unit of area (g m^{-2} day^{-1}) = $E \times I \times$ (stress factors related to temperature, transpiration and leaf nitrogen content).

The transpiration stress factor is taken as a ratio of actual plant water uptake to the potential water uptake. The temperature stress is taken as deviation of the average temperature of a given day from the optimum temperature for the growth. The leaf nitrogen stress is taken as the deviation of the leaf nitrogen content of a given day from the optimum leaf nitrogen content.

2.4.1 Fixed and Variable Growth Stage Periods

There are two options for crop growth. The first option is the crop to grow according to fixed sowing and harvest dates and each growth stage (initial, development and late) has a prefixed duration in days. The second option is to allow the crop to grow according to the accumulated heat units/degree days (sum of the daily difference between average air temperatures minus minimum temperature required for growth). Each growth stage is completed when a certain number of degree days have been reached. The sowing date and harvest date could in this case vary. This is important when studying the impact of climate change on sowing and harvest date as well as the length of the growing season.

2.4.2 Crop Rotation

The model can run with different rotations on different fields (up to 20 rotations). Each rotation could include a variety of different crops, including fallow.

2.5 *Water and Solute Flow*

The water flow in soils was described mathematically by the well-known Richard's equation:

$$\frac{\partial\theta}{\partial t} = -\frac{\partial}{\partial z}\left[K(\theta)\frac{\partial(\psi + z)}{\partial z}\right] - S_w \tag{8}$$

where θ is volume wetness; t is the time; z is the depth; K (θ) is the hydraulic conductivity (a function of wetness); ψ is the matrix suction head and S_w is the sink term representing extraction by plant roots. The movement of solute in the soil system, its rate and direction, depends greatly on the path of water movement, but it is also determined by diffusion and hydrodynamic dispersion. If the latter effects are negligible, solute flows by convection [16]. The one-dimensional transient movement of a non-interacting solute in soil can be expressed as:

$$\frac{\partial(\theta c)}{\partial t} = \frac{\partial}{\partial z}\left(D_a\frac{\partial c}{\partial z}\right) - \frac{\partial(qc)}{\partial z} - S_s \tag{9}$$

in which c is the concentration of the solute in the soil solution, q is the convective flux of the *solution*, D_a is a combined diffusion and dispersion coefficient and S_s is a sink term for the solute representing root adsorption/uptake.

Under irrigation from a trickle line source, the water and solute transport can be viewed as two-dimensional flow and can be simulated by one of the following:

1. A "plane flow" model involving the Cartesian co-ordinates x and z. Plane flow takes place if one considers a set of trickle sources at equal distance and close enough to each other so that their wetting fronts overlap after a short time from the start of the irrigation.
2. A "cylindrical flow" model described by the cylindrical co-ordinates r and z.

Cylindrical flow takes place if one considers the case of a single trickle nozzle or a number of nozzles spaced far enough apart so that overlap of the wetting fronts of the adjacent sources does not take place. For a stable, isotropic and homogeneous porous medium, the two-dimensional flow of water in the soil can be described according to Bresler [17] as:

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial x}\left[K(\theta)\frac{\partial\psi}{\partial x}\right] + \frac{\partial}{\partial z}\left[K(\theta)\frac{\partial(\psi + z)}{\partial z}\right] \tag{10}$$

where x is the horizontal co-ordinate; z is the vertical-ordinate (considered to be positive downward) and $K(\theta)$ is the hydraulic conductivity of the soil. The two-dimension solute flow equation becomes:

$$\frac{\partial(C\theta)}{\partial t} = \frac{\partial}{\partial x}\left(D_{xx}\frac{\partial C}{\partial x} + D_{xz}\frac{\partial C}{\partial z} - q_x C\right) + \frac{\partial}{\partial z}\left(D_{zz}\frac{\partial C}{\partial z} + D_{zx}\frac{\partial C}{\partial x} - q_z C\right) \tag{11}$$

In the model, sprinkler, flood and basin irrigation are described by one-dimensional flow equations (e.g. Eqs. 8 and 9). Furrow and trickle line source are described by two-dimensional equations (e.g. Eqs. 10 and 11). Trickle point source is described by cylindrical flow equations obtained by replacing x with the radius "r" and rearranging Eqs. (10) and (11) as given by Bresler [17] and Fletcher Armstrong and Wilson [18]. The water and solute flow equations were solved numerically using a finite difference explicit scheme [19].

2.5.1 Soil Hydraulic Parameters

Solving the water and solute transport equations requires two soil water relations, namely the soil water content–water potential relation and the soil water potential–hydraulic conductivity relation. They were taken according to van Genuchten [20] as:

$$\theta(h) = \theta_r + [(\theta_s - \theta_r)/(1 + |\alpha h|^n)^m] \tag{12}$$

$$K(h) = K_s K_r(h) = K_s Se^{1/2}\left[1 - \left(1 - Se^{1/m}\right)^m\right]^2 \tag{13}$$

where θ_r and θ_s denote the residual and the saturated moisture contents, respectively; K_s and K_r are saturated and relative hydraulic conductivity, respectively; α and n are shape parameters; $m = 1 - 1/n$ and S_e is effective saturation or normalized volumetric soil water content. α, n and λ are empirical parameters.

2.6 *Calculating Soil Temperature from Air Temperature*

The top soil layer is the most biologically active layer where most of the organic matter decomposition and mineralization takes place. The microbial activity is affected by soil temperature of this layer. This temperature was found to be correlated to air temperature. The approach used here is to infer the soil temperature of the top layer (ploughing layer) from the air temperature based on the work of Kang et al. [21] and Zheng et al. [22].

2.7 *Soil Nitrogen Dynamics and Nitrogen Uptake*

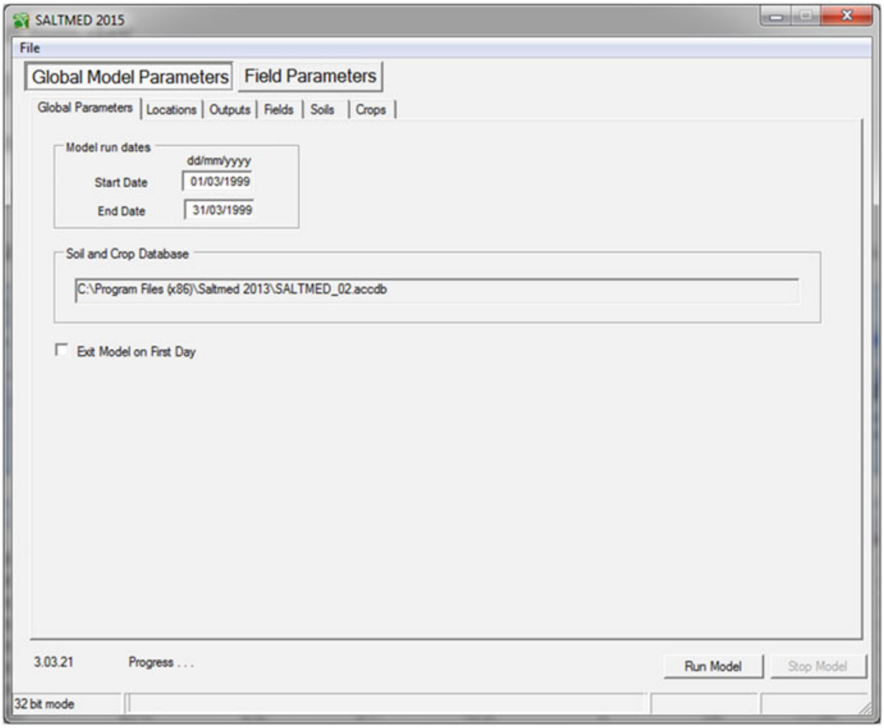
This is very much based on SOIL N model of Johnsson et al. [23]. The following processes were implemented in SALTMED model: Mineralization, Immobilization, Nitrification, Denitrification, Nitrate Leaching and Plant N Uptake.

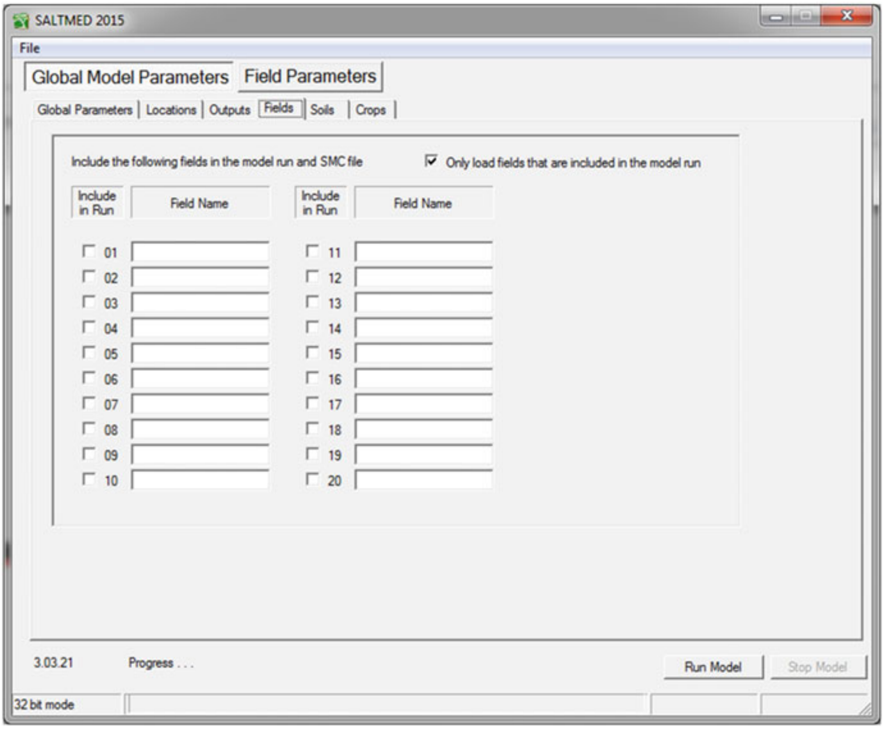
2.8 Drainage

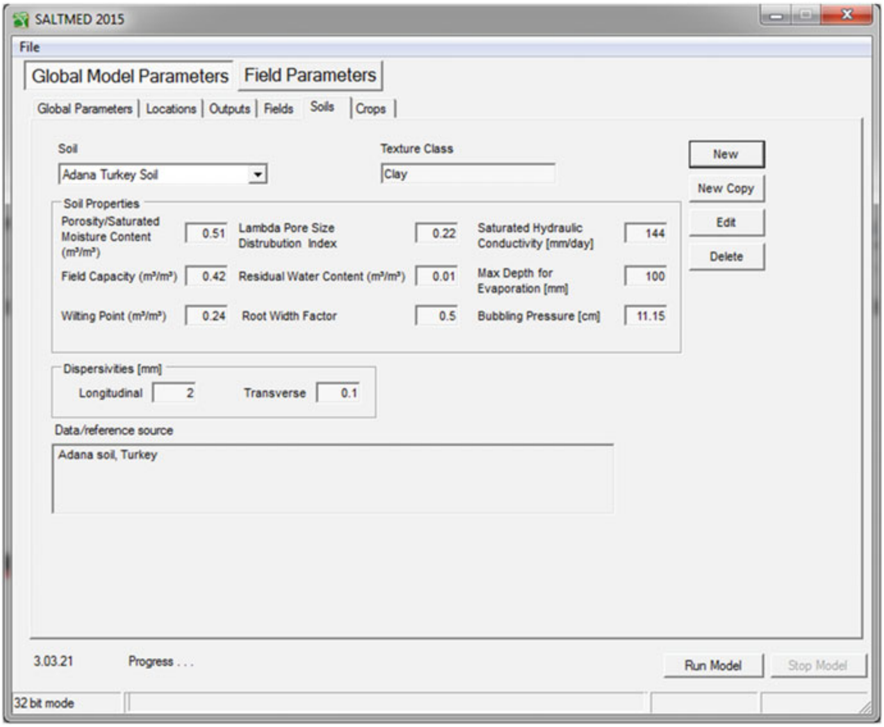
SALTMED 2015 has two options, free drainage at the bottom of the root zone (recharge) or subsurface drainage system (tile drains and open ditches). The latter is based on Hooghoudt's drainage equation [24] and gives a mathematical relation of the parameters involved in the subsurface drainage of flat land by a system of horizontal and parallel ditches or pipe drains without entrance resistance, placed at equal depth and subject to a steady recharge evenly distributed over the area. The most widely known form of Hooghoudt's equation as presented by Wesseling [25] was adopted.

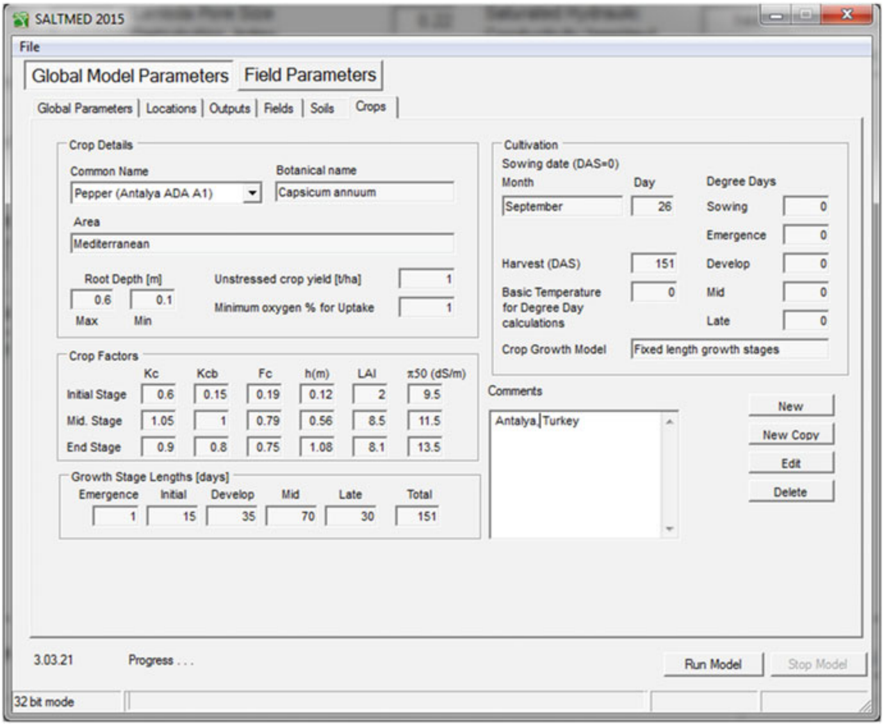
2.9 Multiple and Simultaneous Model Application

The SALTMED model runs with up to 20 fields or treatments or rotations. This facility allows simultaneous runs of different actual systems of soil, crop, irrigation, N-fertilizers and allows different "what if" scenarios as model application in forecasting/prediction mode. Some of the main model tabs and an example of output are shown hereunder.

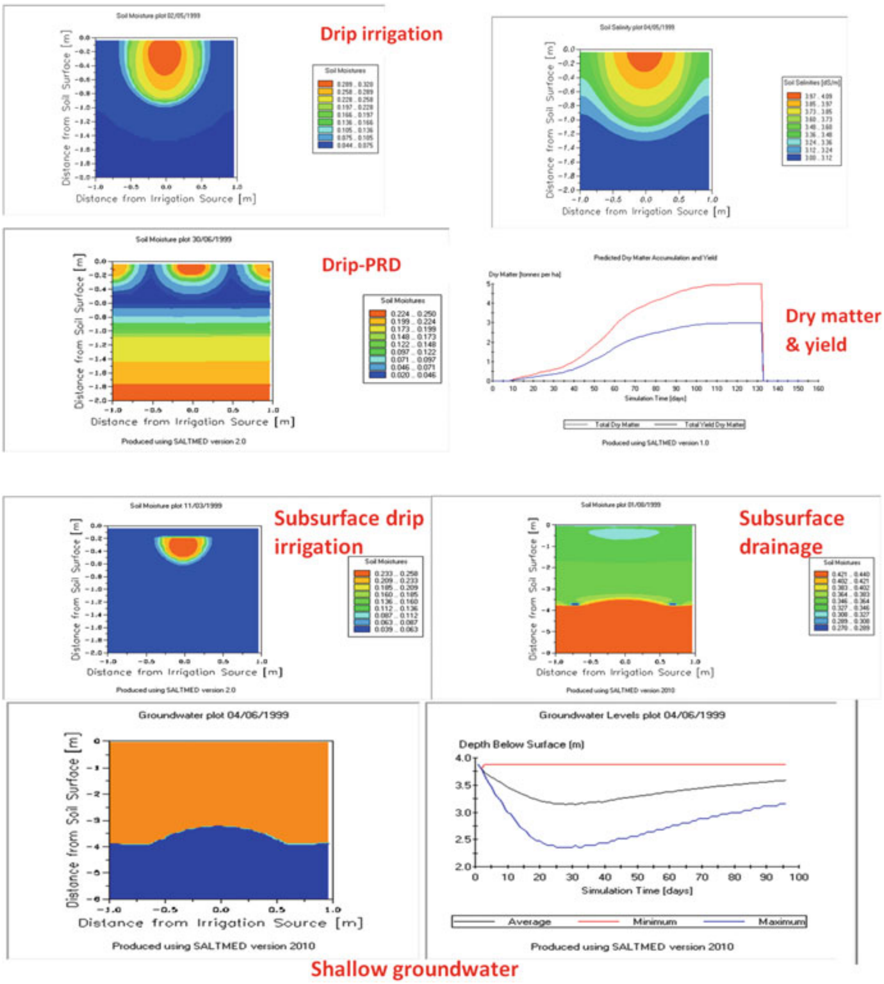

SALTMED 2015
File
Global Model Parameters
Field Parameters
Global Parameters
Locations
Outputs
Fields
Soils
Crops
Model run dates
dd/mm/yyyy
Start Date
01/03/1999
End Date
31/03/1999
Soil and Crop Database
C:\Program Files (x86)\Saltmed 2013\SALTMED_02.accdb
Exit Model on First Day
3.03.21
Progress . . .
Run Model
Stop Model
32 bit mode


SALTMED 2015
File
Global Model Parameters
Field Parameters
Global Parameters
Locations
Outputs
Fields
Soils
Crops
Include the following fields in the model run and SMC file
Only load fields that are included in the model run
Include in Run
Field Name
Include in Run
Field Name
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
16
17
18
19
20
3.03.21
Progress . . .
Run Model
Stop Model
32 bit mode


SALTMED 2015
File
Global Model Parameters
Field Parameters
Global Parameters
Locations
Outputs
Fields
Soils
Crops
Soil
Adana Turkey Soil
Texture Class
Clay
New
New Copy
Edit
Delete
Soil Properties
Porosity/Saturated Moisture Content (m³/m³)
0.51
Lambda Pore Size Distrubution Index
0.22
Saturated Hydraulic Conductivity [mm/day]
144
Field Capacity (m³/m³)
0.42
Residual Water Content (m³/m³)
0.01
Max Depth for Evaporation [mm]
100
Wilting Point (m³/m³)
0.24
Root Width Factor
0.5
Bubbling Pressure [cm]
11.15
Dispersivities [mm]
Longitudinal
2
Transverse
0.1
Data/reference source
Adana soil, Turkey
3.03.21
Progress . . .
Run Model
Stop Model
32 bit mode


SALTMED 2015
File
Global Model Parameters
Field Parameters
Global Parameters
Locations
Outputs
Fields
Soils
Crops
Crop Details
Common Name
Pepper (Antalya ADA A1)
Botanical name
Capsicum annuum
Area
Mediterranean
Root Depth [m]
0.6
0.1
Max
Min
Unstressed crop yield [t/ha]
1
Minimum oxygen % for Uptake
1
Cultivation
Sowing date (DAS=0)
Month
Day
September
26
Degree Days
Sowing
0
Emergence
0
Harvest (DAS)
151
Develop
0
Basic Temperature for Degree Day calculations
0
Mid
0
Late
0
Crop Growth Model
Fixed length growth stages
Crop Factors
Kc
Kcb
Fc
h(m)
LAI
π50 (dS/m)
Initial Stage
0.6
0.15
0.19
0.12
2
9.5
Mid. Stage
1.05
1
0.79
0.56
8.5
11.5
End Stage
0.9
0.8
0.75
1.08
8.1
13.5
Comments
Antalya, Turkey
New
New Copy
Edit
Delete
Growth Stage Lengths [days]
Emergence
Initial
Develop
Mid
Late
Total
1
15
35
70
30
151
3.03.21
Progress . . .
Run Model
Stop Model
32 bit mode

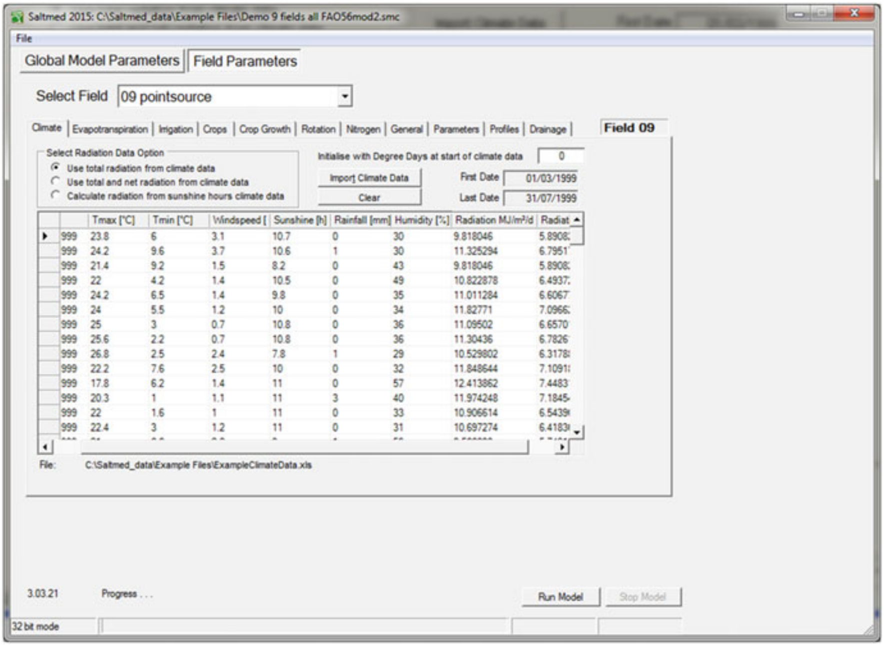
Example of output:



3 SALTMED 2015 Input Data Requirement

The data required depends on the selected application options and the interest of the user. The user does not need to provide all the information in the model tabs. For example, if no drainage system is present, the user does not need to fill in the data for the drainage tab. The model has more than one option for some applications, such as ET, but the user does not need to provide data for all options and can just provide the necessary data and parameters for one ET option. In the following sections, the model tabs will be shown and the data requirement for each tab will be highlighted. The model can run with up to 20 different fields or 20 treatments. Each field or treatment will require its own input, there is no input sharing among fields or treatments. The input data for the different model tabs will be discussed starting from left to right. Details of model processes and equations are given in separate documents.

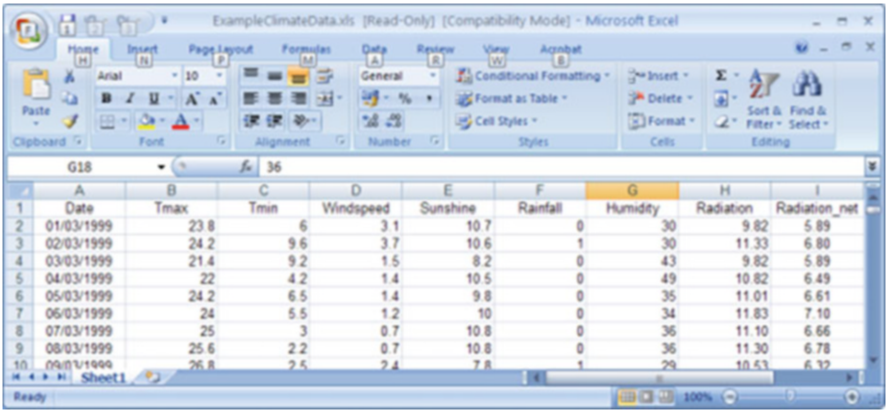
3.1 The Climate Data Tab



As shown, the *daily data* required is:

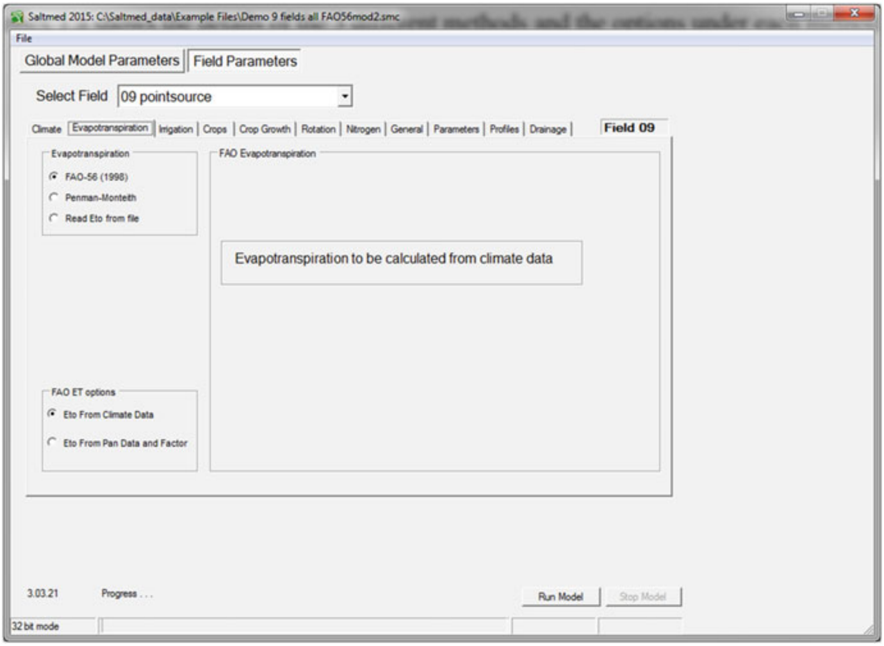
1. Maximum and minimum temperatures in °C
2. Wind speed in meters/seconds
3. Sunshine hours in hours (this is optional if radiation data is not available)
4. Rainfall in mm/day
5. Relative humidity in %
6. Total solar radiation in MJ/m^2/day
7. Net radiation in MJ/m^2/day

The data are imported from excel file (*.xls or *.xlsx) or from tables of Access database.



3.2 The Evapotranspiration Tab

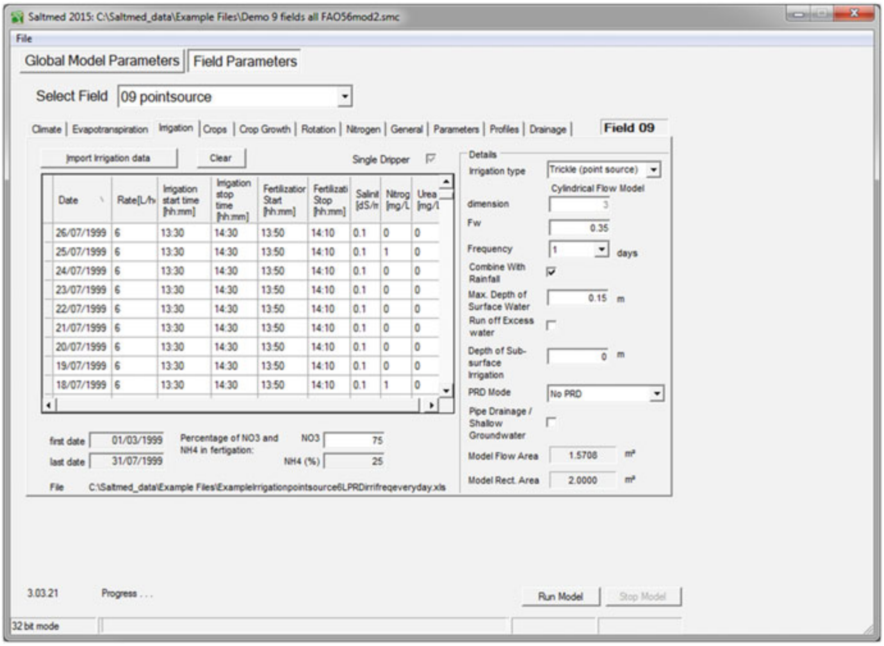
The ET is calculated by three different methods. The user needs to select only one. Annex 1.a shows the details of the three different methods and the options under each method.

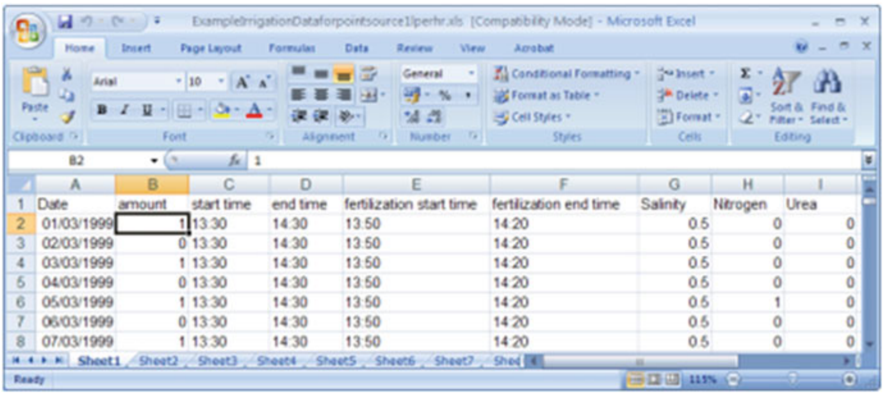


3.3 *The Irrigation Tab*

The data required are:

1. Irrigation rate (amount) in litre/hour, except for furrow and trickle line source in litre/meter of line or furrow length/hour.
2. Irrigation start time and stoppage time in format of hours and minutes: hh:mm
3. Fertigation start and stoppage time (if fertigation is used): hh:mm
4. Water salinity in dS/m
5. Nitrogen in water in mg/l, if fertigation is used. If ammonium nitrate is used, specify the % of ammonium to nitrate, as shown at the bottom of the tab.
6. Urea concentration in water in mg/l if urea is used in the fertigation.

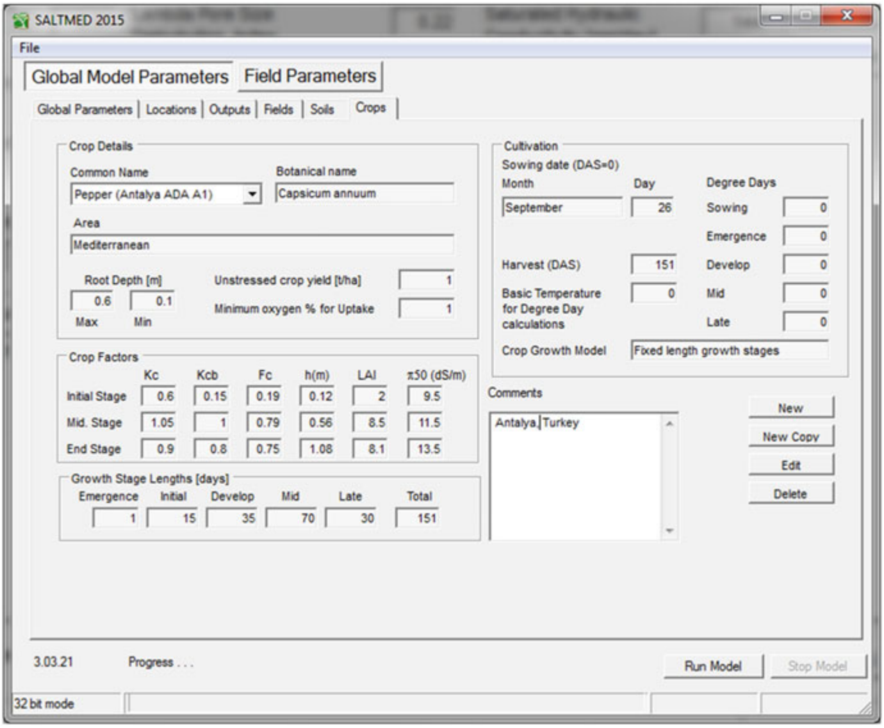




3.4 Crop Parameters Tab

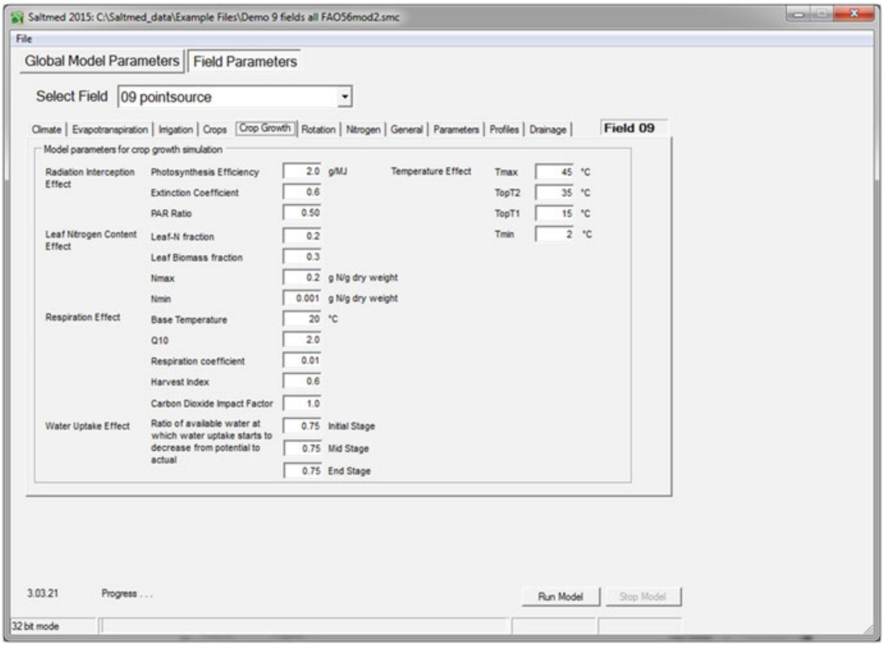
The parameters required are:

1. Minimum and maximum rooting depth in meters
2. Crop coefficients Kc, Kcb, fraction cover, Fc for initial, middle and late growth stages. FAO-56 Irrigation and Drainage paper [11] provides more information.
3. Crop height in meter, LAI (total area of leaves in m^2/m^2 of soil area) and π50 (the osmotic pressure at which the water uptake is reduced to 50% of the maximum or potential water uptake) for each growth stage. This is an indicator of crop salinity tolerance. High values mean that the crop is more tolerant to salinity; the crop salinity tolerance also varies according to the stage of growth.
4. Duration (days) of initial, development, mid and late growth stages according to FAO-56 [11].
5. Sowing date, harvest date, days from sowing to emergency.
6. Minimum basic temperature for growth in °C.
7. Optional: In case the user is interested in using degree days/heat units for crop growth rather than fixed dates, the user will need to input the number of degree days/heat units required to reach each growth stage until harvest. This is useful for those interested in climate change impact on sowing and harvest dates, total biomass and yield, water balance component, nitrogen dynamics and other relevant output of the model.



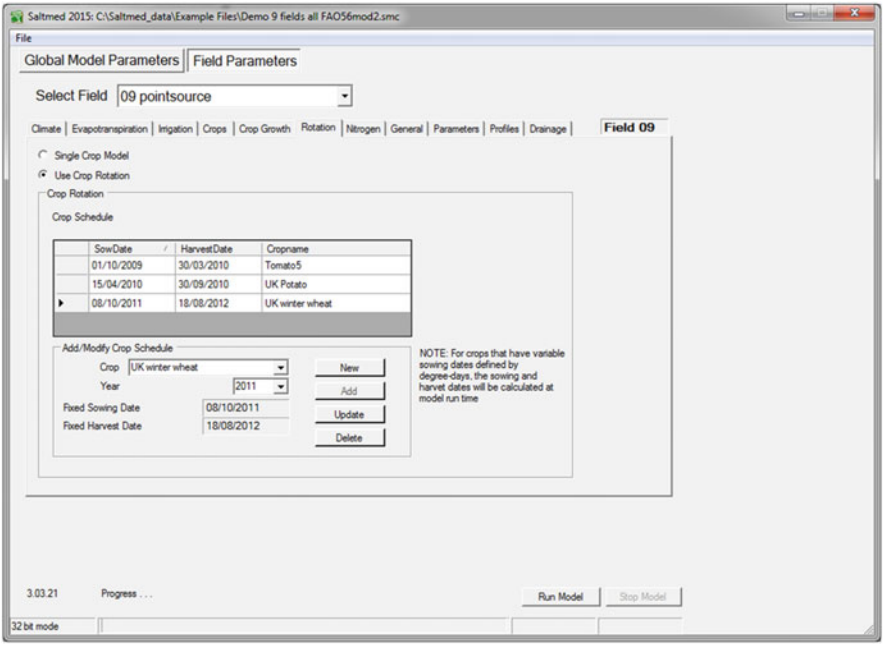
3.5 Crop Growth Tab

The crop growth is calculated as a function of radiation, photosynthesis efficiency (gram dry matter/MJ radiation), stress factors related to water availability, temperature, nitrogen content of leaves, respiration losses (%), minimum, maximum and optimum temperatures (°C) for growth. These parameters are obtainable by measurements or from the literature or by calibration using the default values as starting values. Measured values are always preferred.



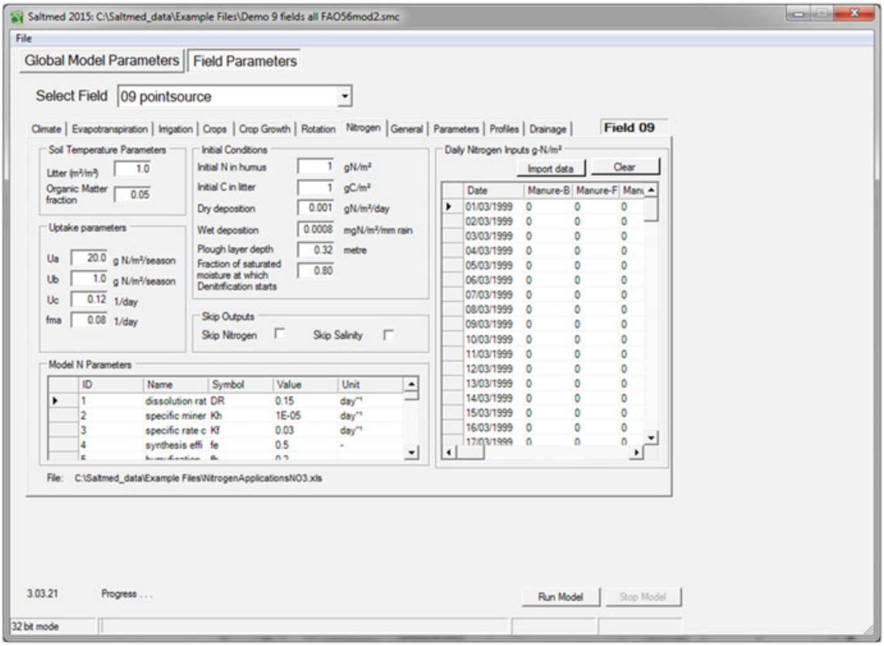
3.6 Crop Rotation Tab

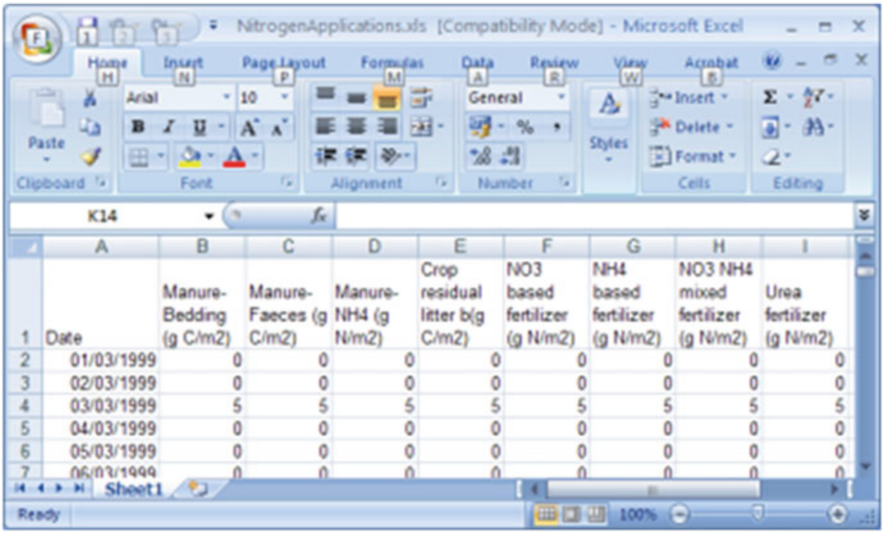
The user can select either single crop or select rotation from the drop-down menu. For rotation, the user needs to select the name of the crop, sowing date and harvest date from the crop database. The crop parameters included in the rotation should have been stored in the database in advance using the crop tab editor under global parameters tab.



3.7 Nitrogen Tab

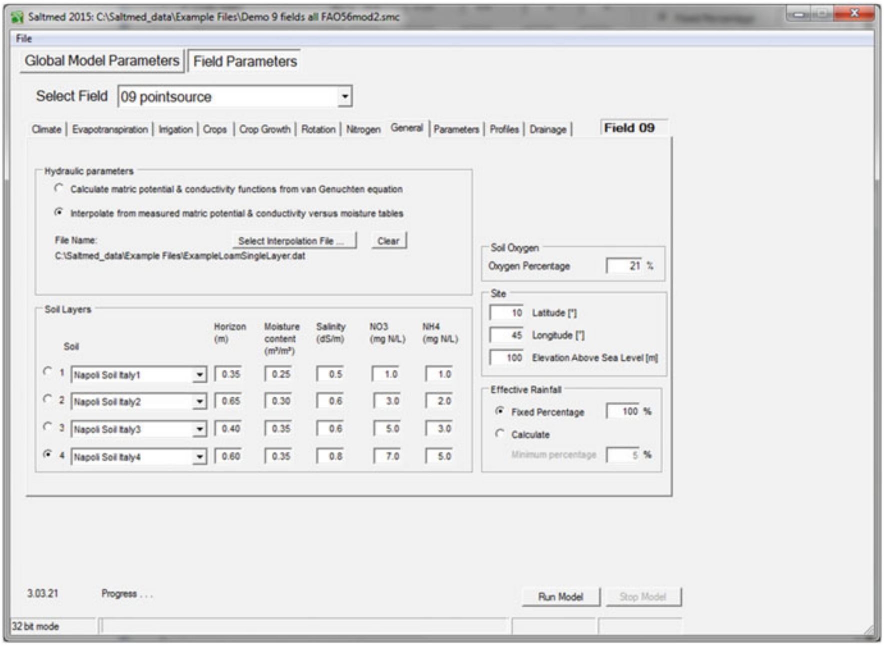
If nitrogen is added in dry form (organic or mineral) not with irrigation water (fertigation), the user needs to specify the amount of nitrogen fertilizer in gram N/m^2 of soil surface. The data should be given in Excel file that includes the date and amount given. The data should be organized using the format of the example file (see below). If fertigation is used, the user can tick the box of “skip Nitrogen” without a need to import a nitrogen file. In addition to daily nitrogen input, there are other parameters related to nitrogen uptake by plant, dry and wet atmospheric deposition of nitrogen, initial nitrogen content of soil humus (gram nitrogen/m^2) and initial carbon content in soil litter (gram carbon/m^2 of soil), litter distribution (m^2 litter/m^2 soil) and soil organic matter percent (% of soil mass). In addition, there are other parameters related to rate constants (rate of mineralization, rate of denitrification, etc.), C/N ratios, dissolution rates, etc., are saved in the input database and can be edited through Microsoft Access.


Saltmed 2015: C:\Saltmed_data\Example Files\Demo 9 fields all FAO56mod2.smc
File
Global Model Parameters
Field Parameters
Select Field
09 pointsource
Climate
Evapotranspiration
Irrigation
Crops
Crop Growth
Rotation
Nitrogen
General
Parameters
Profiles
Drainage
Field 09
Soil Temperature Parameters
Litter (m³/m³) 1.0
Organic Matter fraction 0.05
Uptake parameters
Ua 20.0 g N/m²/season
Ub 1.0 g N/m²/season
Uc 0.12 1/day
fma 0.08 1/day
Initial Conditions
Initial N in humus 1 gN/m²
Initial C in litter 1 gC/m²
Dry deposition 0.001 gN/m²/day
Wet deposition 0.0008 mgN/m²/mm rain
Plough layer depth 0.32 metre
Fraction of saturated moisture at which Denitrification starts 0.80
Skip Outputs
Skip Nitrogen
Skip Salinity
Daily Nitrogen Inputs g-N/m²
Import data
Clear
Date Manure-B Manure-F
01/03/1999 0 0 0
02/03/1999 0 0 0
03/03/1999 0 0 0
04/03/1999 0 0 0
05/03/1999 0 0 0
06/03/1999 0 0 0
07/03/1999 0 0 0
08/03/1999 0 0 0
09/03/1999 0 0 0
10/03/1999 0 0 0
11/03/1999 0 0 0
12/03/1999 0 0 0
13/03/1999 0 0 0
14/03/1999 0 0 0
15/03/1999 0 0 0
16/03/1999 0 0 0
Model N Parameters
ID Name Symbol Value Unit
1 dissolution rat DR 0.15 day⁻¹
2 specific miner Kh 1E-05 day⁻¹
3 specific rate c Kf 0.03 day⁻¹
4 synthesis effi fe 0.5 -
File: C:\Saltmed_data\Example Files\NitrogenApplicationsNO3.xls
3.03.21
Progress . . .
Run Model
Stop Model
32 bit mode


NitrogenApplications.xls [Compatibility Mode] - Microsoft Excel
Home
Insert
Page Layout
Formulas
Data
Review
View
Acrobat
Paste
Arial
10
General
Styles
Insert
Delete
Format
Clipboard
Font
Alignment
Number
Cells
Editing
K14
A B C D E F G H I
1 Date | Manure-Bedding (g C/m2) | Manure-Faeces (g C/m2) | Manure-NH4 (g N/m2) | Crop residual litter b(g C/m2) | NO3 based fertilizer (g N/m2) | NH4 based fertilizer (g N/m2) | NO3 NH4 mixed fertilizer (g N/m2) | Urea fertilizer (g N/m2)
2 01/03/1999 0 0 0 0 0 0 0 0
3 02/03/1999 0 0 0 0 0 0 0 0
4 03/03/1999 5 5 5 5 5 5 5 5
5 04/03/1999 0 0 0 0 0 0 0 0
6 05/03/1999 0 0 0 0 0 0 0 0
Sheet1
Ready
100%

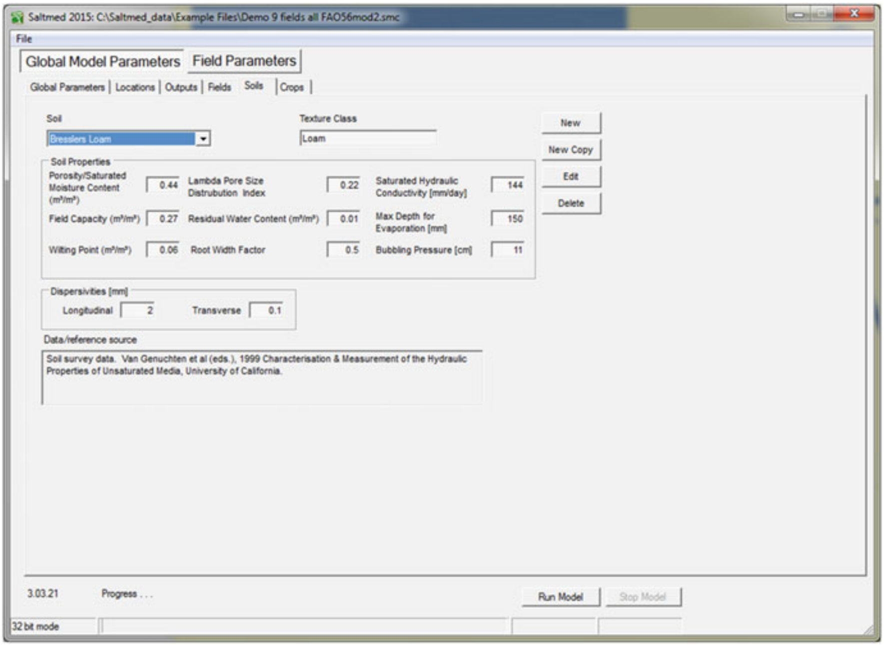
3.8 General Tab

This tab allows the user to specify initial conditions (first day of model run) of soil moisture (m^3 water/m^3 soil), soil salinity (dS/m), soil nitrate NO_3 (mg N/l) and soil NH_4 (mg N/l) for each soil layer, maximum 4 layers. The thickness of each layer should be given. On the same tab, there are two options to obtain the water retention curve and hydraulic conductivity curve. These two functions can either be calculated from other soil parameters given in soil tab (under global parameters tab) or from measured and tabulated pair values: soil moisture (m^3/m^3) versus water potential (m), and hydraulic conductivity (meter/second) versus soil moisture (m^3/m^3). Examples of these pair values are given in example files folder provided by the model.



3.9 Soil Parameters Under Global Parameters Tab

An example of water retention and hydraulic conductivity measured values to be used in SALTMED is shown hereunder. First row is the number of pair values (20), followed by volumetric soil moisture, m^3/m^3, (left) versus hydraulic conductivity, m/s (right), then another 20 values of soil moisture, m^3/m^3, versus water potential, m. This shown data is for a soil of single layer of loam. If more than one layer exists with different water retention and conductivity functions, then using the same format, just add the other layers to the same file, one layer after the other (maximum 4 layers), see example files folder provided by the model.



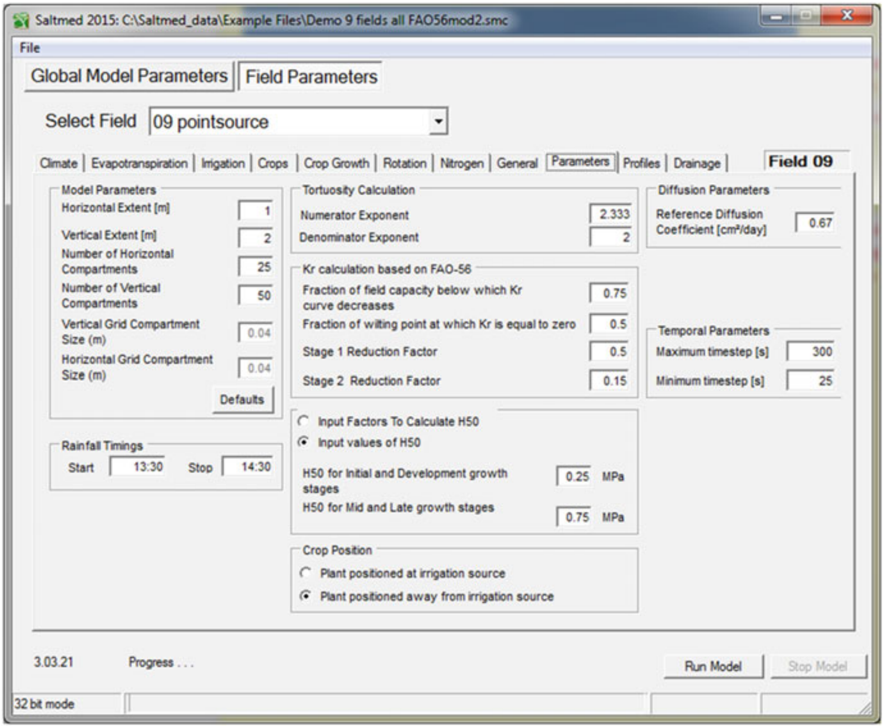
ExampleLoamSingleLayer.d...

File Edit Format View Help

```
20
0.001    4.63333333333333E-14
0.04     4.63333333333333E-14
0.08     1.18500000000000E-12
0.12     1.66666666666667E-11
0.16     1.81666666666667E-11
0.2      1.40500000000000E-09
0.24     8.43333333333333E-09
0.28     3.30000000000000E-08
0.32     1.51000000000000E-07
0.36     4.11833333333333E-07
0.37     5.05833333333333E-07
0.38     6.23000000000000E-07
0.39     7.32333333333333E-07
0.4      8.99500000000000E-07
0.41     1.05900000000000E-06
0.42     1.30233333333333E-06
0.43     1.66666666666667E-06
0.433    1.66666666666667E-06
0.44     1.89333333333333E-06
1        1.89333333333333E-06
20
0.001    -1380
0.04     -1380
0.08     -79.79
0.12     -8.5
0.16     -2.56
0.2      -1.15
0.24     -0.8
0.28     -0.66
0.32     -0.558
0.36     -0.474
0.37     -0.4495
0.38     -0.425
0.39     -0.409
0.4      -0.39
0.41     -0.3474
0.42     -0.2832
0.43     -0.1255
0.433    -0.01
0.44     -0.001
```

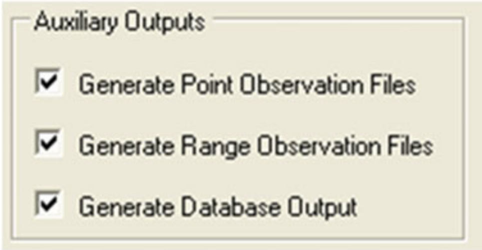
3.10 Parameters Tab

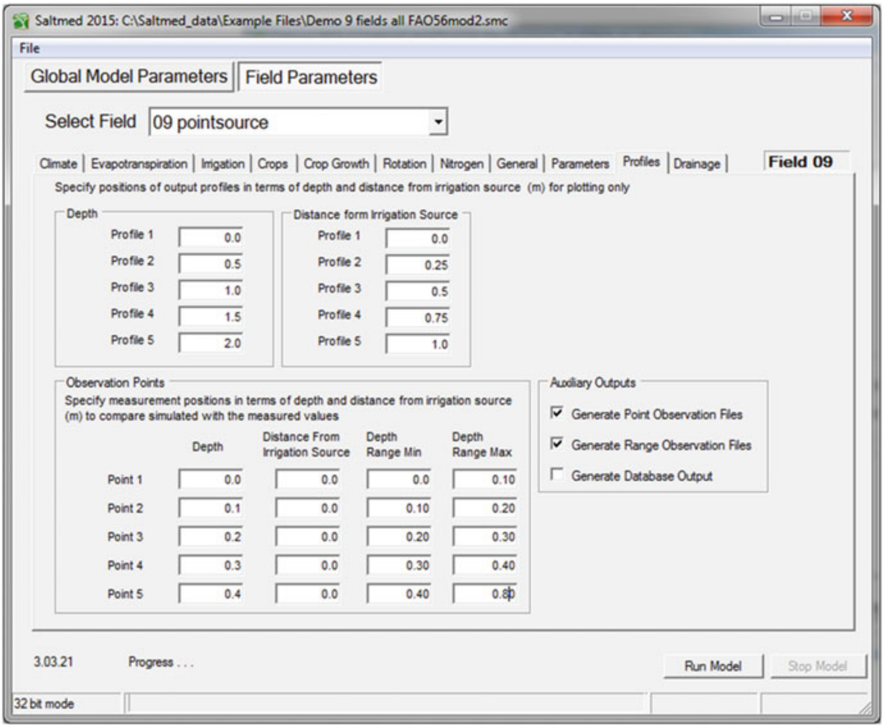
This tab includes a number of parameters, such as depth and width of the model flow domain and size of each square in the flow domain. The model flow domain is divided into squares with default size of 4 cm by 4 cm. However, the size of flow domain and size of the squares can be changed by the user. The model calculates the flows (water, solute and nitrogen) in each square of the domain. There are other parameters related to solute diffusivity, H_{50} (the water potential at which the water uptake is reduced to 50% of the potential water uptake), and parameters related to Kr which controls the bare soil evaporation as given in [11]. Apart from the flow domain dimension, which is user input, the other parameters are default values but the user can change these values according to the measurements or literature.



3.11 Profiles Tab

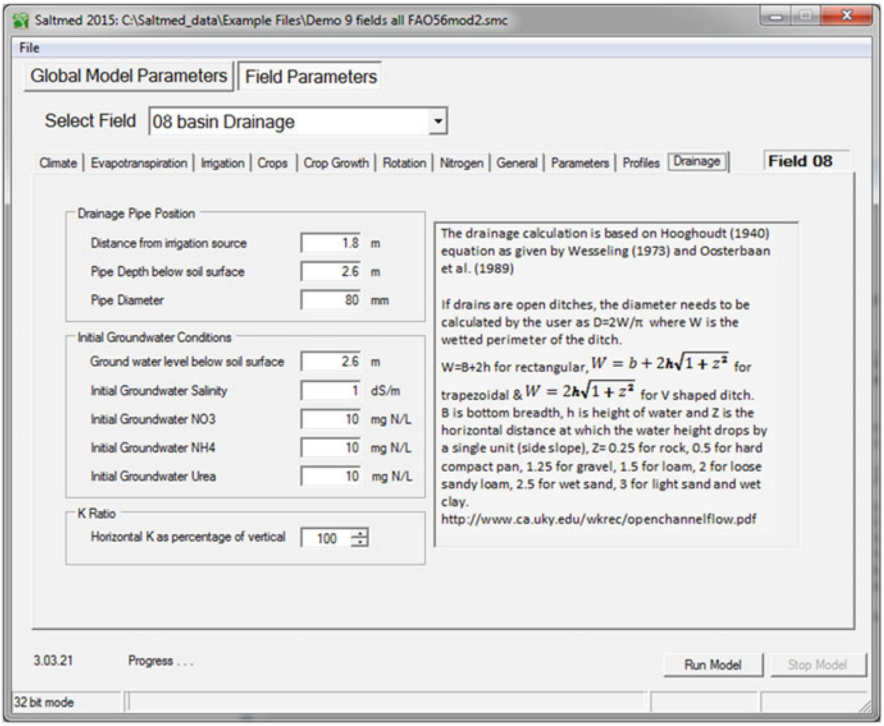
This tab allows the user to specify what depth and how far from irrigation source, the soil moisture, soil salinity, soil nitrogen profiles should be plotted in the figures that appear on the computer screen during model run. In addition, the tab allows the user to select how the data should be recorded in the output file in order to compare measured values with simulated values. In such case, the user can request the simulated values to be recorded at the same depth and distance from the irrigation source exactly like the measured values so that a comparison can be made in minutes using Excel plotting facilities. The user can also request the same variables for certain layers (range values, e.g. 0–30 cm, 40–60 cm depth). The user can also request to save output in Access database if running huge data records (decades of years for climate change scenarios), and these request options are shown below.


Auxiliary Outputs
Generate Point Observation Files
Generate Range Observation Files
Generate Database Output


Saltmed 2015: C:\Saltmed_data\Example Files\Demo 9 fields all FAO56mod2.smc
File
Global Model Parameters
Field Parameters
Select Field
09 pointsource
Climate
Evapotranspiration
Irrigation
Crops
Crop Growth
Rotation
Nitrogen
General
Parameters
Profiles
Drainage
Field 09
Specify positions of output profiles in terms of depth and distance from irrigation source (m) for plotting only
Depth
Profile 1 0.0
Profile 2 0.5
Profile 3 1.0
Profile 4 1.5
Profile 5 2.0
Distance form Irrigation Source
Profile 1 0.0
Profile 2 0.25
Profile 3 0.5
Profile 4 0.75
Profile 5 1.0
Observation Points
Specify measurement positions in terms of depth and distance from irrigation source (m) to compare simulated with the measured values
Depth
Distance From Irrigation Source
Depth Range Min
Depth Range Max
Point 1 0.0 0.0 0.0 0.10
Point 2 0.1 0.0 0.10 0.20
Point 3 0.2 0.0 0.20 0.30
Point 4 0.3 0.0 0.30 0.40
Point 5 0.4 0.0 0.40 0.80
Auxiliary Outputs
Generate Point Observation Files
Generate Range Observation Files
Generate Database Output
3.03.21
Progress . . .
Run Model
Stop Model
32 bit mode

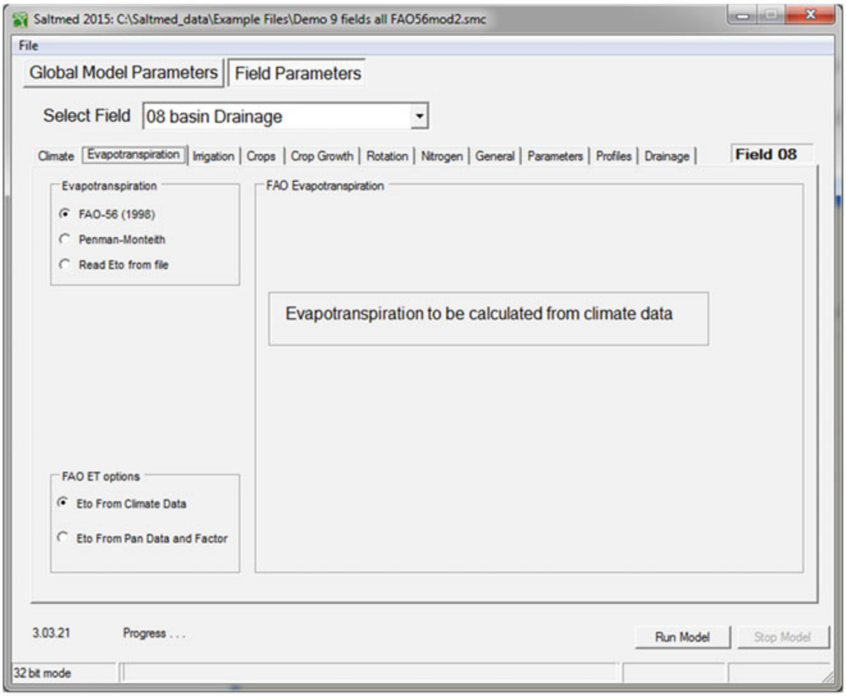
3.12 Drainage Tab

This tab can only be used in the case of presence of tile drains, open drains or shallow groundwater. Parameters needed are: depth of drains, their diameters, initial groundwater salinity and nitrogen content and ratio of horizontal hydraulic conductivity to the vertical conductivity (given in soil tab).

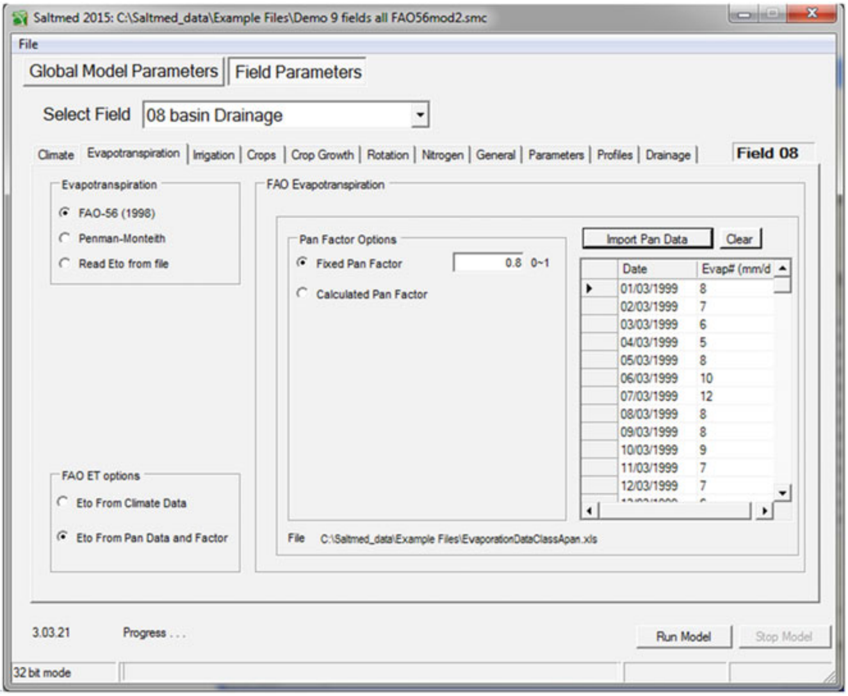


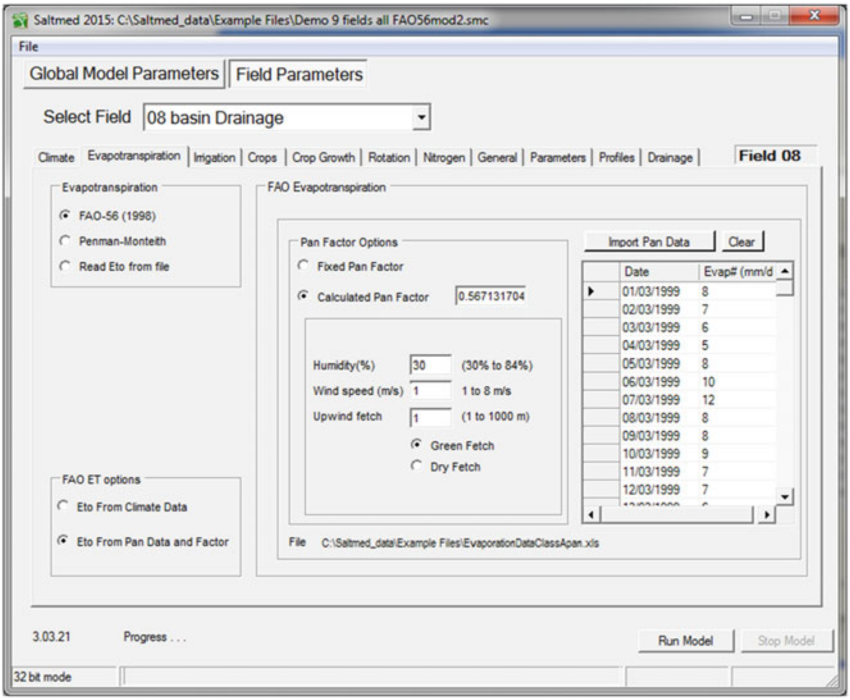
3.13 Evapotranspiration Tab Options

1. Option 1 calculates the ET using climate data according to the FAO modified Equation of Penman–Monteith (FAO-56 assumed stomata conductance of 70 m/s).



2. Option 2 calculates the ET from Class A pan, an excel file containing daily evaporation in mm/day is needed. Class A pan factor can be specified by the user or calculated using FAO formula, see FAO-Irrigation and Drainage Paper No. 56 [11] for more information.

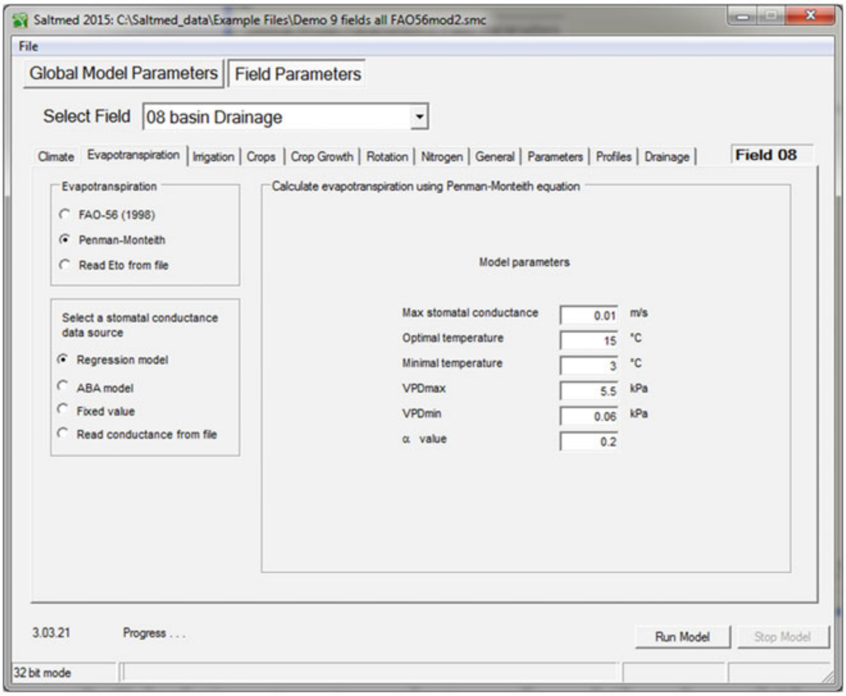




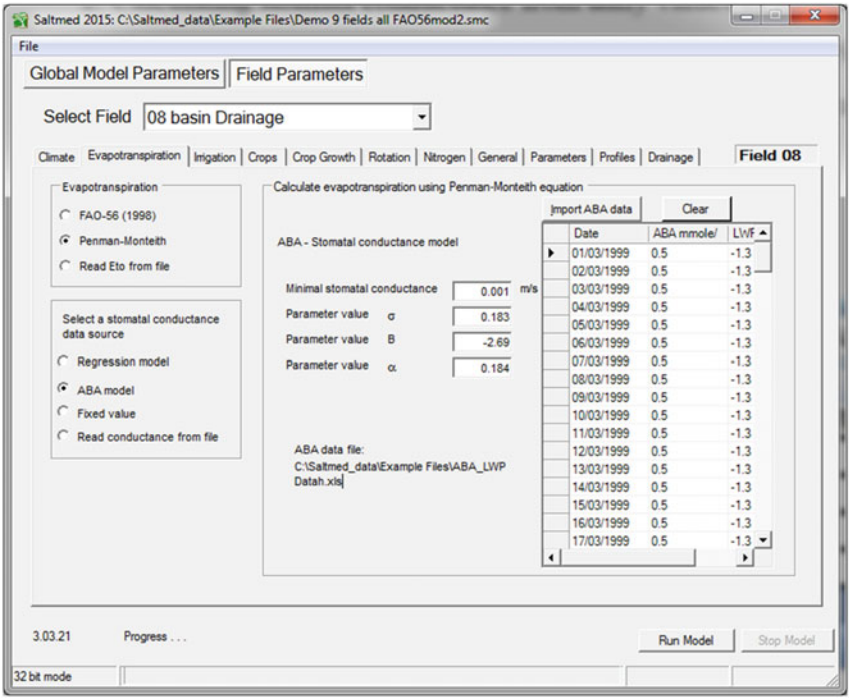
Date	Evap# (mm/d
01/03/1999	8
02/03/1999	7
03/03/1999	6
04/03/1999	5
05/03/1999	8
06/03/1999	10
07/03/1999	12
08/03/1999	8
09/03/1999	8
10/03/1999	9
11/03/1999	7
12/03/1999	7

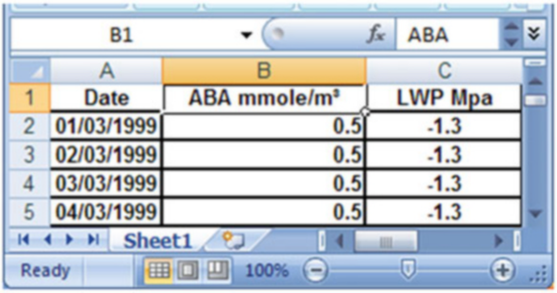
3. Option 3 is to calculate ET from the *original* Penman–Monteith equation, with 4 options to calculate the stomata conductance. This conductance is needed in calculating ET using the original Penman–Monteith equation. The four options are:

   (a) Calculating stomata conductance from environmental parameters, using a regression model [26, 27] and some fitting parameters as shown in the dialogue below.



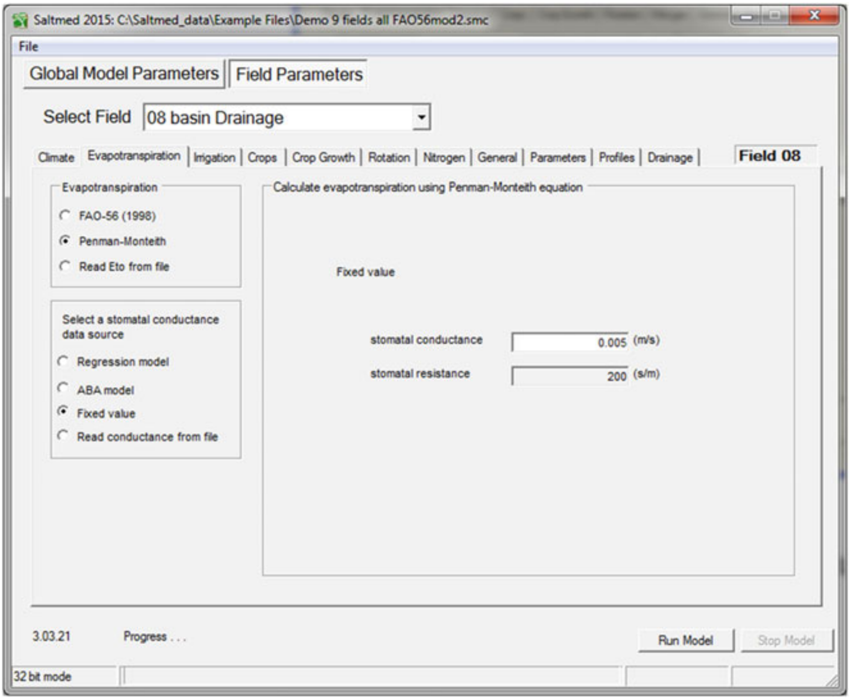
(b) Calculating stomata conductance from daily values of ABA in mmole m^{-3} and leaf water potential in MPa according to Tardieu et al. [28]. Data are provided as Excel file (see example in the example files folder). Other fitting parameter values as suggested by the authors are given as default values in the dialogue below.



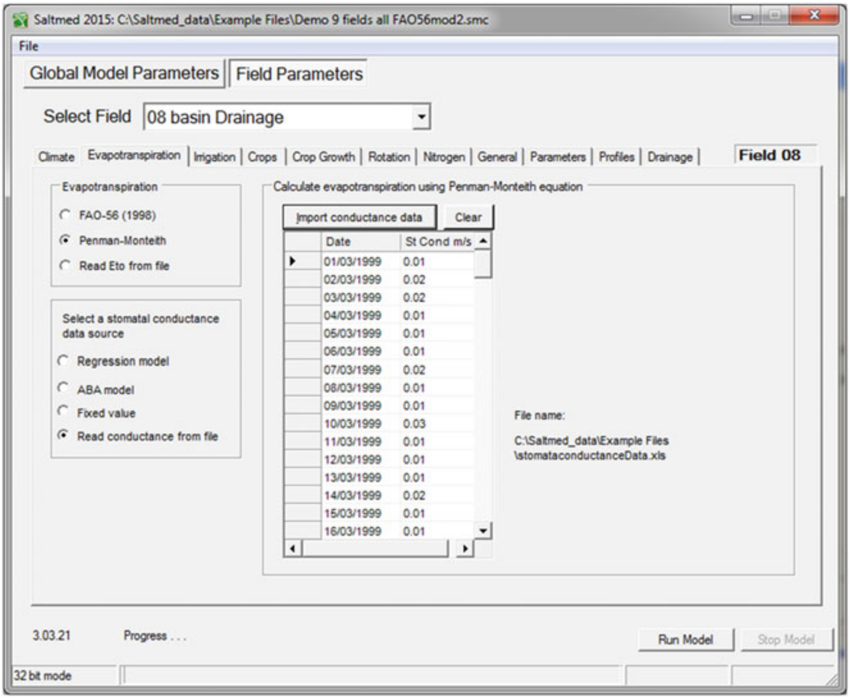


	A	B	C
1	Date	ABA mmole/m³	LWP Mpa
2	01/03/1999	0.5	-1.3
3	02/03/1999	0.5	-1.3
4	03/03/1999	0.5	-1.3
5	04/03/1999	0.5	-1.3

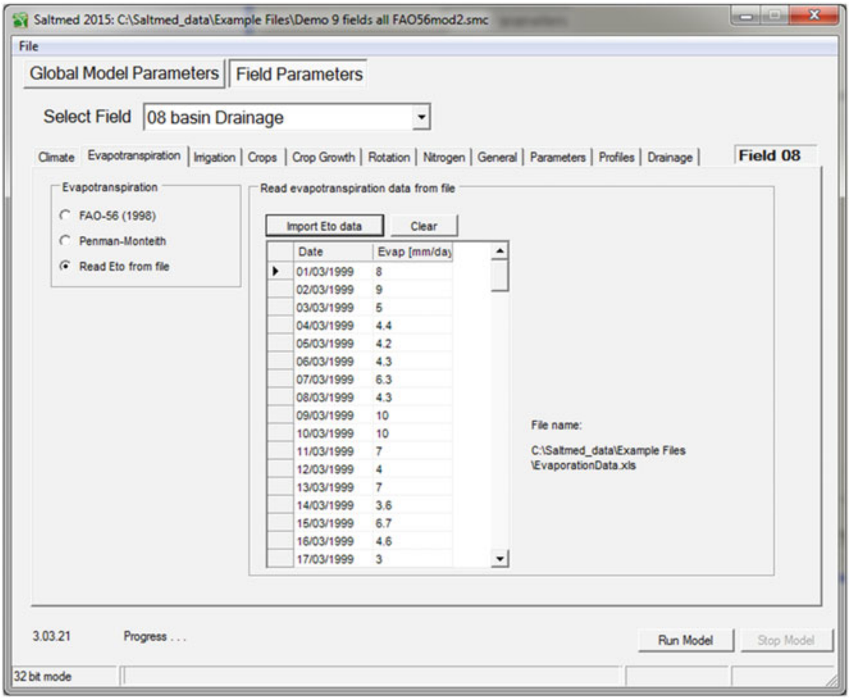
(c) Using measured or estimated seasonal average stomata conductance value as in the dialogue below.



(d) Use daily measured values of stomata conductance. Data are provided in meter/second in an Excel file, see example in the example files folder provided by the model.



4. Option 4: Use readily calculated or measured Reference ET in mm/day given as excel file. This allows the user to use own measured values or calculated values by other methods or equations different from those used in SALTMED, see example in the example files folder provided by the model.



Date	Evap [mm/day
01/03/1999	8
02/03/1999	9
03/03/1999	5
04/03/1999	4.4
05/03/1999	4.2
06/03/1999	4.3
07/03/1999	6.3
08/03/1999	4.3
09/03/1999	10
10/03/1999	10
11/03/1999	7
12/03/1999	4
13/03/1999	7
14/03/1999	3.6
15/03/1999	6.7
16/03/1999	4.6
17/03/1999	3

4 "Goodness of Fit" Indicators

The SALTMED model performance was evaluated by quantitative (statistical) and qualitative (graphical) methods. In the graphical approach, the measured and simulated values of soil moisture were plotted against time. The response of the model can, therefore, be visually quantified. The statistical approach involved the use of the "goodness of fit" test proposed by Loague and Green [29] to compare observed data with results predicted by the model. The "goodness of fit" indicators are: the root mean square error (RMSE), coefficient of determination (R^2) and coefficient of residual mass (CRM).

The RMSE values show by how much the simulations under- or overestimate the measurements:

$$\mathrm{RMSE} = \sqrt{\frac{\sum (y_o - y_s)^2}{N}} \tag{14}$$

where

- y_s = predicted value
- y_o = observed value
- N = total number of observations

The R^2 statistics demonstrate the ratio between the scatter of simulated values and the average value of measurements:

$$R^2 = \left\{ \frac{1}{N} \quad \frac{\sum \left(y_o - y_o^-\right) \left(y_s - y_s^-\right)}{\sigma y_o - \ \sigma y_s} \right\} \tag{15}$$

where

- $\overline{y}_o$ = averaged observed value
- $\overline{y}_s$ = averaged simulated value
- σy_o = observed data standard deviation
- σy_s = simulated data standard deviation

The CRM is defined by:

$$\mathrm{CRM} = \frac{\left(\sum y_o - \sum y_s\right)}{\sum y_o} \tag{16}$$

The CRM is a measure of the tendency of the model to overestimate or underestimate the measurements. Positive values for CRM indicate that the model underestimates the measurements and negative values for CRM indicate a tendency to overestimate. For a perfect fit between observed and simulated data, values of RMSE, CRM and R^2 should be equal 0.0, 0.0 and 1.0, respectively. All the analyses were made using Excel (Microsoft Inc.).

5 Example of SALTMED Application in Souss-Massa Region in Morocco

The SALTMED model has been applied on field crops grown in Souss-Massa region of Morocco (Fig. 1).

5.1 Effect of Deficit Irrigation and Use of Treated Waste Water on Quinoa

A field experiment was performed on the Agronomic and Veterinary Medicine Hassan II Institute, IAV-CHA, farm in Agadir. The study investigated the impact of using treated waste water and deficit irrigation on yield, water productivity (WP),

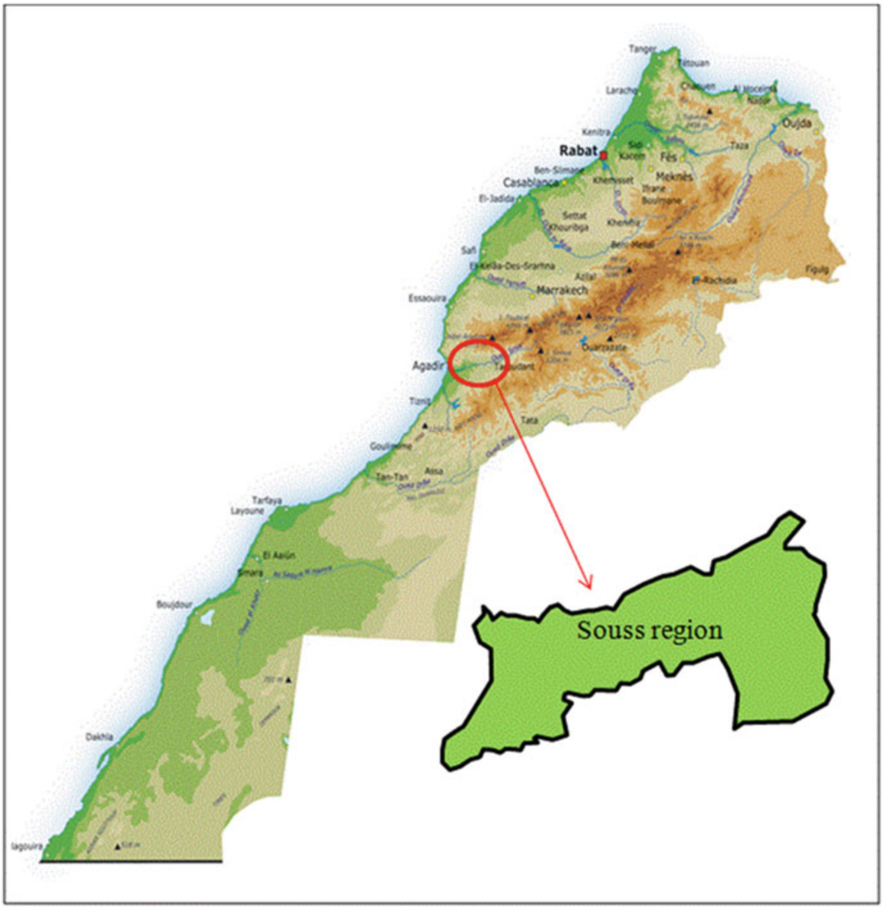


Fig. 1 The Souss-Massa region in Morocco

dry matter and soil moisture availability. Six treatments of deficit irrigation with treated waste water were applied on quinoa (var. D0708) using drip irrigation system. The objective was to test different irrigation strategies applied during several crop stages. These water strategies included following treatments: Q1 was fully irrigated (no water stress), Q2 50% water stressed all the season, Q3 50% stressed during the flowering stage, Q4 50% water stressed during grain filling, Q5 50% water stressed during the vegetative growth and Q6 50% water stressed during vegetative and flowering stages.

The model calibration primarily focused on soil moisture, yield, dry matter and soil salinity. The validation process of biomass production was based on the use of calibrated photosynthesis efficiency value of the control treatment. Plant parameters such as plant height and rooting depth, length of each growth stage, harvest index and LAI were based on field measurements and records. Crop coefficients Kc and Kcb, and fraction cover, Fc, were based on Allen et al. [11]. Soil parameters such as water retention curves were based on laboratory measurements. Initial soil water content and salinity were based on measurements either in laboratory or in the field. Fine tuning of some crop and soil parameters was carried out in order to obtain a good calibration.

The soil moisture calibration was carried out for the control treatment of quinoa, where the sensors were installed. In the model application, the simulated soil depth was divided into three layers. For all depths, there was a very good agreement between simulated and observed soil moisture. In most cases, the R^2 was over 0.80.

The calibration method for biomass and yield aimed at adjusting the photosynthesis efficiency as a crop growth parameter of the model until a minimal difference between observed and modelled yield has been achieved. The calibrated photosynthesis efficiency value of the control treatment (well irrigated) was used in the validation of the other treatments. The photosynthesis efficiency that was applied for validation was equal to 1.64 g MJ^{-1}.

Generally, there was a very good agreement between the measured and simulated quinoa yield with R^2 of 0.96 (Fig. 2). Under different deficit irrigations, the

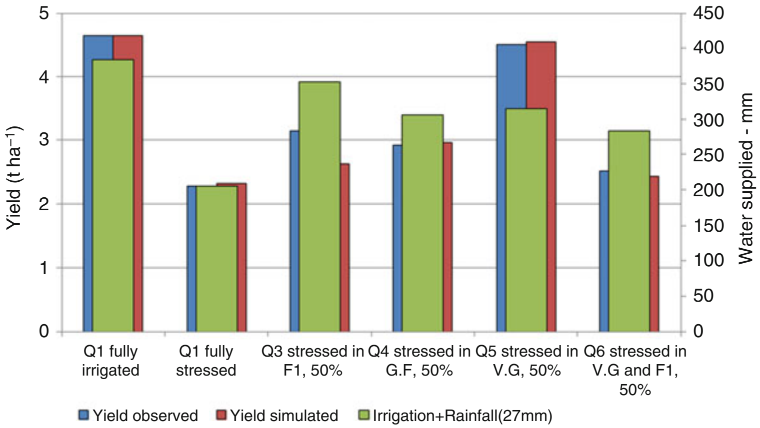


Fig. 2 Observed and simulated yield of quinoa under different water management strategies

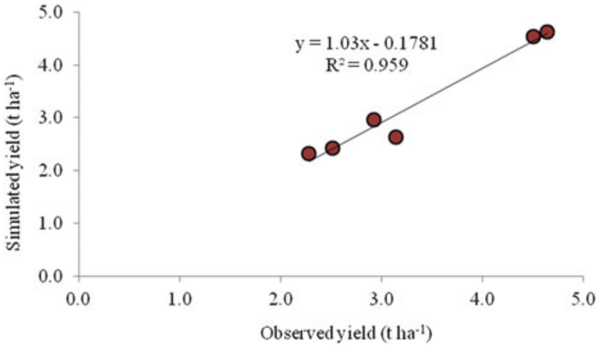


Fig. 3 A 1:1 relation between observed and simulated yield of quinoa under different water management strategies

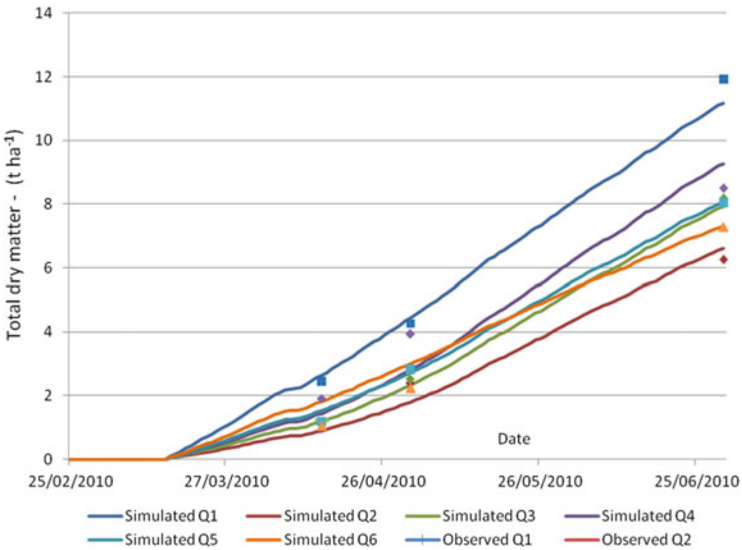


Fig. 4 Observed and simulated total dry matter production during the crop cycle of quinoa

results showed a very highly significant difference between treatments in terms of yield. This difference was mainly due to differences in terms of LAI in response to applied drought stress degrees.

The model has successfully predicted the yield (Figs. 2 and 3) in response to deficit irrigation with treated waste water. In most cases, the relative error was less than 5%. Treatment Q5 showed the highest WP. Under that treatment, plants were subjected to water deficit during the vegetative growth stage, and in response to drought stress the crop developed its root system as the plant devoted most of the biomass to the roots (the ratio of root/shoot was in favour of roots) while during the well-watered period, the plant developed its leaf area in the rest of growth cycle

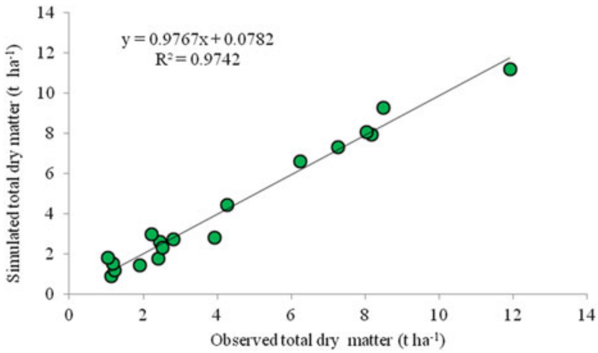


Fig. 5 Observed and simulated total dry matter production during the crop cycle of quinoa

(as the root/shoot ratio was in favour of shoots). This explains why the yields, and the WP, were high.

In addition, again the SALTMED model has been successful to predict dry matter production over time (Figs. 4 and 5) and there was a very good agreement ($R^2 = 0.97$) between observation and simulation.

These results shows that the SALTMED model proved its ability to predict soil moisture, yield and total dry matter under several deficit irrigation strategies using treated waste water.

5.2 *Effect of Deficit Irrigation on Five Different Varieties of Quinoa*

This experiment was also performed on the IAV-CHA farm in Agadir, Morocco.

The aim of this research was to calibrate and validate the SALTMED model with total dry matter and yield data of five *Chenopodium* quinoa lines (L11, L119, L123, L142 and L1143) grown in a semi-arid environment of south Morocco under deficit irrigation with fresh water. Four irrigation levels were applied using a surface drip irrigation system: a fully irrigated treatment (100% of the maximum evapotranspiration, ETm) and three stressed treatments irrigated with 75%, 50% and 25% of the water supplied to control treatment (100%).

The SALTMED model was calibrated using yield, total dry matter (including roots) data from 100% fully irrigated treatment for each line. After the calibration, the model was validated using the same set of crop parameters to validate the stressed treatments for each quinoa line.

The results indicated the model's ability to simulate with good precision, total dry matter and grain yield for the five lines of quinoa under different irrigation strategies with fresh water as shown in Fig. 6.

The figure shows good matching between model predicted and observed yield of the different varieties and it also showed that there is a decrease in yield when

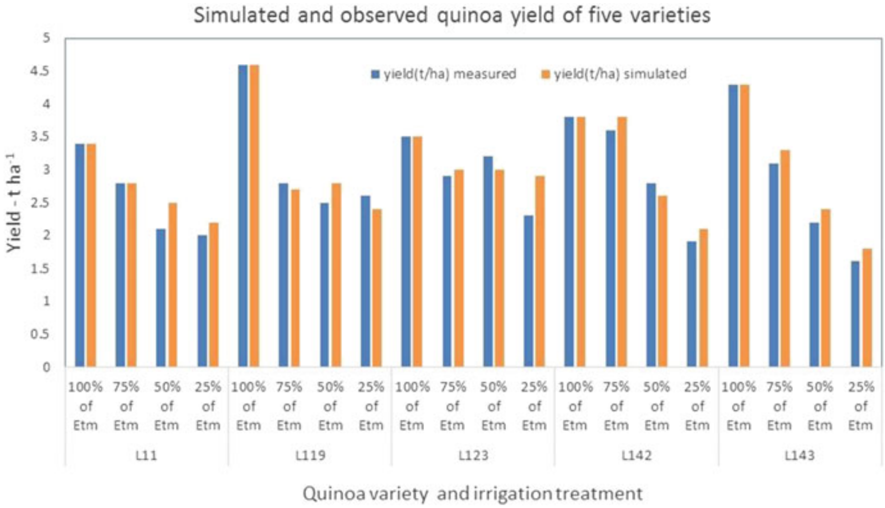


Fig. 6 Observed and simulated yield of quinoa varieties under different water management strategies

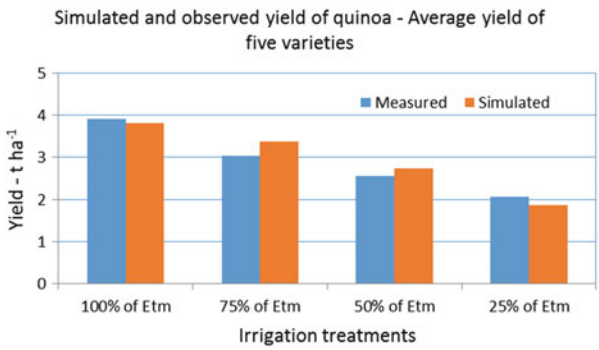


Fig. 7 Observed and simulated average yield of quinoa under different water management strategies

irrigation water amount reduced from amount of water required to meet 100% of the ETm to 25% of ETm. However, the results revealed that the five quinoa lines did not show a superiority of any of them in terms of drought tolerance levels. Therefore, plotting the average yield of all varieties against water supplied (Fig. 7) showed clearly the trend in yield reduction as the water supplied was reduced. The figure shows that yield of the 25% ETm treatment (83 mm irrigation while 100% ETm received 335 mm) was only reduced by 47% (53.1% of 100% ETm yield), the yield of 50% ETm (167 mm irrigation) was only reduced by 35% (65.3% of the 100% ETm yield) and the 75% ETm (251 mm irrigation) was reduced by 22% (78%

of 100% ETm yield). This result to some extent shows that the quinoa is tolerant to water stress and drought. The high values of the coefficient of determination R^2 being 0.94 for yield and 0.96 for dry matter reflected such very good agreement between the model and observed values.

5.3 The Effect of Deficit Irrigation with Treated Waste Water on Sweetcorn and Chickpea

This study investigated the impact of using treated waste water and deficit irrigation on yield, WP, dry matter and soil moisture availability. The experiment included six treatments of deficit irrigation with treated waste water during the 2010 and 2011 seasons and two deficit irrigation treatments combined with three organic amendment levels during the 2012 season.

The experimental and SALTMED modelling results indicated that regulated deficit irrigation when applied during vegetative growth stage could stimulate root development, increase water and nutrient uptake and subsequently increase the yield. The organic amendment has slightly improved yield under full irrigation but had relatively small effect under stress conditions.

Applying 50% of full irrigation requirement during flowering and grain filling stages has led to reduction in yield but the highest reduction in yield occurred when the crop received 50% of full irrigation requirement during both "vegetative and flowering stages" and when the crops received 50% of full irrigation requirement during the whole growing season. The results (Fig. 8) indicated that both flowering and grain filling stages were the most sensitive to deficit irrigation while the vegetative growth stage was the most tolerant. The yield response to several water stress levels, equal to 75%, 50%, 25% and 0% of the full irrigation amount, during the vegetative growth stage showed that applying up to 25% of full irrigation during the vegetative growth stage has not significantly affected the sweetcorn yield. This means applying such stress level could lead to 75% water saving during the vegetative growth stage which represents 20% saving in the total seasonal water requirement.

The results also indicated that organic amendment of 10 t ha^{-1} and 5 t ha^{-1} increased sweetcorn yield by 15 and 1%, respectively, under full irrigation conditions, and by 10 and 4%, respectively, under deficit irrigation conditions (50% of full irrigation requirement).

Applying water stress (50% of full irrigation requirement) during vegetative growth stage significantly improved WP (4.58 kg m^{-3}). On contrast, the lowest WP (2.55 kg m^{-3}) was obtained when the crop was stressed (50% of full irrigation requirement) during grain filling stage. In addition, there were small differences in WP due to organic matter amendments.

The SALTMED model proved its ability to predict soil moisture availability, yield, WP and total dry matter for three growing seasons under several deficit

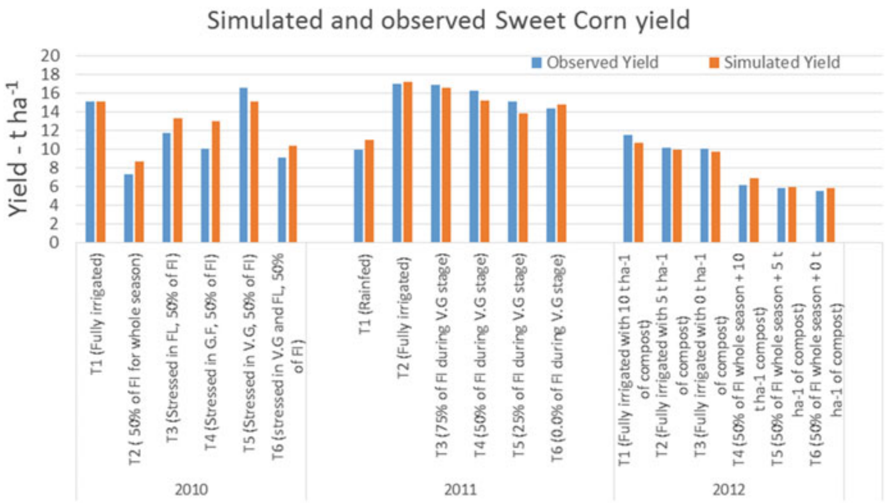


Fig. 8 Observed and simulated yield of sweetcorn varieties under different water management strategies

irrigation strategies using treated waste water. The average relative error in predicting the yield over the 3 years was −3.97%, with a determination coefficient R^2 around 90%.

5.3.1 Chickpea Model Simulation

The drip irrigated with treated waste water Chickpea received five treatments. Fully irrigated, fully stressed, stressed during flowering stage at 50% (of the full irrigation), stressed during the grain filling stage at 50%, stressed at vegetative growth stage at 50% and stressed at both vegetative and lowering stages at 50%.

The simulated yield of chickpeas (Fig. 9) under drip irrigation when applying deficit irrigation with treated waste water showed a very good agreement with the observed data. The SALTMED model using photosynthesis efficiency equal to 2.125 g/MJ for validation was able to predict the yield under field conditions. For most treatments, the % relative error of SALTMED simulated yield was less than 8%. The model was successful in predicting yield and WP for the other treatments. Overall, a 93.2% of correlation between observed and simulated total dry matter was observed.

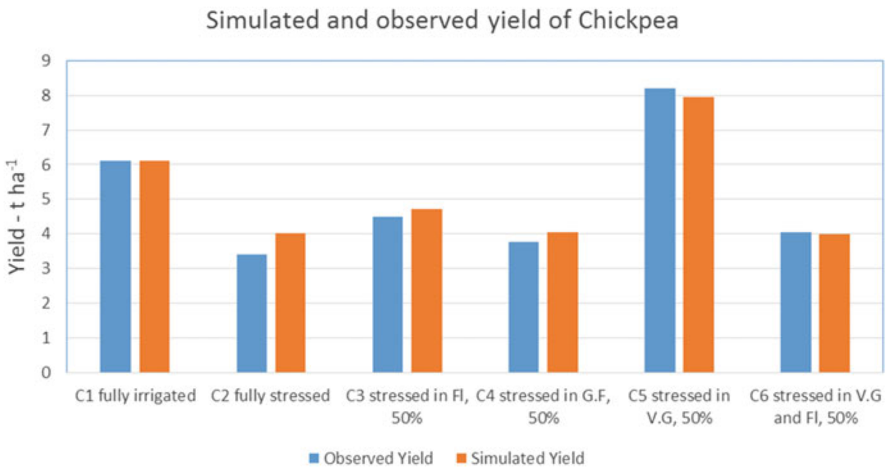


Fig. 9 Observed and simulated yield of chickpea under different water management strategies

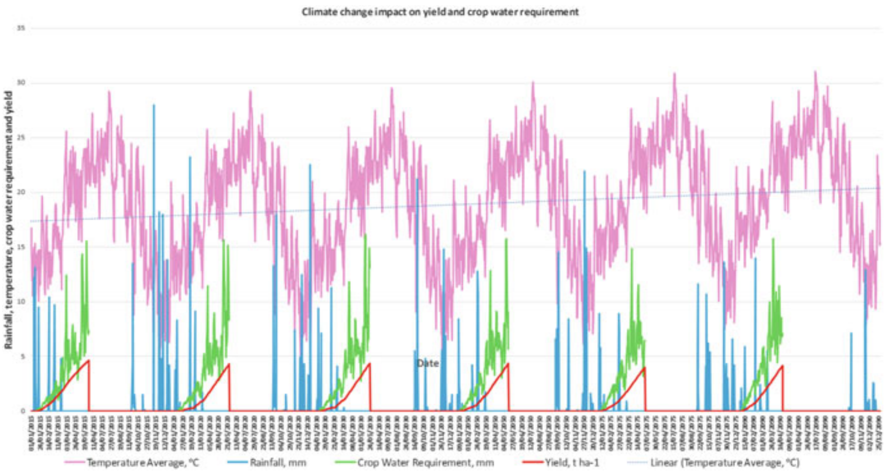


Fig. 10 Impact of change in temperature and rainfall on yield and water requirement

5.4 *Prediction of Climate Change Impact on Corn in Agadir, Souss-Mass Basin*

Future climate projections carried out for the Souss region in the south of Morocco show that temperature will increase by 3°C and precipitation will dramatically decrease by 63% towards the end of the twenty-first century. This will have negative impacts on water resources availability in the Souss region which is

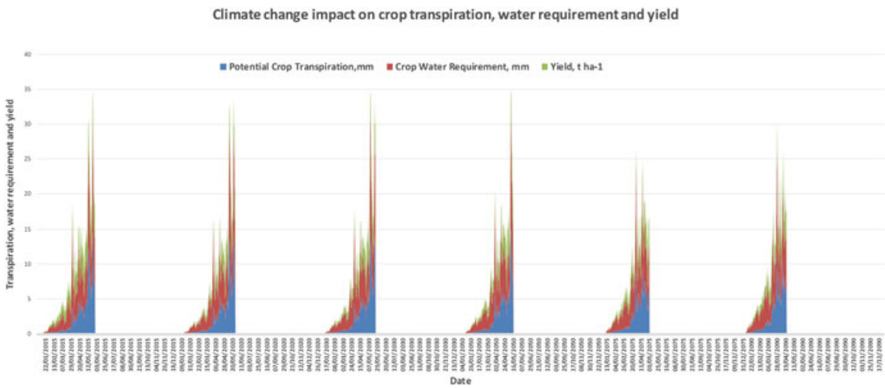


Fig. 11 Impact of climate change on crop transpiration and water requirement

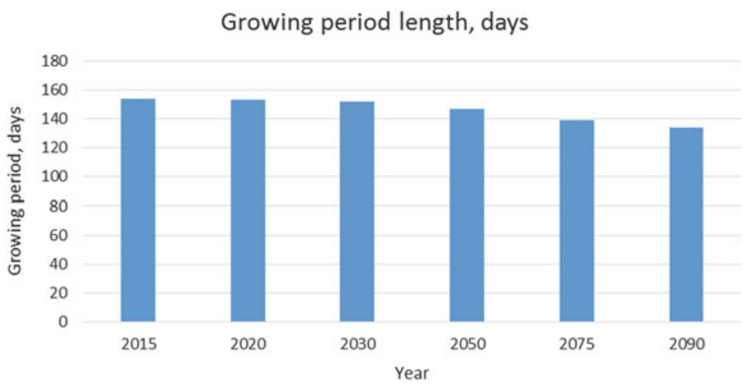


Fig. 12 The impact of future climate change on sweetcorn growing period

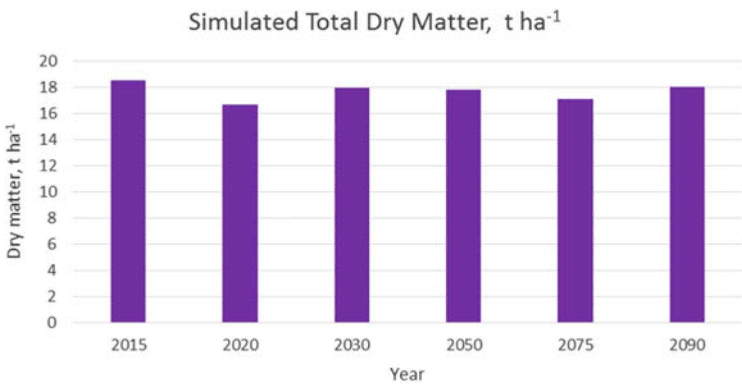


Fig. 13 The impact of future climate change on sweetcorn dry matter

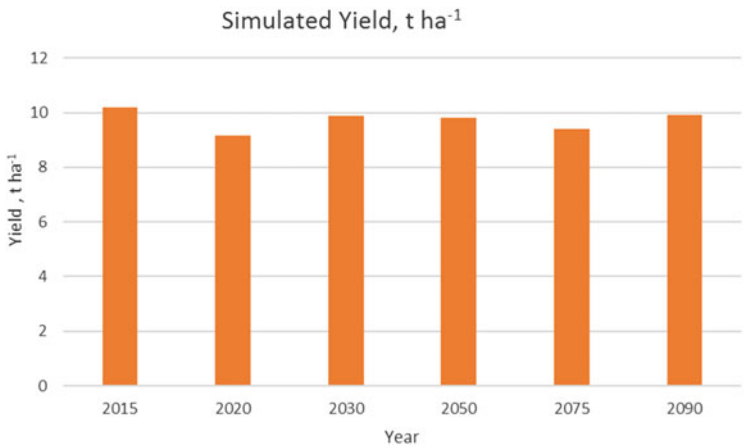


Fig. 14 The impact of future climate change on sweetcorn final yield

already suffering from water scarcity. After successful calibration and validation of the SALTMED model for three growing seasons supplied "baseline data" for sweetcorn, the SALTMED model was run in forecasting mode to obtain future projections of crop ET and crop productivity under changing climate. The results shown in figures 10–14, suggest that, with increasing temperature, the crop ET is expected to increase by 15% while crop water requirement is expected to decrease by 13%, due to the shortening growth season of corn. The results also show that the crop harvest is expected to be 20 days earlier. Crop productivity in terms of dry matter and yield could exhibit a reduction of 2.5% towards the end of the twenty-first century. This study was applied on corn but it is likely that a similar trend could be found for other crops grown in the Souss region. These results indicate that the climate change could have negative impacts on water availability in this water poor region and subsequently may pose a serious threat to the region's food security.

6 General Conclusion

The SALTMED model can be used in forecast mode using "what if" field management scenarios with reasonable degree of confidence. The results confirmed that the model is able to handle several hydrodynamic processes acting at the same time in the soil–crop–water–atmosphere continuum. Good model estimation of soil moisture has practical implications, this means that the model is able to estimate the amount of irrigation supply required to bring the soil moisture profile from a given soil moisture to a desired soil moisture to maximize the crop yield. In addition, good simulation of soil moisture means good estimation of solute and nutrient status and uptake at the same time.

The experimental and SALTMED modelling results indicated that regulated deficit irrigation when applied during vegetative growth stage could stimulate root development, increase water and nutrient uptake and subsequently increase the yield. The organic amendment has slightly improved yield under full irrigation but had relatively small effect under stress conditions.

The SALTMED model results supported and matched the experimental results and showed similar differences among the different treatments. The model proved its ability to predict soil moisture availability, yield, WP and total dry matter for three growing seasons under several deficit irrigation strategies using treated waste water. The high values of the coefficient of determination R^2 reflected a very good agreement between the model and observed values. The SALTMED model confirmed its ability to predict the impact of future climate change on sweetcorn growth, productivity, dry matter, yield, crop ET and crop water requirement under the expected changes in rainfall and temperature up to 2090.

Acknowledgments The work presented in this chapter is based on the results of the EU funded project SWUP-MED, Sustainable Water Use securing food Production in dry areas of the Mediterranean (KBBE-2008-212337), SALTMED: A systems approach to a sustainable increase in irrigated vegetable crop production in salinity prone areas of the Mediterranean region. EU funded project. Contract No. ERB351PL972469, SAFIR: Safe and High Quality Food Production using Low Quality Waters and improved Irrigation Systems and Management. EU funded project. Contract No. Food-CT-2005-023168 and Water 4 crops "Integrating bio-treated wastewater with enhanced water use efficiency to support the Green Economy in EU and India" Grant agreement no: 11933. THEME [KBBE.2012.3.5-03] EU KBBE 2012.3.5-03.

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Water Use Efficiency and Valuation in Agriculture in the Souss-Massa

Fouad Elame, Hayat Lionboui, and Choukr-Allah Redouane

Abstract The Souss-Massa region is experiencing an alarming water shortage, resulting from recurrent drought and overexploitation of water resources, particularly groundwater resources. This situation compromises the production potential and threatens the sustainability of agricultural activities, in particular, irrigated areas.

In this context, irrigation water valuation by crops requires utmost importance in the management of water resources in the region. Improving water efficiency takes multiple dimensions related to the choice of crops that value the water resource better, rationalization of water use, improving the productivity and the economic efficiency of farms, while protecting the environment and limiting the overexploitation of water resources. This chapter presents the results of some water valuation analysis, namely financial valuation (accounting method) and the water use efficiency calculation. The latter is based on the results of the DEA approach (data envelopment analysis).

Keywords Agriculture, Economic efficiency, Souss-Massa, Valuation, Water resources

Contents

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1 Introduction

The issue of water use efficiency and valuation is a topical debate. Water valuation was often approached from the perspective of the farmer; profitability was still confused for the farmer to water efficiency. Several studies estimate the water valuation by the net margin per cubic meter (m^3), whereas the interest of the farmer is not necessarily that of the community which is more interested in the overall income and sustainable development goals and conservation of scarce resources.

Agriculture in Morocco depends on climatic conditions. This makes the water management a technical and an economic requirement and privileged trend for economic and social development. This climate insecurity causes global food insecurity (need for massive imports in dry years) and affects drastically the living conditions of the rural world, with repercussions on other activities [11]. Nowadays, the water issue is crucial in Morocco. However, water losses are high, productivity per hectare has not yet reached the optimum for some crops, and the cubic meter of water is not sufficiently valued by crops.

Indeed, the use and the inefficient allocation of irrigation water is a major constraint to the development of the agricultural sectors in irrigated areas. Incentives for effective and efficient management of water still have a limited impact and the water price does not reflect its scarcity.

In this situation, considerable efforts in scientific research must be undertaken to support the development strategies of Morocco Green Plan in order to ensure a more rational and optimal management of water resources.

In this context, an economic valuation study of water resources in the major districts of the area was conducted. The main objectives of this paper are, first, to analyze the scores of water use efficiency of a sample of farms in the area according to the irrigation water sources (dam, groundwater, and conjunctive water use), and also to assess irrigation water valuation by the main crops based on the financial method (accounting method) and data envelopment analysis (DEA) method.

2 The Irrigation Sector in Morocco

2.1 Introduction

Water is the main factor limiting agricultural production in Morocco. Historically, climatic conditions have made irrigation a technical requirement that has acquired over the years undeniable economic and social dimensions. Although they represent only 13% of the total agricultural area of the country, irrigated areas contribute to the creation of 45% of the agricultural added value, 33% of rural areas employment, and 75% of exports of agricultural products [1].

The development of irrigation has allowed creating a food processing industry. It also led the creation of small trade and service companies inserted in rural areas. Irrigated areas represent an important pillar of development at local and regional level with positive repercussions on the national economy.

Knowing that mobilized water potential is estimated at 20 billion cubic meters of which about 17 billion are reserved to agriculture, irrigation potential is estimated at about 1.664 million hectares plus some 300,000 hectares may benefit from seasonal irrigation and flood irrigation [2]. This potential is still relatively limited compared to the needs of the country. It is therefore appropriate to use it in the best way.

2.2 The Souss-Massa Basin

The agricultural modern sector in the Souss-Massa was developed by a private initiative and holds a prominent place alongside the public irrigated sector developed by the government. The Souss-Massa region is well known for its favorable climate for agricultural development and has an important active population potential.

Agricultural production has an important weight at the national level with, in particular, the production and export of citrus and off-season crops. The economic and social development in this region has led to an overexploitation of groundwater resources. The region is thus faced with a water shortage problem exacerbated by drought effects that becomes increasingly structural.

Looking for solutions to the water economy and conservation is an issue that concerns all development players particularly agricultural water users who consume more than 90% of the resource. It is also one of the Morocco Green Plan priorities.

The Morocco Green Plan has developed a national strategy with regional guidelines for water saving and recycling for irrigated agriculture. Indeed, the National Irrigation Water Saving plan (PNEEI) is part of the transverse measures of the Morocco Green Plan. It aims to mitigate water stress, considered as the main limiting factor in improving agricultural productivity. One of the major projects is the modernization of irrigated agriculture through irrigation development techniques located on a large scale through conversion of existing irrigation with limited efficiency, including surface irrigation. The goal is to fit in drip irrigation for nearly 50% of the total area at national level [3].

Despite its dry climate, the agricultural area in the region occupies 616,500 ha of which 30% is irrigated [4]. These lands are located mainly in the Souss and Massa sub-basins. Irrigation system: The irrigation systems used in irrigated areas of Souss-Massa are, mainly, drip irrigation, surface irrigation in addition to sprinkler irrigation.

According to ORMVASM, areas equipped in 2010 with drip irrigation are around 58,500 ha, which represent 44% of the total area, sprinkling 18%, and surface irrigation 36% [12].

3 Methodology

Assessing irrigation water valuation requires multiple dimensions and scales. At the farm level, water efficiency refers to the productivity and profitability (agronomic and economic dimension). The farmer aims to produce more per cubic meter of water and choose the most profitable crops that can generate the highest profit.

At the community level (region or country), water valuation is assessed according to other factors related to economic and even environmental and social sustainability. This concept is very important and can be used to help decision makers to redefine the appropriate agricultural policies to meet the requirements of socio-economic development and environmental preservation.

In this case, the value added per hectare is used to assess water efficiency levels by farm type in the various areas of the Souss-Massa region.

Since that, at the farm level, the "profit" is the main criteria in the choice of which crop to grow, we will analyze the financial value of irrigation water by farm type and by crop. Then we will compare the different levels of water use efficiency and valuation through the DEA method which is based on the concept of efficiency.

Farrell [5] was the first to clearly define the concept of economic efficiency and to distinguish between efficiency concepts. The relevant work of Farrell [5] served as the basis for several works carried out on the different concepts of efficiency. The issue was whether a farm can increase production simply by improving efficiency and proposed an approach to the estimation of efficiency frontier. The efficient frontier is defined by the most optimal practices of the sample used. To define the frontier as a reference to efficiency measures, it is necessary to define the outputs or aggregated output and production inputs or aggregated input used in a production system [6].

To calculate scores for technical and economic efficiency, an aggregated output of the total production expressed in monetary value was retained. For inputs, five aggregated inputs were considered, namely irrigation water, seed planting, fertilization, treatment plant, labor, and soil preparation. In this study, we choose a variable return to scale (VRS) model, since it is assumed that farms are not all operating at an optimal level. Using a VRS model of the DEA method provides an efficiency measure free of the scale effect. The data were processed using DEAP software (Data envelopment analysis computer program) which is a free version [7].

Data processed in this work comes from the surveys carried out in 2009 by The ORMVASM in the various areas of the region. Data coming from surveys conducted by the ABHSM [8] (PDAIRE) were also used to compare the different water valuation approaches.

4 Results and Discussion

4.1 Assessing Water Use Efficiency by Farm Type

The valuation concept was recently introduced in the large irrigated areas in Morocco. We were interested before on the concept of water saving that is based on a reduction in irrigation losses, a decrease of applied water quantities, and using modern irrigation techniques. However, the irrigation water valuation aims to look for a maximum of efficiency, of technical and financial productivity of the use of irrigation water [9].

The economic valuation tries to optimize the ratio: the production value, the gross margin or the value added per volume of water consumed.

In this case, the water use efficiency will be assessed by the net added value per water consumption. The results of this analysis show that water valuation varies too much and goes from 5 Dh/m^3 for the "Souss amant public" district, and 22 Dh/m^3 for the "private modern Souss" district. This variability also exists between the different farm types. Indeed, in some districts like "G1," "Massa," and "Issen moderne public," farm areas under 5 ha which are the smallest farms have the highest level of water use efficiency (Table 1).

Table 1 Water use efficiency per farm type (Dh/m^3)

Farm type/District	<3 ha	3–5 ha	5–10 ha	10–20 ha	>20 ha	Average
Massa moderne public	22	27	20	24	16	21.7
Massa traditionnelle	13	14	21	13	13	14.8
Massa moderne privé	21	18	17	28	29	22.8
Issen moderne public	15	14	11	10	13	12.5
Issen traditionnel	6	5	5	7	12	7.1
Secteur G1	7	6	8	5	5	6.4
Souss amont public	5	6	5	6	9	6.3
Souss traditionnel	6	6	7	6	10	7.1
Souss privé	8	10	11	8	9	9.3
Sebt al Guardane	7	8	9	15	13	10.5

Table 2 Agronomic and economic valuation according to irrigation type

Crop	Water requirement (m^3)	Yield (t/ha)	Gross margin (DH)	Agronomic valuation (kg/m^3)	Economic valuation (DH/m^3)
Drip irrigation					
Tomato G.H	8000	160	62500	20	7.81
Pepper G.H	7000	80	32000	11.4	4.57
Bananier G.H	12000	60	83000	5	6.92
Tomato	6000	80	10600	13.3	1.77
Pepper	6000	40	6300	6.7	1.05
Potato	6000	60	10200	10	1.70
Peas	3500	8	3300	2.3	0.94
Corn	5000	80	6500	16	1.30
Luzern	14000	100	17000	7.1	1.21
Clementine	10000	30	7500	3	0.75
Olive	6000	12	3000	2	0.50
Surface irrigation					
Tomato	8000	35	1300	4.4	0.16
Pepper	8000	30	800	3.8	0.10
Potato	8000	35	4100	4.4	0.51
Peas	5000	3.5	1000	0.7	0.20
Corn	7000	40	2000	5.7	0.29
Luzern	20000	60	3100	3	0.16
Clementine	14000	22	1000	1.57	0.07
Olive	8000	6	1500	0.75	0.19

Source: ABHSM [10], Rapport mission II. Propositions d'actions pour une meilleure valorisation de l'eau d'irrigation

4.2 *Assessment of Water Use Efficiency by Crops*

The indices used for the calculation of agricultural and financial values are shown in the table above. These calculations are based on the average values of water requirements, crop yields, selling prices, etc (Table 2).

The comparison between surface and drip irrigation shows that drip irrigation increases yields, water productivity, and also water valuation. Indeed, for the main crops, yields represent more than double: corn (5.7–16 kg/m^3), tomato (4.4–13.3 kg/m^3), and potato (4.4–10 kg/m^3). This fact confirms that the irrigation system is a key component of water valuation.

In terms of water productivity under drip irrigation, corn value water better (16 kg/m^3), followed by tomatoes: 13.3 kg/m^3, potatoes: 10 kg/m^3, Luzern: 7.1 kg/m^3, and peppers: 6.7 kg/m^3.

Clementine, peas, and olive give lower yields per cubic meter of water varying between 3 and 2 kg/m^3.

Regarding the financial valuation, the results show that drip irrigation improves 6 times the financial value of irrigation water. Tomatoes and potatoes are the best crops to value water. Water valuation by tomato is about 1.77 DH/m^3 and 1.7 for potato.

If we compare crops under green houses and crops in the fields, we can clearly notice that crops under green houses have a high productivity per cubic meter and also the highest water use efficiency. Water valuation by tomato is around 7.81 DH/m^3 and can reach more than 10 DH/m^3 for the most competitive farms in the region.

4.3 *Water Use Efficiency According to the DEA Method*

In addition to farm types, it seems necessary to study the effect of water sources access on the different levels of water use efficiency (Fig. 1).

The figure above shows that farms using surface water for irrigation are more efficient because their technical and economic efficiency levels are highest. They are followed by farms (mixed) that combine the use of surface and ground water, and finally nonirrigated farms are far from equalizing marginal values of their production to the marginal costs of production factors. This confirms that irrigated farms from one water source manage efficiently the technology available and better allocate the water resources. This can be explained by the fact that the water pricing applied by the ORMVASM on surface water forces farmers to use water more efficiently, while those that combine the two water sources have no constraint on

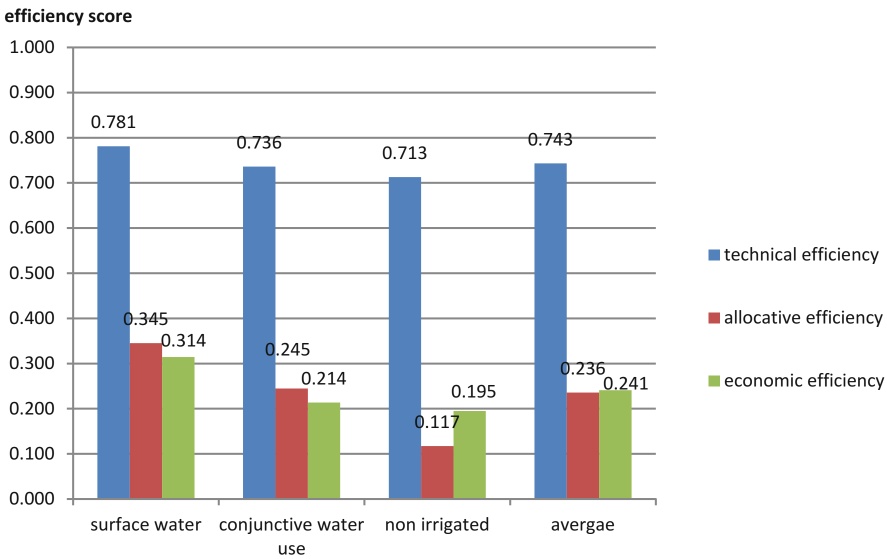

Fig. 1 Technical, allocative, and economic efficiency of farms according to the water access

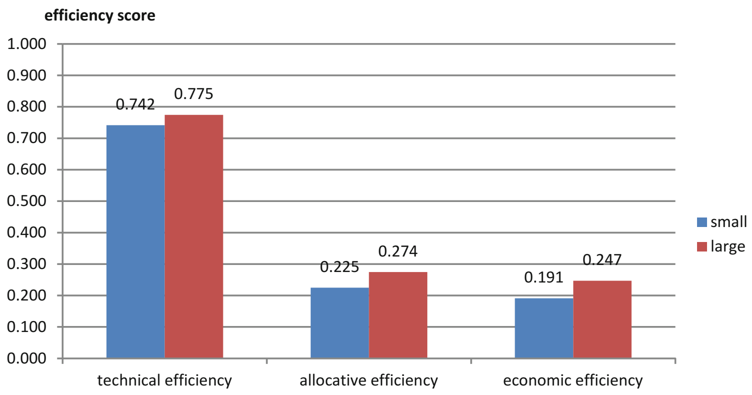

Fig. 2 Water use efficiency depending on the farm size

pumping groundwater except the cost of pumping energy and therefore they value the water resources to a lesser degree.

Figure 2 shows that large farms are more efficient than smaller ones.

Large farms have allocated in an optimal way the technology available and are also more efficient in terms of water use valuation. Small farms are also allocating the technology available and value water resource in a good manner but not at the same extent as large farms. We can explain this situation by the concept of economies of scale, meaning that large farms tend to rationalize the use of inputs and thus earn more on production costs.

5 Conclusion

The issue of water resources management has always been a major concern for decision maker in the Souss-Massa basin. Indeed, the increasing demand of water resources due to the economic development, the overexploitation of the aquifers, and climate change impact make the water resource very scarce. With regard to this, adapted policies of management and water valuation are required in order to better allocate and value the water resources.

This work aims to compare different levels of water valuation taking into account farm type and water sources. Two main methods were applied, the DEA approach and water valuation by the accounting method according to the calculation of the added value. This work was applied to a sample of 30 farms located in the Souss-Massa region.

The results of efficiency levels depending on the access to water sources show that farms using surface water are more efficient than other types of farms. This means that farms that use surface water allocate water resources better than those that combine surface water and groundwater. This can be explained by the fact that the water pricing applied by the ORMVASM on surface water forces farmers to use water more efficiently, while those that combine the two water sources have no constraint on water pumping and tend to pump more water and therefore less value this resource.

As a conclusion, these farmers should improve their knowledge of available technologies and optimize their allocation of water resource in order to increase their efficiency level. Similarly, water valuation and optimal allocation should be among the main concerns of these farmers knowing that the limiting factor in the study area is the water resource. In addition, the government, through its extension services, should also invest in rationalizing the use of resources and technology transfer to least efficient farmers.

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The Great Catchment of Souss-Massa Wadi (Morocco): Relationship Between Protected Areas and Ecotourism

H. Aboutayeb, M. Beraaouz, and A. Ezaidi

Abstract This study focuses on protected areas in the great catchment of Souss-Massa wadi, more specifically in the Argan Biosphere Reserve (ARB).

This region has exceptional biogeographical and sociocultural resources that could help this area to become a sustainable tourism destination.

The investigation specializes on the ecotourism side of the catchment of Souss-Massa through the analysis of its natural amenities especially the ones that are linked with biodiversity. This will position ecotourism as the basis of a development model. There are several opportunities in this region as far as biodiversity is concerned but they need to be valorized. Thus, priority ecotourism areas were identified and some recommendations were made along with strategic planning guidelines for tourism in this region. Such guidelines show the need for strict environmental protection schemes while offering good standards of living for the population and a satisfaction for the tourists.

Keywords Argan Biosphere Reserve, Biodiversity, Conservation, Ecotourism, Protected area

Contents

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Abbreviations

ARB	Argan Biosphere Reserve
BEIS	Biological and ecological interest sites
SMNP	Souss-Massa National Park
TONP	Toubkal National Park
UNESCO	United Nations Educational Scientific and Cultural Organization

1 Introduction

Nature includes both biotic and abiotic components which together form natural diversity on all geographical levels, from local, regional, and continental scales. As established by the World Heritage Convention ([1], article 2), "natural features consisting of physical and biological formations or groups of such formations which are of outstanding universal value from an aesthetic or scientific point of view," as well as "natural sites or precisely delineated natural areas of outstanding universal value from the point of view of science, conservation or natural beauty" should be considered "natural heritage," and therefore need to be preserved as part of the world heritage of mankind.

Bioconservation requires inventory and evaluation procedures which play a decisive role in the implementation of any subsequent conservation. Bioconservation strategies must strengthen the complexity of the field, with regard to both scale and scientific requirements [2].

Ecotourism, when properly practiced, is the prime economic sector of sustainable development [3].

Given the incredible cultural and natural potential of the Souss-Massa region, the tourism sector and more especially ecotourism represents one of the main supports of its economy.

This contribution focuses on the biodiversity of the great catchment of the Souss-Massa wadi. It will start with the inventory and description of biological and ecological interest sites (BEIS) (biotopes), the natural parks (SMNP), the endemic or rare flora and fauna, and an overview of the heritage. It also focuses on the sustainability of ecotourism, but more specifically on the ability of the system to reach its objectives, particularly those related to the conservation of biodiversity and natural environments. Several questions arise from these objectives:

- What are the protected areas of the great catchment Souss-Massa?
- What is the place of ecotourism in these protected areas?
- What are the ecotourism territories that should be included in this framework?
- What are the educational activities, programs, and infrastructure established for the use of local populations, the tour guides, and tourists in the ecotourism framework?
- What measures should be taken in the framework of bioconservation?

The analysis of these questions is designed to produce recommendations which will be used eventually to the improvement of the management and planning of ecotourism projects.

The study of the relationship between ecotourism, local communities, and protected area is therefore crucial in order to assess the level and quality of ecotourism offered in a given area.

2 Presentation of the Study Region

The large catchment Souss-Massa is located between Agadir and Taliouine (Fig. 1) and covers an area of approximately 27,880 km^2 including 25% in lowland areas and 75% in the mountains. Up north, it includes the southern slopes of the western High Atlas, whereas in the south, the area also covers the Western Anti-Atlas foothills where the crystalline Precambrian is shown in the form of many slots. On the eastern side, the Siroua mountain range takes the form of a bulge in Precambrian crystalline coated volcanoes Plio-Quaternary strata.

The Souss-Massa basin is drained by two main wadis:

- The Souss wadi, with its tributaries (Fig. 1), constitutes the main river of the region. Coming from Mokhtar Soussi and Aoulouz dams, it leads to the Aoulouz gorges dam and through the Souss valley from the East to the West on a distance of 185 km before going to the Atlantic Ocean.
- The Massa wadi, located in the South, at 70 km from Agadir city, drains the waters of the northern side of the western Anti-Atlas foothills and constitutes the only perennial flow of fresh waters to the ocean in the south of the Souss. Its journey is cashed and forms a narrow valley on a distance of 36 km before going to the Atlantic Ocean. The Massa wadi flow rate is regularized by the dam of Youssef Ben Tachfine.

Agriculture is the main economic activity of the region. The potential irrigable land has a size of 250,000 ha. The irrigated area, located mainly in the Souss basin, extends on 134,300 ha, of which nearly 60% is irrigated using modern ways. In terms of production, the truck??? farming occupies 34% of the area. The main productions are: citrus fruits 25%, cereals 10%, and livestock 28%.

Tourism is the second economic sector of the region. With a capacity of 26,400 beds, the region has nearly 30% of the national accommodation capacity.

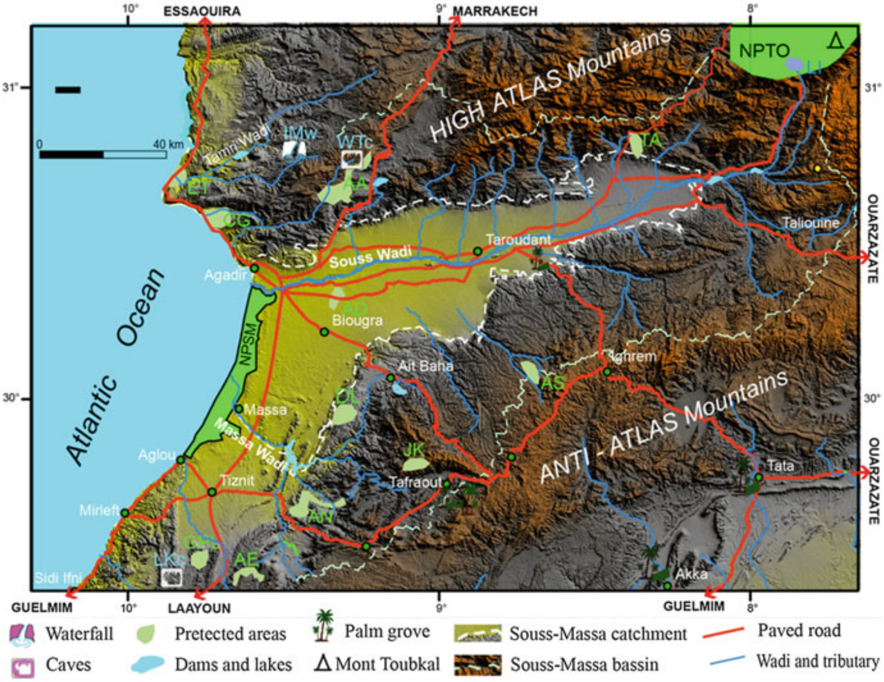

Fig. 1 Map of protected areas in the catchment of Souss-Massa wadi. *SMNP* Souss-Massa National Park, *TONP* Toubkal National Park. Biological and Ecological Interest Sites (BEIS) (CP: Cap Ghir, TM: Tamri, AD: Adnine, IL: Ifni Lake, AT: Assif N'Tifnaute, AA: Ain Asmama, TF: Tafenoulte, JL: Tbel Lkest, AN: Anzi, and AE: Ait Er-Kha). LKc: Lakhsass cave; WTc: Win Timdouine cave; IMw: Imouzzer waterfall

This region is rich in natural heritage as well as biodiversity and geodiversity, which gives it an indisputable ecotourism and geotourism vocation.

3 Regional Biodiversity

The Souss-Massa catchment is part of the Argan Biosphere Reserve (ARB). In its Atlantic part, it is located in the Souss-Massa National Park, while the eastern part includes the western boundary of Mount Toubkal National Park (TONP). The area is also well-provided with protected biological sites. The main sights are the biosphere reserve core areas that benefit from long-term protection for both biodiversity and development promotion.

3.1 The Natural Parks

3.1.1 Souss-Massa National Park

The Souss-Massa National Park (SMNP) is located at a few kilometers from Agadir on the coastline of the Chtouka-Ait Baha and Tiznit Provinces (Fig. 1). It was created in 1991 and extends over an area of 33,800 ha, from the Oued Souss mouth to Aglou in the form of a coastal strip of 65 km long and with an average of 5 km width.

The SMNP is equipped with a strategy for the organization and the rationalization of activities in order to better meet the requirements of ecotourism promotion, the local population development, and natural resources preservation. It contains a wild population of bald ibis that is unique in the world. It is also possible to observe all reintroduced species (Fig. 2) to the park: *Addax nasomaculatus*, *Oryx dammah*, *Gazella mhorr*, *Gazella dorcas*, and red necked Ostrich.

The Massa wadi mouth has the richest and most diversified wildlife of the whole park. The most remarkable species are: the wild boar, the jackal, the fox, the Genetta, the mongoose, the African wildcat, and the hare as well as reptiles, amphibians, fishes, and butterflies. It is also a site of great importance for water birds. It regularly welcomes thousands of individuals and a large number of species that overwinter to rest or reproduce.

The park is home to very diverse and endemic biotopes. The procession plant is marked by a coastal steppe made of euphorbia, dune vegetation, and aquatic vegetation on the shores of the Massa wadi.

Many tourists visit this natural park for ecotourism, discovery, and leisure. These visits are spread in a balanced way in the backcountry of Agadir, while promoting the richness of the park fauna and flora. The 30 km tour shows a great amount of bioecological elements, animal reserves, home to some species of Saharan wildlife in acclimatization, and endangered bird species (the bald ibis), that can be observed between the villages of Tifnit and Sidi R'bat.

This natural park represents a management tool for the preservation of natural resources and the encouragement of ecotourism.

3.1.2 Toubkal National Park

The western part of the national park is located 175 km from Agadir city. The park extends over the central part of the High Atlas mountains, between three valleys: N'Fiss in the West, Ourika in the East, and Tifnout in the South. It is the first national park in Morocco, established in 1942. It presents a varied relief of 1,200–4,167 m of altitude (the highest summit of North Africa is mount Toubkal), plains, Ifni Lake, deep gorges, granitic landscapes, and springs.

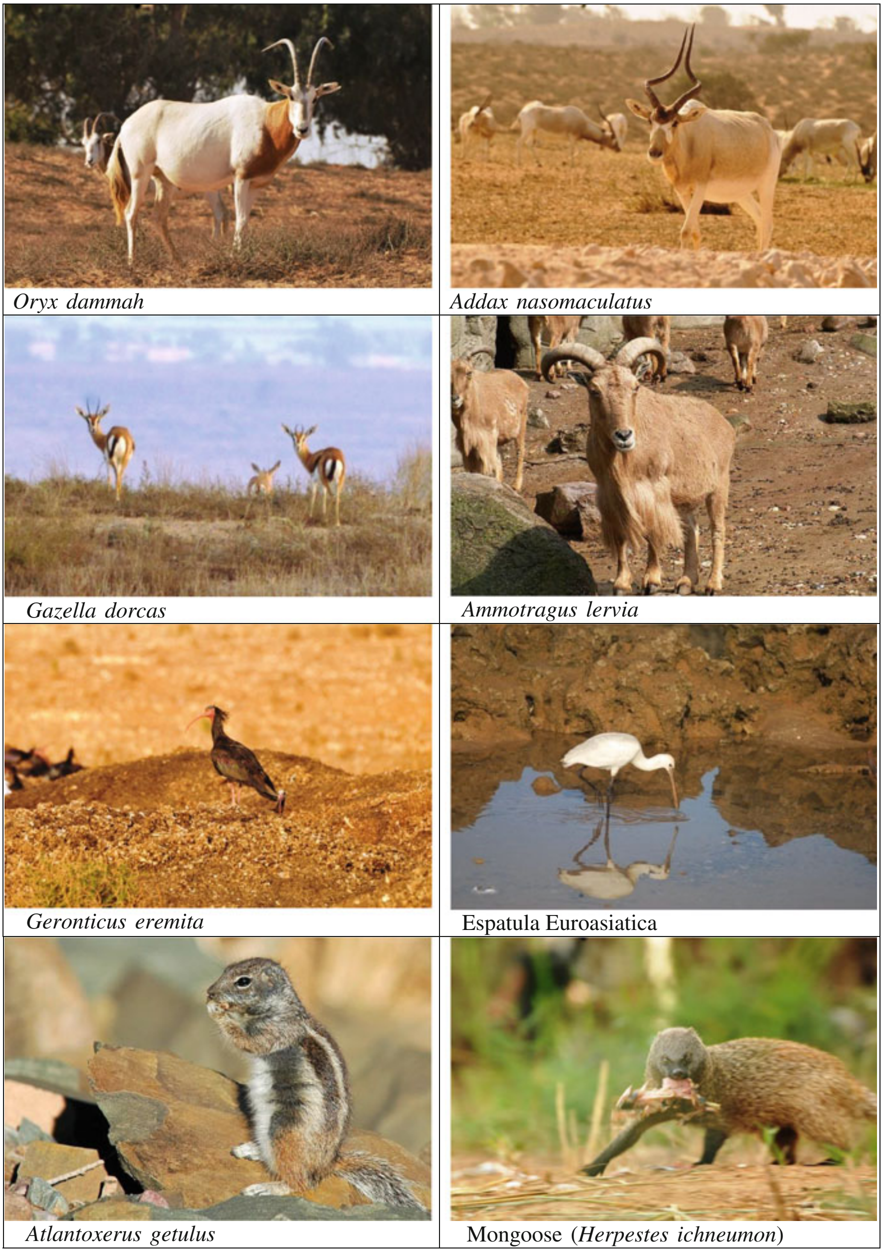

Fig. 2 Examples of endemic mammals and birds of the protected areas in the Souss-Massa great catchment

The observable wildlife (Fig. 2) while hiking is the *Gazella cuvieri*, *Ammotragus lervia*, *the* caracal, and numerous species of bird of prey such as the royal eagle and booted eagle, the Bonelli's eagle, and the short-toed snake eagle.

In this park, flora is also diverse with stands of holm oak and thuya: Phoenicean juniper, walnut, thorny xerophytes, *Juniperus thurifera*, and endemic plant.

The cultural heritage, natural picturesque landscapes, green valleys (such as Tifnout), very rich flora and fauna, as well as a high mountain lake (Ifni Lake) give a great ecotourism potential to the TONP.

Recently, the promotion of the park was organized in a different way, as being a tourist destination for its several attractions and not only the Toubkal summit. More and more Moroccan tourists and foreigners come to the Ifni Lake and the Tifnout Valley.

Tourists awareness and information along with local guides training are essential to protect these very sensitive and fragile natural spaces.

3.2 Biological and Ecological Interest Sites

For the sake of its conservation and value, a number of biological and ecological interest sites (BEIS) were identified at the large Souss-Massa watershed. The BEIS show a strong index of high biodiversity and a remarkable ecosystem, with endemic species and/or rare or endangered ones. In the study region, there are a number of BEIS in the littoral as well as in the plains and on mountain slopes (Fig. 1).

3.2.1 The BEIS of the Coastline and Plains

On those areas the main BEIS are:

Cape Ghir It is located 40 km to the north of Agadir. The site belongs to the western High Atlas. The land is limestone from the Jurassic period, and sometimes caves. The coast is rocky, with a sandy beach.

Vegetation includes argan trees and euphorbia (*Euphorbia beaumierana* and *Euphorbia regis-jubae*). This area is unique because the argan tree reaches the seashore. Also, near the coast marine pelagic mammals including killer whales can be observed.

The site is the northern boundary, along the coast for the species *Bufo brongersmai*, an endemic toad from Morocco. The main birds are passerines (Tchagra, Gobemouche gray, and Warbler Orpheus).

It is possible to observe the passage of migratory birds on the coast.

Tamri Wadi Mouth This BEIS occupies the coastal cliffs (30–50 m). The ecosystem is made of sand dunes, on both sides of the Tamri wadi mouth. This wadi runs throughout the year, with a terminal delta? occupying half of the downstream watercourse.

Many bald Ibis can be observed in this site as well as large flocks of gulls and Terns (Audouin's Gull). We can also observe the Falcon Peregrine and the Falcon Kestrel.

In addition, many other marine birds congregate on the beach at dawn. The Cormoran posh (subsp. *riggenbachi*), endemic to Morocco's Atlantic coast can also be observed.

Since 1990, couples of unicolor Martinet species which used to be endemic to the Canary Islands and Madeira have been implanted in this site.

In addition to five endemic species of Moroccan amphibians and reptiles, this site constitutes the northern limit of distribution of a pre-Saharan endemic species of Morocco (*Acanthodactylus busacki*).

Admine Forest This BEIS occupies 350 ha and is located in the province of Inezgane Ait Melloul, in the Admine forest. It is marked by plains where Argan trees are very anthropized. About 20 species of mammals have been identified, 50 species for the avifauna, and 25 for the herpetofauna. It constitutes one of the privileged places for relaxation of the local population in the spring. This area has a full argan protection, which should ensure a reserve and help in the replenishment of deteriorated areas.

3.2.2 The Mountain BEIS

These BEIS are present in the High Atlas and on the Anti-Atlas foothills.

The Western High Atlas constitutes a privileged place for the practice of ecotourism activities. The BEIS of the Atlas are:

Ifni Lake It's a natural lake with a depth of 65 m and a size of 35 ha. Its location at the bottom of a "valley" gives it its value and beauty. It's surrounded by arid mountains, and very steep slopes. The cirque glacier which is the origin of this lake is a hundred meters high.

The green color that sometimes appears on the lake's surface is linked to the abundance of an alga (*Cyanophyceae*).

The lake is poor in fauna: a species of culturing??, a species of Copopoda and form quite special of *Salmo trutta macrostigma* (probably an ecotype). No water birds can be found on the lake.

Tifnoute wadi It is the main tributary of the Souss wadi, although in offseason a very low quantity of its waters arrives to the Souss wadi. It takes its origins in the southern flank of the Jbel Toubkal where two large tributaries feed: assif N'Izli from a resurgence in the south of the lake of Ifni and Assif N'Wakten, the valley of the Tifnoute is about thirty kilometers further downstream.

The flora is relatively varied with a dozen of biogeographically interesting species: *Dactylorhiza elata*, *Juncus fontanesii*, *Juncus pygmaeus*, *Lolium perenne*, *Medicago sativa*, *Paspalum paspaloides*, *Persicaria lapathifolia*, *Persicaria salicifolia*, *Ranunculus trichophyllus*, *Sphenopus divaricatus*, and *Trifolium michelianum*.

The invertebrate fauna is also varied. The fish population is composed mainly of barbels and introduced trout, but it is necessary to point out the presence of Cincle plongeur, and the Bergeronnette creeks.

Ain Asmama This SBEI is situated in the commune of Tiqqi, in the province of Agadir on a surface area of 23.5 ha [4]. It is located on bottom of the great cliff of the valley of the Argana. Biodiversity is very important. The main tree species of the area are the argan, the green oak, western red cedar juniper, the pistachio, and the acacia. There are many rare plants and the rate of endemism is high enough. It also consists of 25 species of mammals, 70 species of birds, and 20 species of reptiles. It's a limestone plateau of Jurassic age, based on clays sandstone of Permian and Triassic appearing below the cliffs overlooking the valley of the Argana. Its waterfalls are similar to the ones at Imouzzer Ida Outanane and Tamaroute, its surroundings beautiful landscapes, as well as the big dam of Abdelmoumen, constitute a highly attractive site for the tourists.

Tafingoult It is located in the South of the High Atlas, in the province of Taroudant. The site represents a reserve of 400 ha. The vegetation is composed of the Arganeraie, tetraclinaie, and oak woodland green. Thirteen species of mammals among which are: Shrew Murette, *Atlantoxerus getulus*, Hystrix, Genetta, ichneumon mongoose, gloved cat, lynx caracal, and Cuvier's Gazella. There are also 50 species of birds and 20 species of reptiles.

In the north slope of the western Anti-Atlas, the main SBEI are:

Jbel Lkest This SBEI is located in the province of Tiznit and covers an area of 1,300 ha. It represents a siliceous mountain of the Anti-Atlas foothills and is known for its pink granitic rocks. The altitude in the SBEI varies from 1,600 to 2,258 m. Vegetation includes argan trees, western red cedar, green oaks, pistachios of the Atlas, carob trees, and acacias gummiferes. In regards to wildlife, there are a dozen species of mammals classed as rare or threatened with extinction including more than 27 herds of gazelles, wild boar, a rich and varied herpetofauna, and 8 endemic species. It is also an area recognized internationally for its richness in butterflies. Fifty-five species of birds nest here. The mountain of Jbel Lkest has an international reputation among the followers of nature tourism and hiking.

Anzi It is located in the province of Tiznit on an area of 475 ha. It is formed by the plates of the western Anti-Atlas. The vegetation (Fig. 2) consists of argan trees, carob trees, holm oaks, Draco trees, and Sage Thrasher. In addition, some 60 species of birds nest in the sector. There are also a few hyenas and Gazella of Cuvier.

Ait Er-Kha It is located in the rural commune of Ait Er-Rkha on an area of 4,000 ha. The ecosystem here is well preserved. The plant species are composed mainly of argan trees and cedar. The fauna consist of gazelles, wild boar, and reptiles.

3.3 The Argan Biosphere Reserve

This reserve includes all protected areas described above. It was created in 1998 and is designed around an endemic tree species of Morocco that is the *Argania spinosa* [5, 6].

With 830,000 ha and approximately 20 million trees, the Arganeraie constitutes the last bulwark face to the advancement of the Sahara desert. It constitutes an ecosystem singular by its dimensions ecogeographic and socioeconomic [7]. It occupies the Atlantic coastline from the north of Essaouira to the south of Tiznit, on a continental depth reaching hundred kilometers, and on altitudes up to 1,500 m [8]. The largest stands of argan forest cover the southern slopes of the High Atlas Mountains and northern reaches of the Anti-Atlas foothills, that is to say a large part of the basin of Souss-Massa.

The ARB covers both the plains and plateaux (Souss, Massa, and Tiznit) and surrounding mountains (western High Atlas to the north and western Anti-Atlas foothills in the south), at altitudes up to a maximum of 2,000 m.

The creation of the ARB is justified by the fact that the forest of argan provides multiple uses for the population (argan oil, ecotourism, and products of terroir) likely to contribute effectively to the socioeconomic development of the region of the South West of Morocco.

The mammals that may be encountered in this reserve are:

– The species well represented are *Ammotragus lervia*, *Gazella cuvieri*, and *Gazella dorcas*.
– The species moderately represented are genus *Lepus capensis*, *Hystrix cristata*, *Canis aureus*, *Vulpes rueppellii*, *Felis silvestris*, *Genetta genetta*, *Herpestes ichneumon*, and *Lutra lutra*.
– The species minimally represented are *Leptailurus serval*, *Mustela vulgaris*, *Acinonyx jubatus*, *Felis margarita*, *Caracal caracal*, *Ictonyx libyca*, *Mellivora capensis*, and *Gazella dama*.

The flora is very diverse and rich in endemic and rare species [9–12]. In the coastal part grows [7] crassulescents elements and often leafless (*Euphorbia officinarum* ssp. *echinus*, *Euphorbia obtusifolia* ssp. *regis-jubae*, *Euphorbia beaumierana*, *Warionia saharae*, *Senecio anteuphorbium*, *Caralluma burchardii* var. *maura*, *Caralluma commutata*, *Aeonium arboreum*, etc.) and endemic plants (*Asparagus pastorianus*, *Helianthemum canariense*, *Bupleurum canescens*, *Artemisia canariensis*, *Sonchus pinnatifidus*, *Thymus broussonetii* var. *hannoni*, etc.)

Many endemic characterize the region as: *Periploca M. laevigata* subsp. *angustifolia*, *Genista ferox* subsp. *Sutherlandia microphylla*, *Bupleurum dumosum*, *Hesperolaburnum platycarpum*, *Lavandula maroccana*, *Satureja macrosiphon*, *Sideritis cossoniana*, *Thymus leptobotrys*, *Chamaecytisus albidus*, *Satureja arganietorum*, etc.

The species of tropical strain among the most rare of the North African flora are: *Chloris gayana*, *Kalanchoe faustii*, *Commelina rupicola*, *Leptochloa ginae*, *Enteropogon rupestris*, *Heteropogon contortus*, and *Dichanthium ischaemum*.

Very locally, it is found that the argan cohabited with populations of lone rider (*Dracaena draco* subsp. *ajgal*) at the level of the Jbel Emzi (at the Anzi SBEI).

Very locally, we find that the argan tree cohabits with populations of dragon tree (*Dracaena draco* ssp. *ajgal*) at the Jebel Emzi in the Anzi SIBE [13].

The argan tree *Euphorbia echinus* is the best represented Training (borders Kerdous plateaus, massive Lakhsass, and Ifni). It is in the mountain of Ifni that training is the most original with the presence of *Euphorbia* [14].

The vegetation types also contains many elements halophiles (saline soils), often endemic (*Suaeda ifniensis*, *Salsola longifolia*, *Traganum moquinii*, *Asparagus pastorianus*, *Artemisia reptans*, etc.) and the cliffs are rare species (*Hibiscus micranthus*, for example).

The vegetation types of cedar (*Tetraclinis articulata*) and *Euphorbia echinus* are presented in Idaou Tanae and Bou Izakarn.

Some plants in this pre-Saharan region are toxic including the Thistle glue (*Atractylis gummijëra*), the Harmel (*Peganum harmala*), the apple of Sodom (*Calotropis procera*), the desert melon (*Citrullus colocynthis*), etc.

The slopes of the Souss-Massa basin are characterized by several spontaneous aromatic and medicinal plants [15] such as rosemary (*Rosmarinus officinalis*), sagebrush (*Artemisia tridentata*), thyme (*Thymus vulgaris*), wild chamomile, carob (*Jacaranda procera*), oregano (*Origanum vulgare*), mastic (*Pistacia lentiscus*), lavender (*Lavandula dentata*), myrtle (*Myrica cerifera*), etc. (Fig. 3).

4 Ecotourism and Biodiversity Conservation

4.1 Ecotourism Concepts

Since the creation of alternative forms of tourism, among which ecotourism, it became obvious that mass tourism has been perceived in a negative way. One of the main reasons is that it generates a significant number of negative impacts especially at the level of natural protected areas. Therefore, ecotourism was created largely because of the growing dissatisfaction toward mass tourism, the proliferation of ideas concerning the conservation of biodiversity, and the increasing demand of tourists wanting to visit protected areas [16].

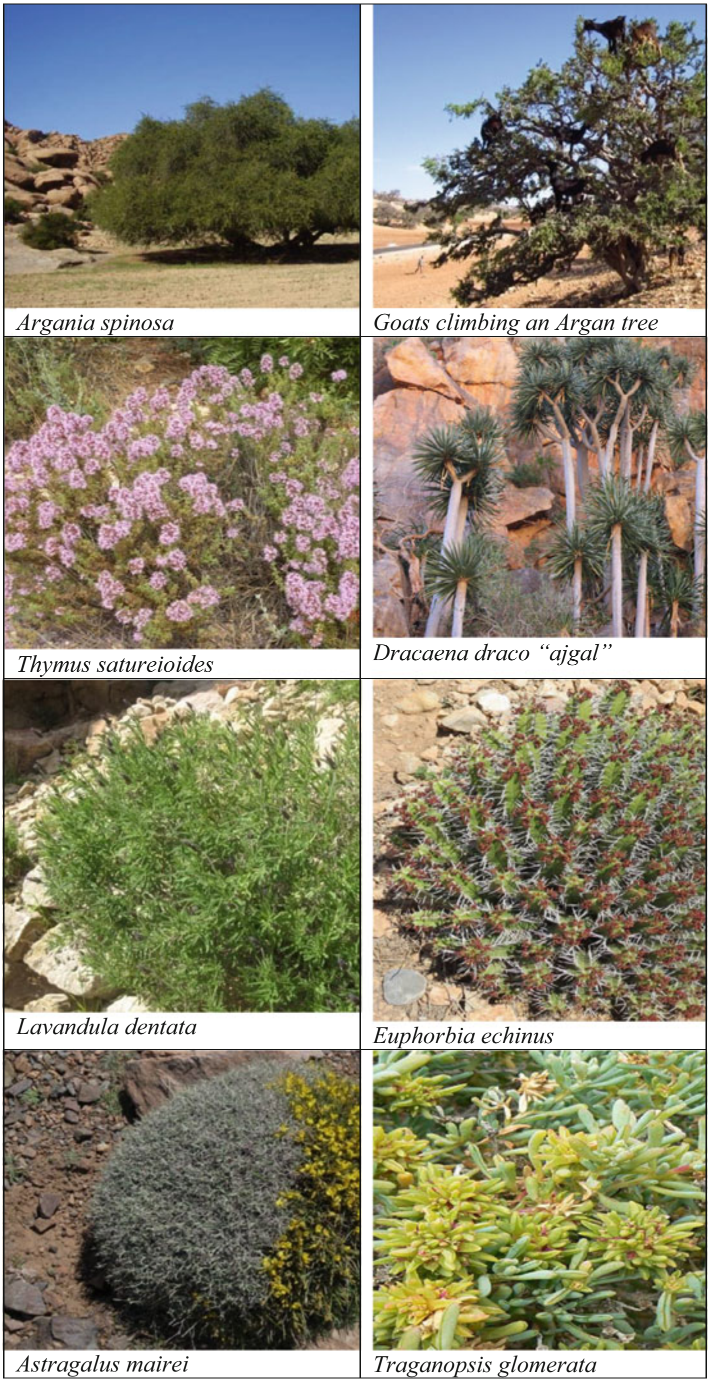

Fig. 3 Examples of flora of the Souss-Massa great catchment marked by a large variety of species

Ecotourism is often associated with the designations of "responsible" or "sustainable" tourism and linked with "conservation" and "low impact." Tourism industry frequently links it with nature tourism or adventure [17]. However, with the prefix "eco" standing for ecology there is a special connection between ecotourism and natural unaltered environments [18]. Currently, there is a consensus to say that ecotourism is part of a broader category, represented by nature tourism [19].

There is still no standard definition of ecotourism to which reference can be made [18].

According to Blamey [16], ecotourism activities should therefore be conducted in natural environment, should contribute to cultural and environmental education toward tourists and local communities, support the conservation of the environment, improve the well-being of local communities through economic benefits in a sustainable development perspective, and should operate on a small scale in order to strengthen the empowerment and participation of local communities.

It has been shown that ecotourism preserves threatened biodiversity and enhances local economies in remote regions [20].

In the ARB, ecotourism should promote the creation of new jobs in rural areas and assist the development of rural infrastructure, which will contribute to the economic development of these regions and reduce the rural exodus [21, 22].

Often, the local populations do not receive much benefits from tourism because of the leakages as the profit remains in the tourists' countries of origin or in the hands of national urban entrepreneurs. In the great Souss-Massa watershed, tourism benefits are distributed unevenly and are concentrated in the two crowded, Agadir and Taroudant.

4.2 Biodiversity Conservation

Biodiversity and ecosystem services are both important management and conservation targets.

On the Earth, the percentage of the land area under some form of legal protection has risen sharply from <4% in 1985 to nearly 15.4% by 2014 [23].

While protected areas can protect vegetation and minimize land-use pressures after establishment [24], coverage is still inadequate because many endemic and threatened species are found entirely outside the global protected-area network [25]. Furthermore, many protected areas – especially in the tropics – are failing to fully protect their biodiversity [26].

The biological heritage of the catchment area of Souss-Massa is remarkable because of its great diversity, including many rare and endemic species. This important reserve of biodiversity can be used for ecotourism while preserving it.

The establishment of regulated spaces (natural reserves, national parks, and BEIS) faces economic land exploitation in an ever increasing way. The establishment of protected areas (flora and fauna) allows the conservation of certain threatened animal species, provides the foundation for the development of ecotourism, and also contributes to lower rural flight??.

The concept of protected areas is useful in case of rapid loss of wildlife habitat, but it does nothing to resolve the social and economic dimensions of fundamental threats to biodiversity [27]. One of the challenges encountered by conservation specialists is the implantation of strategies to protect the natural environments in the regions dominated by poverty and characterized by a strong biological richness [28].

Ecotourism can have negative consequences for the areas too, and in particular on the environment and the socioeconomic situation. The arrival of tourists without any structure or management can play a part in the degradation of the environment and ecosystems [29].

Landfill sites are found in the vicinity of agglomerations, and especially in the edges of the roads leading to the protected areas. Tourism is also with waste management even if the population itself contributes to increase the quantity of waste and plastic bags. To reduce or even eliminate the waste in these protected areas, the systematic collection of waste and the development of landfills and regulatory infrastructure for waste incineration by rural towns must be organized. In addition, it is necessary to organize awareness campaigns for local people, with guides and tourists for managing more eco-friendly waste.

One of the most positive aspects of ecotourism may be that it is considered, even by the local and indigenous communities, as a potential strategy for biodiversity and natural environment conservation [30].

Ecotourism contributes to strengthen the conservation of a protected area by generating revenues. The income is then reinvested in the strengthening of the conservation strategy of the region [17]. These economic benefits have also aim to prevent the tensions which have often taken place in the past and which have had the effect of disrupting the experience of tourists, and the perception of tourism by local communities. However, the improvement of the well-being of communities is closely linked with the quality of the ecotourism experience offered to tourists.

The teaching materials on the protected areas should be implemented in the Souss-Massa great catchment such as guides, brochures, interpretation boards, exhibitions, museums, websites, and digital guides.

4.3 The Ecotourism Territories

In order to ensure an ecotourism development integrated in the studied region, it is necessary to put in place a regional action plan that integrates all the stakeholders on a multisectoral logic. This approach will encourage local parties to act in consultation and in solidarity in order to enhance the whole of local tourism resources. This vision of integration is even more at the desired level of ecotourism.

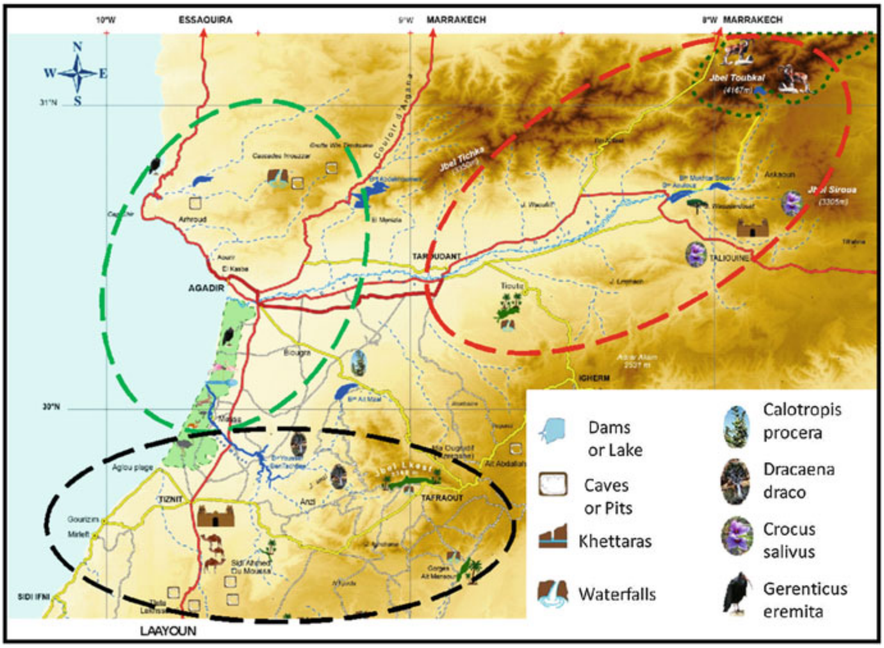

Fig. 4 The three major ecoterritories that were selected in the studied area according to their richness in terms of biodiversity and as a function of their sociocultural heritage. The *Red ellipse* shows the ecoterritory of Taroudant region, the *black ellipse* marks the ecoterritory of Tiznit region, and the *green ellipse* indicates the ecoterritory of Agadir region

It will involve the whole key areas as well as socioeconomic and cultural activities [31].

In this perspective, three major territories with ecotourism priority were selected according to their richness in terms of biodiversity and as a function of their intangible sociocultural heritage. The presence of a real dynamic of local actors is also a determining factor in the choice of the territory. These priority ecotourism areas are the following (Fig. 4):

– Taroudant region: Tafingoult BEIS, TONP, Tifnout and Talkjount valleys, Khettaras, dams, sources, and Ifni Lake;
– Tiznit region: Jbel Lkest BEIS and dispositions at Anzi, springs, caves, almond trees and dragonia, granitic chaos;
– Agadir region: Cape Ghir BEIS, Massa Natural Park, win Timdouine cave, Imouzzer waterfalls, aromatic and medicinal plants.

For these reasons, ecotourism plays its full role of conservation in these economically poor areas. It must provide the population with significant revenues to support the local and regional economies, and restrict other forms of nonresponsible use of wild territories.

In order to promote rural tourism, the Department has also adopted the concept of “Country of Tourism” or “PAT.” This concept identifies a specific territory to make it become a tourism destination thanks to a comprehensive approach based on the tourist’s experience. He/she will discover the rural areas of the country by meeting the population and observing their way of life directly in contrast to normal channels.

This concept brings together regions sharing certain characteristics under one designation to offer them as a tourist destination on its own. In the studied areas, there are Ida Outanane, Chtouka Ait Baha, Taroudant, and Tiznit that were chosen for this concept.

5 Conclusion

The main objective of this contribution was to examine, through the relations between local communities, tourism, and protected areas, more specifically the relationship between protected areas and ecotourism in the catchment of the Souss-Massa wadi.

The native people seem to agree with the creation of protected areas and their conservation. However, the revenues generated by ecotourism toward the natives are not significant.

The impacts of tourism on the environment including on biodiversity are nowadays an unquestionable reality in the protected areas of the Souss-Massa great watershed. This impact may be physical (change in the soil, trails, plastic and other waste, water pollution, etc.) or biological (change in the vegetation, risk of invasive plant species development, flora and wildlife disturbance).

These protected natural areas become even more attractive and therefore subject to even more anthropogenic pressures. In fact, there is a growing demand of preserved mountainous areas, wild landscapes, and observation of diversified wildlife. In addition, the attractivity is emphasized by the easy access to these areas by false guides or even professional guides that have not followed any training about such specific areas.

The protection of nature is fundamental to the success of the tourism sector, as well as for the scientific knowledge of certain ecosystems.

Several shortcomings and deficiencies in terms of communication and signage (educational pathways, explanatory signs, topoguides, brochures, exhibitions, museums, internet sites, etc.) are observed in the protected areas. It is used therefore to improve the information of such sites management, make sure of their understanding by the general public and the promotion of collaboration between the mountain professionals (guides, tourist offices, and hosts) and academics.

In addition, the limited budgets of the protected areas slow down this expansion, thus contributing to the deterioration of the local environment and decreasing the quality of the natural experience offered to tourists.

The main recommendations are:

- To achieve media and teaching activities for tourists and general public in protected areas;
- To install protected areas signs, interpretation boards, and appropriate marking of pathways.
- To implement environmental awareness and educational activities on a regular basis among the native people and the tour guides.
- To establish a reform in the income distribution structure, aimed at encouraging neighboring communities to maintain the protected areas.

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Experiences, Success Stories, and Lessons Learnt from the Implementation of the Water Law Framework Directive in the Souss-Massa River Basin

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Abstract By its transitional location between the Mediterranean and Saharan environment and its opening on the Atlantic, the Souss basin represents a specific hydraulic space across Morocco and the Maghreb countries. Its limited water resources formed through the phases of the long history of Morocco a real support to help the building of the foundations of the Moroccan hydraulic civilization. The authors of this chapter of varied specialties and belonging to different institutions relevant to water present from their experiences a synthesis of good practice in water planning and management in Souss basin.

The surveyed subjects concern the contributions of the new water law and the need for its renewal for a better adaptation to space and society developments, the implementation and evaluation of the operation of the hydraulic basin Agency, the ingrained hydraulic prospective in the basin level, and its transition from a sector planning to integrated planning.

Other current issues are discussed. It concerns participatory management of water that presents a promising approach at the local and national levels, the advanced state of resources development which has just reached the desalination of seawater for population supply and irrigation, and attempts of widespread access

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to water between state intervention and local initiative. Also, the aspects of the conservation of natural sites and actions to reduce water excess as the risk of flooding were analyzed.

At the end of this chapter, the international dimension of planning, development, and management of water is discussed. Souss basin has benefited from many water projects in the framework of cooperation between Morocco and foreign partners.

Keywords Access to water, Fight against water excess, Hydraulic foresight, The basin agency, Water development and management, Water law

Contents

1 Introduction

In theory, with its latitudinal extension around the parallel 30°Nord, Souss-Massa basin should be a part of vast hyperdry areas situated further east. However, the local orographic configuration, taking the shape of a gutter surrounded by impressive mountains and widely opened on the Atlantic Ocean, succeeds in snatching this basin of the suffocating aridity of Great African Sahara.

In reality, this situation gives to Souss-Massa basin a character of a transient hydraulic space between the Mediterranean environment and the Saharan environment. On the contrary to the rest of the Maghreb territory, this transition takes place in a progressive way and it is further to the south. Thus, this basin with subterranean and superficial hydric potentialities relatively better in volume and in quality has successfully established itself as a specific link in the Moroccan hydraulic landscape.

Endowed with a rich capital of know-how in water resources development and management in a semiarid to arid environment, Souss-Massa basin represents a "real laboratory" for the various actors, the researchers, and the observers of water sector.

Today, the revisit of major facts of the recent history of the hydraulic domain transformations and their appreciations by researchers and managers of different profiles is considered as an important act mattering in the way of capitalization and generalizations of the achievements of water sector at the level of this basin.

In this chapter, we will be accentuating the experiences, the best practice, and the lessons to be learned from the functioning of the development system and water resources management in Souss-Massa basin. The Moroccan water law 10-95 and the aspects of its application will serve as guideline in this review.

2 Contributions of the Water Law 10-95: Principles, Objectives, and Tools

The legal system governing the exploitation of water resources in Morocco is very old; it draws its foundations of capitalized know-how through the long history of the Moroccan hydraulic civilization, and also the adaptations with the recent transformations of the national economy.

The law 10-95 governing the hydraulic domain is elaborated to create a framework to facilitate the decision-making on water resource management in the whole of the national territory. Before 1995, the numerous participants found enormous difficulties to arrive at a harmonious application of the attributions spread through a range of scattered texts.

The analysis of "the water law 10-95" text shows that this one is an innovative legal support based on principles, objectives, and tools adapted to the new realities of the country [1].

2.1 The Principles

The principles adopted in the elaboration of the water law 10-95 are numerous; they are selected to form a framework favoring the repositioning of the national water policy and the support of the process of the sustainable development of the country in its economic, social, and environmental dimensions.

The public ownership of water is considered as a key principle confirmed by this law, while giving the possibility of the recognition of the rights of possession acquired and managed within the framework of the common law.

Similarly, among the adopted principles, water has enjoyed a status of property having an economic and social value. Any use has a cost which must be compensated according to the "withdrawers–payers" principle, and any damage touching its quality must be repaired according to the "polluter–payer" principle.

Access to water for all is put forward. To improve the equality of water accessibility opportunities of all the users in space and time, and also to guarantee the hydraulic security of the whole national territory, the law recommends the adoption of the interbasin solidarity principles between social categories.

Always in the same spirit to ensure a mobilization and an effective management of the hydric potential and at a lower cost, the law adopts other principles as: the quantitative and qualitative preservation and the protection of the available resources, the choice of the participative work steps between the actors, the recourse to the partnership for the realization of projects of development and distribution of water resources, and the adoption of a management system directed to the management of the demand more than water supply.

2.2 The Objectives

By explaining the motives for its elaboration, the law 10-95 text defines in its introduction a number of objectives to be achieved through the application of the contents of its articles. The main stated objectives are:

- The optimal mobilization and the rational management of the various resources by taking into account the priorities. This is often expressed by the migration of the supply management system towards the demand management system;
- The protection and the complete preservation of the public hydraulic domain. The law presents a legal basis for the regulations of water resources exploitation and various activities that could affect the quality of these resources;
- The search for a better valuation of water resources and for a profitability of the committed investments in the hydraulic development, while protecting the economic and the social interests of the various participants.

2.3 The Tools

Any legal text is judged as vain when it is not supported by adequate means and tools to impose its application. Indeed for the case of the water law 10-95, the legislator defines relevant tools for the realization of its various attributions.

The hydraulic basin is considered as the adequate geographical unit to establish a decentralized water resources management. This management is entrusted to a very precise administrative entity which is the Hydraulic Basin Agency. Just after the adoption of the law, regulatory authorities passed to the restructuring of the national hydrographic landscape in nine agencies of the hydraulic basin, among them the Agency of Souss-Massa and Drâa Hydraulic Basin (ABH-SMD). Souss-Massa basin is a part of the action area of this agency.

Worried about the importance of the prospective in the achievement of its objectives, the law in question drew a clear framework for a coherent and flexible planning of water resources. In addition to the Water National Plan stopping the strategy and the global priorities on a national level, the law stipulates that each basin, or group of basins, should have *a Master plan of the Integrated Development of Water resources*.

The water law 10-95 presents, in its last chapter, the water Police and the penalties to be applied in case of illicit act. The Criminal Investigation Department officers and the agents commissioned by the agency of the concerned basin are accredited charge offenses noticed on the ground. The facts mentioned in the reports of the Water Police are valid until confirmation of the opposite.

It is obvious that the use of the various tools cannot be reliable without the use of innovative working steps and in breaking with the downward and centralized sectorial approaches. The law 10-95 is clearly opened on the adoption of the principles of the consultation between the actors participating in water domain. Also the recourse to partnership under its various forms is encouraged.

Finally, by this new law the institutional framework is well strengthened. Adopted as a close member in the national hydraulic board, the basin Agency is put in the center of the water resources management system. It is situated downstream to the Superior Council for Water and Climate and the interministerial Water Commission on the one hand, and upstream to Provincial commissions or Prefectural of Water on the other hand.

After about 20 years of the promulgation of the water law 10-95, it would be relevant to focus on the experiences, the good practices, and the lessons to be learned from the application of its attributions on the scale of Souss-Massa basin, a specific component in the Moroccan hydraulic space.

3 Agency of Souss-Massa and Drâa Hydraulic Basin

After editing the text of the law 10-95 and after the trial phase by a progressive implementation of basin agencies, the creation of the ABH-SMD was decreed in 2000 before its effective start on 2002, then since 2009 it has been decided to widen its action area to cover the vast basin of Drâa besides the basin of Guelmim [2].

3.1 The Action Area

The ABH-SMD has been substituted for the former Regional Directorate of the Hydraulics Souss-Massa-Drâa to take charge of the application of the new prerogatives of the law 10-95, mainly the management and the protection of the capital water and of the public hydraulic domain.

With an action area of 130,000 km^2, that is, approximately 1/5 of the surface of the national territory, the ABH-SMD is considered as one of the agencies in the largest working range. In this vastness, Souss-Massa basin covers only 21%, but it occupies a vital position inside the entire zone. It is considered as a "golden triangle" in the North of the Moroccan Sahara (Fig. 1).

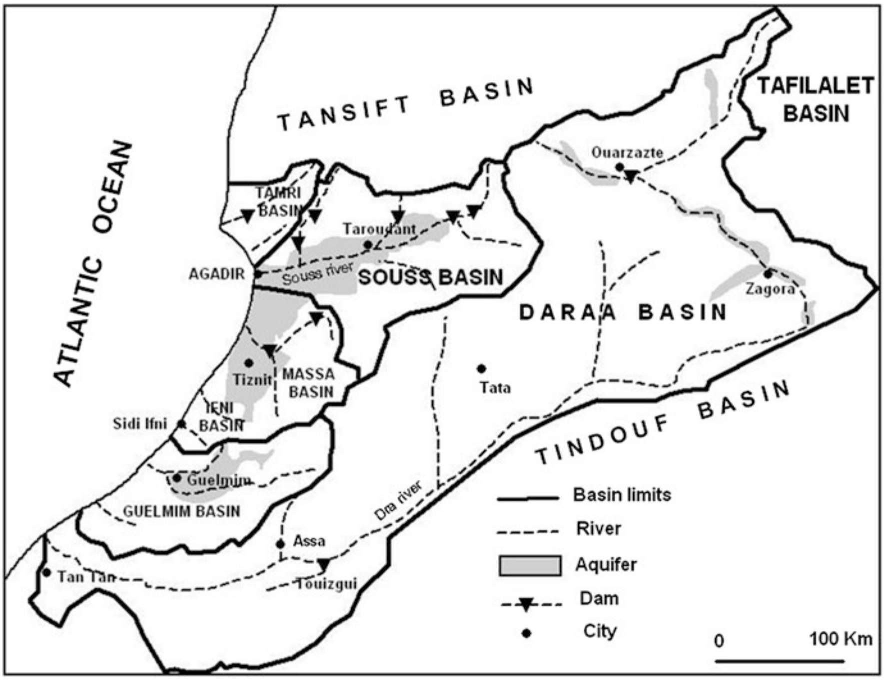

Fig. 1 The action area of the Hydraulic Basin Agency of Souss-Massa-Draa (ABH-SMD)

Table 1 The Souss-Massa basin in the action area of ABH-SMD

Basins	Water resources (mm^3)		Dam		Irrigated area (ha)
	Surface water	Underground water	Number	Capacity (mm^3)	
Souss-Massa	668	425	8	730	148,640
Drâa	762	192	1	728	55,449
Guélmim	57	49	–	–	27,160
Total	1,487	666	9	1,458	231,249

Source: ABH-SMD

Souss-Massa basin is home to 2/3 of the inhabitants of the action area of the agency, with an urbanization rate of 51%. Situated around the mouth of Wadi Souss, the conurbation of Greater Agadir exceeds the threshold of one million inhabitants and is among the five big cities of the country.

On the economic plan before being a very dynamic regional pole, Souss-Massa basin is considered as a national economic place with international scale. Besides being the first export zone of citrus fruits, early vegetables, and seafood, Souss-Massa is a first-rate tourist destination.

Such an economic position would not be possible without an advanced mobilization of the hydraulic potential in place. The basin has 1 billion m^3 of renewable water resources, which means half of the total volume of the ABH-SMD zone. Surface waters represent 61% of the water resources which mobilize 8 dams with a global capacity of restraint of 765 million m^3 (Table 1).

Generally, dams have constituted a strategic alternative to support the irrigation of the perimeters in crisis because of the overexploitation of the subterranean waters potential, for the creation of new agricultural surfaces, and for the supply of urban tissue in potable and industrial water.

3.2 *Missions*

Since its establishment as a territorial public institution endowed with the legal personality and financial autonomy, the ABH-SMD is committed in the execution of its attributions by gathering all the actors of the water management system at the level of its action area. As stipulated by law, the agency has performed since its creation missions touching diverse aspects of its exercise.

Saving the hydric capital and the hydraulic public domain of any offence or trampling is a major mission in the activity of the agency. It keeps an inventory of water rights recognized according to current provisions of law 10-95, as well as a register of concessions and authorizations which it grants for water withdrawal or for the use of the hydraulic public domain.

For a good grasp of the local hydrosystem reality, the agency ensures the quantitative and qualitative follow-up of water resources. The agency's services ensure the realization of piezometric measures and the gauging of the Wadis' flows in a continuous way, as well as the hydrogeological, hydrological, management and planning studies of water.

By adopting the prospective tool on a local level, the agency assures the mission of the elaboration of an integrated development planning of basin water resources covering its action area. Also, it shall ensure the implementation of the recommendations adopted by the aforementioned planning in a consultation framework.

The prediction of the hydraulic risks and the implementation of the adequate measures for their management are considered among the key prescriptions of the agency. In this connection, it is requested to ensure the users water supply in periods of shortage, as well as to anticipate and set up the infrastructures of preservation of sites exposed to flood risks in partnership with the concerned actors.

In terms of the protection and preservation of water resources against pollution, and the restoration of their quality, the legislator grants to the agency the mission to take the necessary measures in narrow coordination with the authority in charge of the environment.

The agency is also in charge of supporting the actions of pollution prevention, the development or the use of the hydraulic public domain. This support can take forms of financial aid, service offer, or technical assistance.

3.3 Organization

In keeping with the spirit of cooperation between the actors for basins management, the agency is managed according to the model of board of directors that is chaired by the governmental authority in charge of water resources.

The size of the ABH-SMD council is considered among the biggest ones, that is, 47 members, while the current law defines 48 members as maximal size. This fact demonstrates that besides the importance of the expanse, the action area is known by a big diversity of actors and by a big level of organization.

The members of the agency council represent public and private sectors and practice fully their rights and duties. Three big categories of members are to be distinguished: the representatives of local authorities, chambers of trade and water users of 20 members, the representatives of public institutions involved in the cycle of the water of 12 members, and the representatives of the central Government of 15 members (Fig. 2).

The direct management of the agency affairs is entrusted to a director after examination of his or her candidacy according to the legislation in force. He or she holds the powers and the necessary attributions for the execution of the decisions of the board of directors and the board committees in case of need. It comes also to the director to issue the authorizations of water withdrawal and the concessions of using the hydraulic public domain.

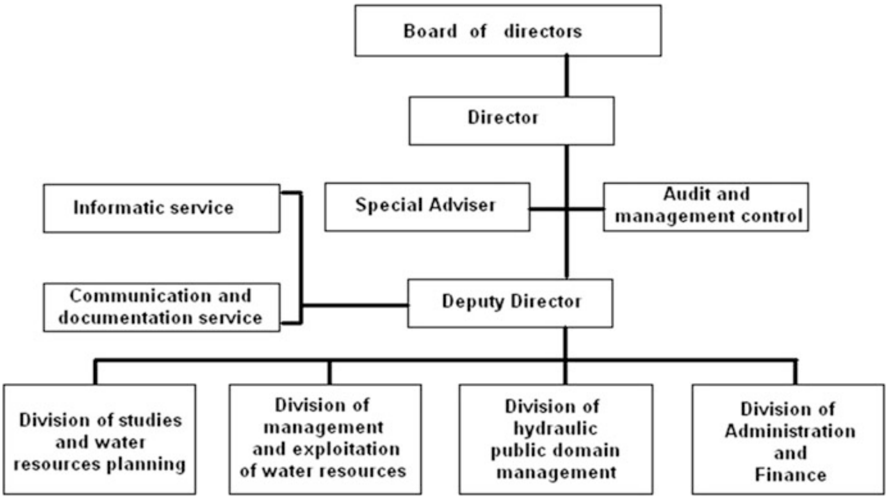

Fig. 2 Organizational chart of the Agency Souss-Massa-Draa basin

In carrying out these activities, the director is assisted by a staff of executives and collaborators distributed according to an adapted organization chart. The agency is structured in several divisions with different tasks: studies and planning, management and exploitation of water resources, amenities and quality of waters, general matters relating to finance, hydraulic public domain management, administration, and finances. The follow-up of the agency activities is coordinated by a General Secretary and an audit and management control entity.

To be closer to the actors, the agency is represented by two delegations in Ouarzazate and Guélmim in charge of various missions assigned to ABH-SMD at the level of Drâa and Guélmim basins. A water service which reports to the Ministry in Charge of Water is implemented at the level of the various provinces of the action area.

3.4 Budget

Under the water law 10-95, to honor its missions the basin agency has to settle diverse responsibilities. Besides a functioning and investment budget, it is called to have the appropriate solvency for the advances covering the asked loans and borrowings, and also the remaining expenses related to its activities.

To ensure a balanced financial balance, the same law provides various posts of resources in the agency budget. The receipts which should have an important part in the composition of this budget are represented by the product costs of water resources exploitations and those of the use of the hydraulic public domain.

Costs in question concern several sectors: the water withdrawal intended for irrigation and for potable and industrial water supply, the use of the hydraulic public place for the extraction of construction materials, the occupation of the same space for diverse uses, the studies' expenses of authorization demands files of the concessions and administrative certificates, etc.

After an exercise of 15 years, the agency still benefits from the financial support of the State on the basis of an action plan. It is the case of all the basin agencies of the country.

4 Hydraulic Prospective, a Well Deep-Rooted Choice

The modern hydraulic prospective has been introduced into Souss-Massa basin only since the 1970s of the last century. The State was forced to intervene to protect the citrus and the traditional perimeters suffering from the reduction in Souss groundwater [3].

In their interventions, the public authorities adopted a hydraulic prospective at the same time for the protection of the existing irrigated heritage and for the exploitation of the hydric potential in the extension of the economic basis of the zone.

The elaborated first plans had a sectoral character. They affected domains in an isolated way or separated geographical entities inside the basin. The integrated hydraulic planning was able to be established only with the appearance of the law 10-95; this one imposed precisely the elaboration of the Master plan of the Integrated Development of Water resources for each basin on a national scale.

4.1 Sectoral Hydraulic Planning Phase

To develop the irrigated agriculture in Souss-Massa, the government has opted for a double objectives action: the protection of modern and traditional perimeters thirsty by the continuation of the reduction in the groundwater under the influence of the overpumping on one hand and the extension of irrigated surfaces by the creation of new agricultural perimeters on the other hand.

At Souss plain level, the Hydro-agricultural Development plan of Souss Valley, developed with the support of the FAO, has established an intervention strategy based on the following main objectives: the protection of Ouled Teïma citrus agriculture perimeter by the mobilization and the transfer of surface waters; the rehabilitation of the traditional irrigated perimeters by equipping them with deep drillings and with water feeder canals; the creation of new irrigated perimeters from subterranean waters within the agrarian reform framework; the stop of the development of new irrigated surfaces, and the ban on digging of new water sources in areas suffering strong piezometric reductions.

A second plan is developed at the level of Massa basin; this time the main objective is to endow the zone of a new modern irrigated perimeter. It is Chtouka-Massa perimeter using the technique for high added value agriculture intended mainly for export. The realization of this perimeter has requested for the construction of the large dam Youssef Ibn Tachfin, as well as the realization of a network of irrigation under pressure by sprinkler [4].

Gradually, the development of the urban phenomenon, mainly Greater Agadir which has been developed in a spectacular way around Wadi Souss mouth, has required the passage to a planning for the supply of the conurbation in potable and industrial water at first, then a planning of the sewage treatment in the second phase.

This sectoral planning has succeeded certainly in covering the water requirements of the functional irrigated perimeters and the urban tissues in continuous extension, but it did not succeed to limit the overexploitation of the capital water worsened by the growing frequency of droughts, probably, in reason of climate change affecting the planetary system.

4.2 The Integrated Hydraulic Planning Era

The progress of the implementation of both plans of hydroagricultural development allowed developing the agricultural activity, but it did not succeed to restore the balance of the local hydric balance. Practically, the Souss water table continues to undergo a relentlessly destocking of 250 mm^3/year.

Consolidated by the development of the concept of "water integrated management" in the 1980s, and to face this alarming situation, a Master plan of the Integrated Development of Water resources of Souss and Massa Basins (PDAIRE) was elaborated in 1988. It constituted the bridge towards a federative planning of water sectors users, within the framework of a geographical unit of management grouping the basins of Souss and Massa and the two small basins Tamraght and Aït Amer situated further north [5].

The same plan was taken back and approved in June, 2001 by the Upper Council of Water and Climate to constitute the Master plan of the Integrated Development of Water resources of the Hydraulic Basin of Souss-Massa (PDAIRE), as stipulated by the water law 10-95.

From the end of 2006, the agency proceeded to the launch of a study of updating the PDAIRE with the objective to spread the area of the plan to cover the small basins of Anti-Atlas (provinces of Tiznit and Ifni) situated further south, and to remodel the hydraulic development program in the light of the arisen developments.

The PDAIRE updation only confirmed the worrisome situation of water resources exploitation state at the level of Souss-Massa basin. Besides the natural character constraints that represent the modesty and the variability of water contributions, subterranean waters undergo an advanced qualitative and quantitative exhaustion. The continuation of the supply development way by only mobilizing surface waters could merely have risky consequences; the change of course by the integration of demand participative management principles is imperative.

Taking advantage of its status "of space" of consultation, coordination, and even empowerment of all the actors and users of water, the ABH-SMD knew how to quickly overtake the purely physical interventions to contract out initiatives of participative management with precise commitments. The water table contract and the outline agreement are so two innovative initiatives whose echoes ring at the level of the other basins of the country [5].

5 The Participative Management of Water, a Promising Approach

In its action of putting in conformity of the hydraulic space exploitation with the new water law provisions, and the realization of the protection strategy of the hydric potential balance, the Regional council of Souss-Massa and Drâa has launched a participative process for the integration and the empowerment of the various actors. The various attempts ended in several realizations, of which the "water table contract" and the "Outline agreement" are the most striking [6].

5.1 The Water Table Contract, a Pledge to Act Together

Upon the recommendation of Taroudant ABH-SMD Administrative Council of 2005 and of the Agriculture Committee of the Council of Souss-Massa and Drâa Region met in Agadir in 2006, the ABH-SM created "the water table Contract" committee to examine the means of the realization of the subterranean water resources preservation strategy in a short-term.

The planed objectives for the works of the water table Contract committee concern the information and raising awareness of the various participants in water management, the putting in conformity of water sources with the new law provisions, and the control of the irrigated surfaces extensions: ban unauthorized digging of water sources, follow-up and control the hydraulic public domain, identification of the indebted, and the cost recovery.

At the same time as the works of the water table Contract committee, which lasted more than 1 year, the ABH-SMD launched a study on the implication of the users in the participative management of subterranean waters. The accomplished actions in this context have been ended by the adoption of the contract by the various participants.

5.2 The Outline Agreement

The results of the first attempts of the ABH-SMD, to raise awareness to farmers of the current regulations through a water caravan which concerned the most far regions, have demonstrated that the application of the new measures overtakes by far the simple granting of the authorizations of water withdrawal and that this application cannot come true without a joint implication of water users.

Supported by the regional council, ABH-SMD chose to integrate the regularization of water sources subject into the global framework of the problematic sustainable management of water resources in the basin. After long negotiations, the representatives of water users syndicates, the local elected representatives, the administrations which operate in the field of water, and the ministries particularly that of finance, eventually approved an "Outline agreement" for the protection and development of water resources in Souss-Massa basin.

In search of restoring the lost balance between water withdrawals and renewal capacities of the local hydric potential, the "Outline agreement" focused on four main axes.

The economy and the valorization of water of irrigation are put forward by the actors. We more exactly aim: the migration towards the localized techniques of irrigation, the choice of evaluative cultures of water, the control by water police, and a characterization of agricultural exploitations.

A second axis is reserved for the development and the mobilization of subterranean waters by control support, the fight against the quality degradation, the strengthening of the artificial refill of water table, and the development of deepwater tables prospection. The choice to continue on the mobilization of surface waters is supported in this agreement by the development of the small and average dams sites. The scientific research is taken under consideration in the agreement with the objective to have adapted information to better rationalize water of irrigation.

For financing of the programmed actions within the agreement framework, it was planned, besides the State subsidy, to mobilize the budgetary resources generated by water withdrawal cost and the use of the hydraulic public domain. Also, to protect water resources against wasting, it was planned to increase the cost in case of overtaking of the prescribed thresholds of irrigation. But the recovering, that has begun since 2008, remains partial; fees are generally collected in the occasion of authorization requests.

Today, 20 years after the promulgation of the water code 10-95, the ABH-SMD, following the example of the other agencies, has difficulties in recovering all of fees. It seems that the same phenomenon of the refusal to pay dams water by farmers in the 1970s, used to "the water of the sky," is found in the payment of fees on the withdrawals from subterranean waters. We do not need to remind that these withdrawals require investments and costly expenses for the digging and the deepening of wells and drillings, and especially for pumping.

The "water table Contract" and the "Outline agreement" certainly constitute a real innovation since the appearance of water law 10-95, but the effective application of their contents cannot be made without the strengthening of the water resources management powers in on a local and regional scale.

5.3 The Associative Movement

As a matter of fact, water resources in Morocco were always managed in a community framework according to precise customary arrangements; in this framework, Souss-Massa basin does not make an exception. However, the arisen changes in the hydraulic system did not give important role to the collective organs in the management of the new agricultural perimeters.

However, in front of the shortage of water resources worsened by a structural overexploitation and drought situation, the implication of the users in a collective framework became an inevitable alternative to satisfy their water requirements. In this sense, two cases of associative water management in rural areas are worth to be presented: the associations of agricultural water users (AUEA) and associations of local development.

The current legal framework allows the farmers organized in AUEA to participate in taking charge of the business of their agricultural perimeters and grants to these associations to be represented to the Board of directors of the Basin Agency.

Taking advantage of this framework, the farmers got organized in numerous AUEA whose big share is active in the "rehabilitated traditional agricultural perimeters." To reduce the expenses of the hydraulic service provided at the level of these perimeters, the associations are taken charge of the management of the pumping stations and the distribution of water of irrigation.

But there are, in the zone, other forms of farmers' associations of more important size: the producers–exporters of citrus fruits and early vegetables get organized within the framework of groupings to represent the sector and defend the interests of their members: Moroccan Association of Producers and the Exporters of Fruits and Vegetables, Association of Producers of Citrus fruits of Morocco, and Association of Producers and Exporters of Truck farming and early vegetables.

Similarly, the local development associations have played a key role in the supplying domestic water to rural populations. In view of the negative impact of successive droughts of the 1980s and the difficulties to generalize water service to rural human groups, local associations, which have known extraordinary expansion in the rural areas of Souss-Massa basin, have widely contributed to filling the gap in Program of the Grouped Water Supply of Rural Populations (PAGER) program developed and implemented by the Department of Hydraulics since 1995 to speed up the pace of the service.

Thus, before that the potable water sector in rural areas was entrusted to the National Potable water office in 2003, almost all the rural localities, under the aegis of local associations, were equipped with independent systems of potable water supply. The average rate of access to the water passed from 14% before the PAGER to 90%. The financing of these initiatives was based on the members' contribution, but the aforesaid associations also benefited from the support of the various programs of the State and from the support of the international cooperation.

6 The Development of Resources, from Groundwater to Seawater Desalination

The examination of the oldest vestiges of human presence in Souss-Massa basin and the existing hydraulic system reveals an increasingly efficient mastering of the mobilization of the available water potential. After a long phase of complementarity between surface water and groundwater to maintain traditional agricultural operating system, the area was drawn into a groundwater overexploitation phase of the water table of Souss valley.

Since then, independent governments have continued to increase efforts to improve the hydraulic system [7–9]. Thus, after a costly transition to the large hydraulic to mobilize surface water at a fairly advanced level, the recourse, today, to the alternative of non-conventional water has become a strategic choice.

6.1 The Traditional Hydraulic System

As everywhere in arid and semiarid environment, the possibilities of mobilization water resources for domestic and human activities use, mainly irrigation, constitute a determining factor in human settlement, and Souss-Massa does not escape this configuration.

The distribution of the human densities corresponds perfectly to the distribution of the appropriate sites to the diversion of the surface water flows by seguia or to the lifting of subterranean waters from wells.

In the case of surface waters, two systems of mobilization distinguish themselves: the semi-perennial diversion said *Seguia feïd* whose waters are channelled for the moistening of the ground allocated to the cultivation of cereals, mainly barley; and the perennial séguia diverting a relatively stable water resource to irrigate agricultural perimeters, the size of which is proportional to the importance of water resources and the human grouping which exploits them.

Major components in this hydraulic system *seguia* are the repeated construction of dikes of diversion in the course of Wadis beds and the digging of canal to direct water until the agricultural plots of land to be irrigated. The development of these two works is done in a community framework and therefore, the mobilized water is distributed according to the contribution of each home in the community works of installation and maintenance of the hydraulic system.

The system of *seguia* is not necessarily attached to a diversion of surface water; it is sometimes developed from natural reappearance of subterranean water or water table seizure by the system of *Khettara*. The sharing of the water between interested parties is made according to water tours of more or less long duration.

Within the framework of this traditional hydraulic system, the resort to subterranean water is essentially fulfilled for the domestic use and for the supplement contributions for irrigation in times of water shortage. The *aghrour* or the well with inclined plane using the strength of animal drive is the most spread technique of water lifting in the area. But considering its low reach – reduced depth and flow – this technique was not able to develop a real agricultural irrigated activity in the region.

In areas that are devoid of rational water potentialities, the human groupings have developed the *Tanoutfi* systems or reservoirs of rain and streaming water collection. Of different sizes and forms, these reservoirs have an individual or community status, and their stocks in water are essentially intended for the domestic use and rarely for the livestock drinking.

After the worsening of the water shortage weighed down by the frequency of the droughts and the overpumping, the realization of the traditional irrigated perimeters rehabilitation suggested within the framework of the Master Plan of the Hydraulic Development of Souss Valley became necessary. This alternative of the irrigation water supply from subterranean waters or partially from waters of the new dams was only intensifying the pressure on the water table. The used cultivations with subsistence character do not give a good valuation of water and the conversion of the localized techniques of irrigation was not planned in this type of agricultural perimeter.

6.2 The Exhaustion of Subterranean Waters

The positive results of the explorations of the development possibilities of a speculative agriculture at the level of Souss plain have activated a fast expansion of irrigation with the arrival, since the 1940s, of European colonists equipped with the thermal motor-pump [10].

Modern irrigated perimeters of high-level organization quickly appeared, and it is about Ouled Teïma, El Guerdane, Taroudant, and Ouled Berhil perimeters. On the eve of the independence in 1952, the new irrigated plantations reached a total surface of more than 2,700 ha with an endowment in groundwater of more than 30 million m^3/year.

The appearance of the water table overexploitation symptoms did not manage to slow down the plantations extensions, even after the independence. The process of retrieval and Moroccanization of the farmlands was only increasing surfaces irrigated from the water table. In 1968, the irrigated surface exceeded 18,000 ha and was raised to 46,000 ha in 1987 with a capacity of equipped pumping of more than 400 million m^3/year and more than 8,500 wells and drillings counted by the Regional office of the Hydraulics at that time. In 2007, the volume of water withdrawals by pumping intended for irrigation is estimated at 600 million m^3 by the last study of updating of the PDAIRE, among which 521 million m^3 are from Souss water table and 78 million m^3 from Chtouka water table [5].

At the same time as this extension of the irrigated surfaces, the free water table of Souss, even if it is renewable, entered a phase of deficit balance of an annual average of more than 200 million m^3/year. This deficit showed itself by a deliberated tendency to the reduction in the piezometric level according to an annual average of more than 2 m at some perimeters level as that of El Guerdane.

Quickly with the development of the early vegetables cultivation, mainly the production of the tomatoes intended for export, the reduction also affected Chtouka water table situated in Massa basin further south.

The deficit situation of subterranean water resources has been complicated with the spectacular extension of the urban fact which competes with the agricultural use of water. The groundwater withdrawals for supplying cities passed from 9 million m^3/year in 1979 to more than 33 million m^3/year in 2007, while the global consumption in potable water during this latter year exceeded 66 million m^3.

The covering of the cities water needs for domestic use and for the urban activities utilizations as industry, tourism, and services obliged the hydraulics planners to equip more and more distant capturing fields. The conurbation of Greater Agadir represents a significant case of the important extension of urban hydraulic radiance.

In this context, Souss-Massa basin entered a phase of shortage putting the whole area in a hydraulic crisis situation where the passage, even expensive, towards the mobilization of surface waters became an inevitable alternative.

The recourse to surface waters contributed certainly to the protection of the citrus agriculture of Ouled Teïma perimeter from Abdelmoumen dam and recently that of El Guerdane perimeter from the hydraulic complex Aoulouz-Mokhtar Soussi. But for all that the deficit balance of Souss water table was not recovered.

Within the framework of the new prerogative of the law 10-95, the Agency of the Hydraulic of Souss-Massa and Drâa basin was involved, since its creation, with a consulting approach to reduce the pressure on the water table. In this sense, significant breakthroughs concerning empowerment of the actors are realized, in particular by the implementation of the multi-parties *outline agreement* and *the water table Contract* [11, 12].

6.3 Passage Towards the Mobilization of Surface Water

Souss-Massa territory is a centerpiece in the economic and social national board, and almost consistently finds a place in the strategies and plans of the development of the country. The policy of dams and the million of irrigated hectares initiated by Morocco constituted a bridge which facilitated the passage of this basin towards the mobilization of surface water. But in the hydraulic development process of surface water [13], it is necessary to distinguish at Souss-Massa basin between three major tracks of hydraulic action with distinct objectives (Fig. 3).

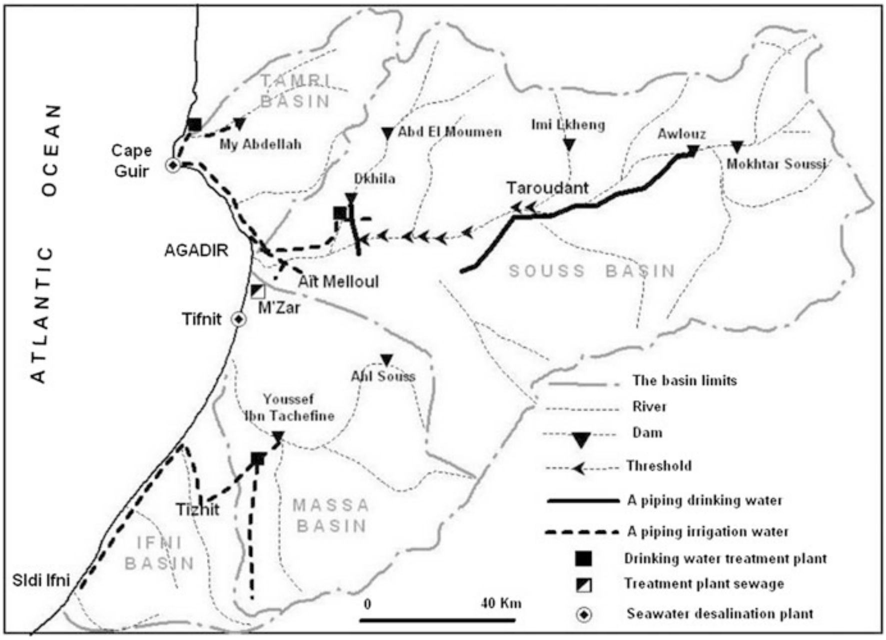

Fig. 3 Water resources development

The first track involves facilities dedicated exclusively to the support of irrigated farming. In this sense, and to enter the era of large hydraulic, the basins of Souss and Massa are endowed with two dams.

Youssef Ibn Tachfin dam built on Wadi Massa in 1973 to regulate a water volume of 85 million m^3/year has as main objective the creation of new irrigated agricultural perimeter of 18,000 ha in Chtouka-Massa plain.

Abdelmoumen dam, built on Wadi Issen, High Atlas tributary, to regulate a water volume of 70 million m^3/year, is mainly dedicated to “safeguard” the citrus agriculture perimeter of Ouled Teima suffering from the lowering of the Souss water table level.

Lately, Mokhtar Soussi dam is built on Wadi Tifnout to mobilize and transfer 45 million m^3/year to El Guerdane perimeter.

The impoundment of these big dams was a source of relief and development for agriculture. But these works, important as they are, have not so far stopped the continued decline of groundwater that reached alarming levels. Starting from 1990, the decision was made to move into a second phase, to the artificial recharge of Souss groundwater from releases of mobilized surface waters of Aoulouz dam. Unique in this kind, the dam, which was reinforced by other water infiltration systems brought to the water table, constituted an axis of specific intervention in the area [14].

The third development axis of surface water concerns the production of potable water. Facing the saturation of equipped groundwater resources and with the need to catch up with the deficit of generalization access "for all" to potable water, the superficial water mobilization has become an obligatory passage since 1985.

At the beginning, this passage is marked by withdrawals from existing dams, although these withdrawals were not planned in the hydraulic scheme of Abdelmoumen and Youssef Ibn Tachfin dams. But then a new work, Moulay Abdellah dam, was built on Wadi Tamri to regulate 27 million m^3/year dedicated exclusively to the strengthening of the supply system of the conurbation of Greater Agadir and centers of the High Atlas coastline.

Today, within the strategic objective of management and development of supply, the ABH-SMD pursues these actions of water resource mobilization. Small- or medium-sized dams were made, such as Ahl Souss dam, and others are scheduled on the various Souss and Massa tributaries.

6.4 Sanitation and Wastewater Purification

Since the publication of the law 10-95 and adoption of the "polluter–payer" principle, the restitution of raw wastewater into the natural water cycle has become almost forbidden. The most concerned urban areas by this decision are forced to be equipped by sewage sanitation networks and also wastewater purification stations, sometimes with an option to reuse the purified water.

The establishment of sanitation networks and wastewater purification stations is the responsibility of local communities. However, lack of technical and financial resources in almost all of these communities tends to delegate this service to specialized bodies. So far, it is ONEEP – water Branch – public company which is responsible for the potable water production, in addition to sewerage and wastewater treatment. The conurbation of Greater Agadir is the exception in this domain, since sanitation and wastewater purification are attributed to an inter-municipal utility: RAMSA.

Generating a significant flow of wastewater, the conurbation of Greater Agadir has attracted the interest of developers to set up a reliable system of sewerage and wastewater treatment. The discharges of raw sewage have begun to seriously harm the image of this modern city and its touristic activity. Launched around 1984, the satisfactory results of the experiments of wastewater purification process by stabilization ponds and infiltration are resumed in a large station that takes in charge the wastewaters of Greater Agadir: the station of M'zar opened in 2008.

Located south of the conurbation on the left bank of Wadi Souss mouth, M'zar station is designed as a mode of purification based on three treatment stages: a primary treatment by anaerobic sedimentation, a secondary treatment by infiltration–percolation through sand filters, and before being reused in watering, the treated water undergoes a tertiary treatment by ultraviolet.

In achieving M'zar station, it is intended to treat at the primary stage a volume of 75,000 m^3/day of raw sewage, 30,000 m^3/day at the secondary stage, and 10,000 m^3/day at the tertiary stage; some of this water is used for watering a golf course. The station will be resized in a progressive manner proportionally to the evolution of the volume of the collected wastewater and the demand for irrigation water [15].

In rural environment, after a long period of concentrating the efforts on improving the population's access to domestic water and livestock watering, the ABH-SMD pilots a vast sewage sanitation program in the objective of developing and improving the living environment and preserving water resources from pollution.

6.5 *The Desalination of Seawater, a New Era*

The Souss-Massa basin has now reached a very advanced mobilization rate of available water resources and the possibility to transfer water from neighboring hydrographical or hydrogeological systems is not economically profitable. To avoid getting into a situation of shortage, the maintaining of the balance between the water supply and demand cannot be done without mobilizing the invaluable oceanic resource by desalination. The basin also has an underground brackish water still not very explored.

Taking advantage of the established facts of many experiences in Moroccan Saharan provinces, the Regional Directorate ONEEP – Water Branch has launched the implementation of a large seawater desalination station for strengthening the supplying system of the conurbation of Greater Agadir with potable water.

With a capacity of 100,000 m^3/day expandable to 200,000 m^3/day, this large-sized station ever realized in Morocco will help to perpetuate the potable water supply of Greater Agadir and its touristic littoral area until the horizon of 2030 [16].

Technically, the new station will be performed by sections at Cape Guir in the north of Agadir by using the reversed osmosis process around which the ONEEP – Water Branch has acquired a great experience in the southern provinces.

The use of seawater also interests the agricultural sector. After starting the project "Safeguarding El Guerdane perimeter" by the transfer of Mokhtar Soussi dam water on a distance of 90 km in a public–private partnership framework, the agricultural authorities launched an appeal in February 2015 for expressions of interest for the construction of a seawater desalination project for irrigation.

The projected work of a final production capacity of 167,000 m^3/day by using the reverse osmosis technique aims at safeguarding and creating an agricultural area of 13,000 ha in Chtouka plain of a high potential production of early vegetables.

As announced by the Government, this new project will be implemented under a public service delegation and the promotion of private sector participation in different stages for a period of 30 years.

7 Access to Water, Between State Intervention and Local Initiative

The important position of the Souss-Massa basin in the Moroccan economy is explained mainly by the tireless efforts to provide the area with a powerful hydraulic system. The access of the various water users, on an equal footing, by the correction of the spatial and temporal disparities has been a hobbyhorse for all the participants.

The fame of the Souss-Massa basin as a main area of export flows and supply of the domestic market in citrus fruits and early vegetables could not be possible without the relentless commitment of the various actors to ensure farmers' access to water in a semiarid or arid environment.

Obviously, the government intervention was necessary for the establishment of the large hydraulic work and appropriate administrative bodies of management, but local initiative held a vital role in the generalization of the water service.

The experiences of maintenance or the generalization of access to irrigation water are many and concern the different farming systems in the area.

7.1 The Rehabilitation of the Traditional Agricultural Perimeters

Originally, to access to irrigation water farmers have developed an ingenious hydraulic system along the bed of Wadi Souss and at the piedmont areas. For proof, one needs only to remind that the complementarity between the mobilization of Wadi Souss flows and the underground waters by khettaras helped to develop in the sixteenth and seventeenth centuries, under the Saadian dynasty, a sugar industry based on sugarcane irrigation. However, further development of speculative agriculture by pumping groundwater and drought frequency have made the traditional agricultural sector a difficult situation. The water allocation of inherited perimeters, spread over a total area of 32,000 ha, decreased significantly due to reduction of flood and drought of resurgence.

Aware of the situation of an uneven competition over water between a "modern" agricultural sector with a strong solvency to access to capitals and new pumping technology and a "traditional" agricultural sector, almost deprived and with derisory means, planners suggested to the State, as part of "the Master plan of the hydraulic development of Souss Valley," to provide support for this latter sector [3].

Thus the "rehabilitation of traditional irrigated perimeters program" is implemented on an area of 18,000 ha. The selected facilities were intended to provide the beneficiary perimeters, located along the bed of the Wadi Souss and the piedmont of the High and Anti-Atlas, with a battery of drillings, pumping stations, and water supply networks in the form of channels carried up to parcels to be irrigated. The programmed water allocation was approximately 160 mm^3.

The achievements of this rehabilitation program have affected several perimeters, but all of the considered perimeters were not equipped. Difficulties related to lack of funding or trampling of urbanization fronts on some perimeters, such as that of Aït Melloul, did not facilitate the achievement of all the planned developments.

7.2 The Modernization of Agricultural Activity

After the country's independence, Morocco was involved in a rural development policy by the modernization of agricultural activity. In this context, Souss-Massa has attracted significant public investment for the creation of two modern irrigated perimeters of significant size.

Chtouka-Massa perimeter: This is a new creation of 18,000 ha of land mainly for pastoral use. The justifications of the choice of this site are numerous: favorable climate characteristics to the production of the out of season agricultural commodities to thwart the Mediterranean competition in the European market, contribution to the equipment strategy of one million irrigated hectares, support to exports and foreign exchange revenues, development of rural environment, etc.

From a technical point of view, the new perimeter was connected to water after the inauguration of Youssef Ibn Tachfin High Dam in 1973 with a carry of 300 million m^3 capacity, and the establishment of a distribution network of irrigation water by sprinkler. The undulations of the sandy soil and the concerns of irrigation water economy were behind this technique regarded at the time as sophisticated.

A second project, of less importance, called “upstream-Souss Project,” was carried out in the eastern part of Souss plain. It generally had the same objectives as Massa project, but especially aimed to facilitate access to irrigation water for a farming category with low means of production.

In this new project which is made of isolated units of a total area of 6,300 ha, it was designed to create irrigated perimeters from a battery of drillings, a pumping station, and a network of sprinkler irrigation. It is therefore a hydraulic scheme combining between the adopted equipment in the rehabilitation of traditional perimeters and that of the modern perimeter of Massa.

The operation of the units of this perimeter is entrusted since the beginning to cooperatives regrouping farmers that are beneficiaries of the project. The management of the hydraulic equipment, requiring a high level of know-how, was provided by the local Administration of Agriculture. But, with the aim of reducing the costs of irrigation, this management was entrusted thereafter to cooperatives.

In the same context of modernization of agricultural activity, from support to access to irrigation water and following the construction of Abdelmoumen dam, developers planned to compensate farmers who will lose their rights of spreading floodwaters by creating a new agricultural perimeter. It is about a perimeter of

4,400 ha in the piedmont area of Wadi Issen equipped with a network of canals for the supply of water released from the dam.

7.3 The Protection of the Suffering Citrus Perimeters

Morocco's largest citrus area is located in Souss plain, that is, 33,000 ha constituting 40% of the total area. Introduced since the 1940s to be irrigated by pumping, this agricultural speculation with big needs of water has gradually encountered serious difficulties. The gradual decrease in the level of underground water has forced farmers to leave their crops to dry, mainly in two perimeters: Ouled Teima and El Guerdane.

But the stakes for the future of citrus cultivation in Souss are considerable. First of all this is a strategic heritage of the region at least in terms of know-how acquired in practicing a citrus cultivation of high reputation in European market. The activity then presents an important offer of employment days for rural areas and a significant entry of currency through exports. Also the State decided to intervene on the basis of recommendations of the "Master Plan of Hydro-agricultural Development of Souss Valley." Certainly this intervention has taken a long time, but it has nevertheless been accomplished in both perimeters of Ouled Teima and El Guerdane in two different ways.

The first perimeter has benefited from a specific action of large scope under the framework of "the project of the protection of citrus perimeter of Ouled Teima." The surface water of the Issen subbasin located on the right bank was mobilized to rescue the perimeter of citrus plantations in question. The decision to go to surface waters constituted a turning point in irrigation in Souss.

The adopted hydraulic scheme consists firstly in building Abdelmoumen dam with a carry of 200 million m^3 put into service in 1985. The reservoir is relayed immediately downstream by a regulating dam for pressurizing the irrigation water. Water is then passed through an underground intake of 4.6 m^3/s to the left bank where the orchard to be "protected" is located. On the spot, water is distributed through a new pressurized network that ends with limits dedicated to drip irrigation with a total area of 2,900 ha. This new network has made obsolete the old way of gravity irrigation by submersion.

El Guerdane perimeter located further south on an area of over 10,000 ha did not benefit from Abdelmoumen dam water. The chosen alternative was the artificial supply of Souss groundwater from the hydraulic complex of Aoulouz-Mokhtar Soussi, hoping to swell this perimeter water table.

The hydraulic complex set in place since 1992 consisted of two main components: a dam of a storage of 96 million m^3 and a series of separate dikes built downstream. The water released from the dam is broken at the dikes and finds its way into groundwater. After a significant period of operation of this process with injection of a volume of annual supply of 100 million m^3, the groundwater level has not registered any notable swell at the perimeter in question. The increasing frequency of drought years and the continued deepening of water points, among others, have not contributed to the expected success for this project.

Following this moderate result, the PDAIRE, enacted in 2002, suggested to adopt a more rigorous solution by looking for a surface water resource surer and more distant at the level of the subbasin of Upper Souss. The design and installation of this new alternative have taken a long time, it also asked for important investments. The long discussions and negotiations between the actors resulted in the establishment of a system of delegated management of the distribution of irrigation water in the partnership framework.

7.4 Delegated Management: An Innovative Initiative

El Guerdane perimeter occupies a central place in the citrus cultivation of Souss-Massa basin; it covers more than 40% of the planted area and enjoys a high level of professional organization, technical skills, and a wide range of citrus varieties adapted to different export markets. The options of successive deepening of water points and the use of micro-irrigation techniques have not succeeded to avoid this perimeter to be found in a threatening situation in the medium and long term. The water table level continued to go down by 2.5 m/year in some places, and the alternative of protecting the area by a surface water transfer has become a key priority.

The hydraulic scheme created to quench the thirst of El Guerdane perimeter is to build a headwork upstream Aoulouz dam for the mobilization of 45 million m^3, an intake of 90 km for water transfer, and a pressurized distribution network for irrigation of an area of 10,000 ha.

The impoundment of the perimeter from Mokhtar Soussi dam opened in 2002 has not been realized until 2009. This relatively long waiting period was necessary to the testing of institutional and financial installations, and to multiparty negotiations grouping public authorities, farmers, and the private sector.

During this period, after the scrutiny of the conventional installation expected by the Agricultural Investment Code and the one of the partnership with area farmers through a local AUEA, it turned out that the installation of delegated management to the private sector is the best offer. According to the results of the investigations, this type of management, based on the principle of “Public–Private Partnership,” may allow, thanks to contractual obligations, to ensure the sustainability of infrastructure and equipment, the maintenance of the management performance and a better quality of water services [11].

In the case of the accepted delegated management for a total project cost of 987 million MAD, the government contribution will be limited to 17% instead of 67% for installation as part of the Agricultural Investment Code and 53% as part of the partnership with AUEA. Similarly, the subscription right of farmers to the irrigation network will decrease from 49,000 MAD/ha in case of partnership with

AUEA to 8,000, and the price of the irrigation water is estimated at 1.80 MAD/m^3 instead of 1.85 in the case of AUEA partnership.

Having given the best proposal of irrigation water price of 1.48 MAD/m^3, the ONA-CDG-BRL-Inframan Grouping is declared beneficiary. In 2004, represented by "Amensouss" company this group has signed an agreement of financing the public contribution with the "Hassan II Fund for Economic and Social Development" and the Ministry of Agriculture as the authority delegating.

In 2009, El Guerdane perimeter was put into water to save 10,000 ha, as part of a project considered as "innovative" and pioneering by delegating the management of irrigation water to the private sector.

This form of public–private partnership seems to increasingly attract actors of water cycle. The ONEEP – Water Branch also signed in 2014 an important contract with a private grouping concerning the sitting of a seawater desalination station for strengthening the supply of the conurbation of Greater Agadir of potable water.

7.5 Potable Water for All

Souss-Massa basin does not escape the principle of accessibility to water in the localization of human groups. The spatial distribution of cities and rural villages is closely linked to the existence of a perennial water resource.

The three historic urban centers in the area were supplied with water from local resources. Taroudant, the oldest city, drew its water needs from water diversions of Wadi Souss and from water drawn from the groundwater, the city of Tiznit used water of a local resurgence, and the ancient city of Agadir was supplied from small local sources and rainwater collection.

The recent acceleration of the urban phenomenon in the area ended up with a spreading of the ancient cities, the emergence of new urban centers, and therefore a rapid evolution of urban water needs. Coverage of water needs of urban populations and their activities has grown from a stage of mobilization of local resources often underground to an expensive step that requires remote surface waters. The case of the conurbation of Greater Agadir is very significant (Fig. 4).

In a first phase, the small fort of Agadir, appeared in the sixteenth century, was content with traditional resources of the two neighborhood sources: Founty and Tildi. The developing of the new city required to seek increasingly distant groundwater. The capturing field system developed around the conurbation quickly reached saturation. Since 1985, to reduce pressure on the water table widely used in irrigation, in addition to the appearance of some signs of salinity in the coastal zone, the passage to the mobilization of surface water has become inevitable.

Initially, a first potable water treatment station is fitted downstream of Abdelmoumen dam then, since April 2007, a second station has been put in service for the treatment of Moulay Abdellah dam water dedicated exclusively to the production of potable water.

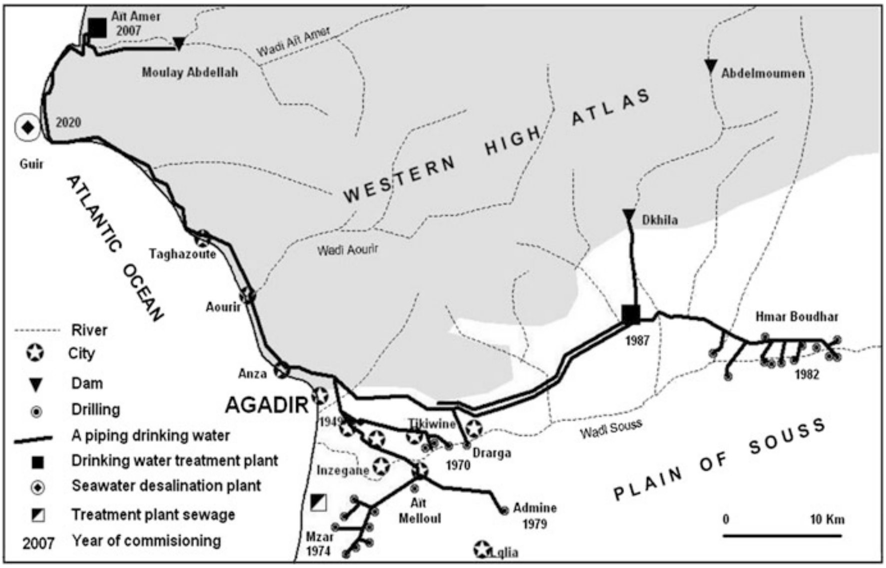

Fig. 4 Urban hydraulic radiance of Great Agadir

The other cities have gone through the same process with a time lag imposed by the available hydraulic potentials and by the changing needs. Thus the city of Tiznit has moved to the use of Youssef Ibn Tachfin dam since the 1990s; on the contrary, Taroudant is currently benefiting from a regional supply program from its neighborhood dams.

At the same time to the establishment of the mobilization equipment, distribution networks were developed to make the potable water service accessible to "all." By the force of law, the management and mobilization of water are under the authority of the Basin Agency, and the production of potable water is assigned to the National Electricity and Potable Water Office – Water Branch. On the other hand, water distribution is an attribution that goes to local authorities. But, for lack of adequate technical and financial resources, the communities tend to delegate this latter attribution to ONEEP-SE. The conurbation of Greater Agadir stands out because its municipalities conducted within the framework of inter-municipality, to the setting up of a specific utility; it is the Agadir Multiservice Utility (RAMSA).

In order that the potable water arrives at different spatial and social entities of the urban tissues, the delegated institutions for water distribution carry out, in a partnership framework, social programs for hydraulic development of under-equipped neighborhoods and for individual connections for households with limited financial resources.

In rural environment and outside the areas deprived of perennial water resources, the various water supplying programs of rural populations have succeeded to equip the villages of the Souss-Massa basin with an access rate considered among the most performing ones throughout the national territory. This rate could reach 100%

since a long time in many municipalities, but it was not until the results of the last Census of Population and Housing in 2014 to see how it is in other municipalities of the basin.

The improvement of the water access level for rural populations went through several stages. Apart from irrigation, so as to be supplied with water in suitable quantity and quality for domestic and livestock watering uses, the population covered its needs on the basis of individual or community initiatives sometimes in an intervillage dimension. But when water is scarce or becoming scarce, the Administration of Agriculture will be in charge, through the Department of rural Engineering, of water points development in different forms: pumping, sources development, building reservoirs for runoff water collection, etc.

Successive droughts since the 1980s had negative impacts which, the most striking images, remain as the amplification of rural exodus flows and the "chore water fetching" whose victims were indisputably women and children. Faced with the lack of state action in this field, village communities, deriving from the values of solidarity and mutual assistance, took up the challenges of water access and other basic services such as electrification and roads. We witnessed throughout the area the spectacular expansion of associations dedicated to local development. Since the 1980s, almost all human groups have organized themselves in associations with implementation projects for potable water supply systems.

By settling down to these local and community initiatives, relevant state institutions have multiplied and diversified forms of support in order to improve the rate of access of rural-people to potable water. Thus, the PAGER was launched with the support of the international cooperation in 1995. Thanks to operational and reactive of associative tissue in Souss-Massa, the PAGER has known a significant success rate compared to the rest of the country.

Recently, to bring potable water to all with the same quality and in adequate allocations, without segregation between urban and rural areas, or between areas with potentialities and areas with poor perennial water resources, an important decision was taken in 2010. It aims to unify the potable water sector management by allowing the ONEEP-SE to expand its activity to cover rural areas.

Since this extension of its activity in rural areas, ONEEP-SE continues its actions of the generalization of the Master Plans of Supplying Rural Populations with Potable Water and its implementation policy of perennial rural systems of potable water supply. In Souss-Massa, the regional supply systems from dams, which are already put in place or in process for the supply of rural populations, are counted among the largest across the country.

For cities as for villages of the region, the mobilization rate is very high. In order to maintain the needs/resources balance positive, seawater desalination projects for supplying people are underway at the basin level.

8 Conservation of Natural Sites and Reduction of Floods Risks

8.1 The Conservation of the Natural Sites

Plantation with a transitional position between the Mediterranean world and the Saharan world and with a wide opening on the Atlantic Ocean, Souss-Massa basin constitutes a specific environment with a perfect framework for the development of particular ecosystems.

The entire basin territory is part of the argan forest constituting a forest system based on argan tree, a plant species in the form of an endemic tree of tropical stump. Seeing the importance of its environmental characteristics, socioeconomic and cultural, this natural environment has been integrated since 1998 in the network of Biosphere Reserves managed by UNESCO to constitute the argan forest Biosphere Reserve.

Furthermore, within the national inventory studies of natural areas to be protected, a significant number of sites of Biological and Ecological Interest were spotted across the expanse of the Souss-Massa basin. Among these sites, it would be appropriate to name the wetlands that are at Lake Ifni and the mouths of Wadi Souss and Wadi Massa. Recognized as Ramsar sites, these two last wetlands are integrated in Souss-Massa National Park; on the other hand, Lake Ifni is assimilated to Toubkal National Park.

With the objective of maintaining the covering of the demand for environmental water and the prevention of natural environment degradation caused by the advanced mobilization of water resources, several actions were recommended in the revised version of the latest PDAIRE. Among the most important suggestions we quote: the elaboration of a regional strategy for environment, take in consideration the environmental dimension in future hydraulic developments, the requirement of the impact studies for all development projects, the restoration and rehabilitation of degraded wetlands, the reevaluation of the impacts of dam reservoirs on wetland ecosystems, the assurance of environmental water supply in sufficient quantities for the suffering sites for maintaining their equilibrium, etc.

8.2 The Fight Against Floods

In addition to the highly concentrated nature of the flow regime of surface water and the quite reduced time response of this flow to precipitation, the hydraulic system of Souss-Massa basin is exposed to important restraints due to the development of agricultural land and urban tissue. The different types of development drawn up in submersible lands by the flow of flood and runoff water, the weakness of maintenance actions, the degradation of plant hatching, illegal occupations of public hydraulic domain, etc, are factors that have contributed the establishment of areas highly exposed to the risk of flooding.

As part of its efforts to prevent and mitigate flood risks, the ABH-SMD has implemented a privileged strategy for the control of the public hydraulic domain from all interferences that could disrupt the water flow, as well as the establishment of infrastructures in partnership with local communities exposed to this type of risk.

Immediately after its creation, the basin Agency conducted the updating of the inventory of flood risk sites, conducting throughout studies, and proposing protection schemes of easily flooded sites.

As part of implementation of the development Scheme of Floods Prevention, the ABH-SMD proposes to the actors the performance of Hydraulic works adapted for different situations such as:

- The pursuit of dam construction in different sizes,
- The implementation of protective dikes on the sections of Wadi banks at risk,
- The creation of preferential flow channels in case of absence of natural Wadi beds,
- The creation of discharge or diversion channels of runoff water,
- The cleaning and recalibration of flow channels.

The realizations already started in partnership with various actors for the protection of the conurbation of Greater Agadir site have shown their importance during recent heavy rains that lashed the area during the hydrological year 2014–2015.

9 The Contribution of the International Cooperation

Due to its specificities in Moroccan territory, the Souss-Massa basin has attracted the interest of various international cooperation agencies since the beginning of independence. Considering only the water sector, many projects have been carried out in the region with the support of several organizations of bilateral and multilateral international cooperation.

In terms of project planning studies of the great hydraulic, UN agencies FAO and UNDP contributed significantly to the achievement of the Master Plans of hydraulic Development of Souss and Chtouka plains.

Concerning irrigation improvement, the supply of cities and rural human groups, the wastewater purification, and the institutional capacity reinforcement, the area has received important and numerous projects in the framework of bilateral international cooperation particularly with France, Belgium, Germany, Japan, the USA, etc.

For the implementation of its programs and action plans, the ABH-SMD promotes the installation of its projects in a partnership framework with national and international bodies. Currently a project is underway to develop a Master scheme of Development and Management of Water and setting up a supply intake of potable water for rural people at *Arghen Subbasin*, one of the poorest areas in water resources in the region. The realization of this project is conducted in a cooperation framework between the Regional Council Souss-Massa and Draa and ABH-SMD on the one hand, and the General Council of Hérault and the Water Agency Rhône – Mediterranean and Corsica, on the other hand.

10 Towards an Update of Water Code

Today, 20 years after the promulgation of the Water Law 10-95 in Morocco, it appeared certain that this code came in time to comprehensively provide the country with an adequate institutional framework for the modernization of water resources management system. At Souss-Massa basin, this code has allowed to progress in a certain way towards decentralized water management by creating the agency of the basin and to initiate, as a pioneer, participatory work steps and consultation between the different actors.

A quick evaluation of the agency action let glimpse certainly that difficulties still persisting, particularly in the field of cost recovery on water withdrawals and the control of the hydraulic public domain. But, in return, real breakthroughs are made on hydraulic prospective and accountability of the different categories of water users and of the users of public water resources: updating of PDAIRE, framework convention, water table agreement, study of environmental impacts of construction materials extraction, etc.

But beyond these immediate implications, the period spent is more than enough to notice and agree by the managers themselves that the Law 10-95 shows or begins to show some limitations that require that the current texts should be revised. Several formalities are thus taken in consideration: the valuation formalities of purified wastewater, the methods of management of risks such as droughts and floods, the complexities of the management procedures of the public hydraulic domain, insufficient or even empty legal state in terms of sewerage and desalination of seawater, etc.

Let's consider here that the hydraulic authorities, aware of the achievements and the limits of the law 10-95, have just organized a public debate for revising the aforesaid law, with the aim not only to revisit the text but also to make the law more adapted to the recent changes occurring in society and space and thus to better join the orientations of the national water strategy.

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Socio-Economics and Governance of Water Resources in the Souss-Massa River Basin

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Abstract This chapter introduces the water resources management in the Souss-Massa basin from socio-economic and institutional points of view. This basin is very important providing most of the Moroccan agricultural exports and covers more than 10 months of the food system needs in the country. However, the basin faces growing recurrent droughts exacerbated by climate change.

Moreover, agriculture intensification based on the intensive use of irrigation decreases the groundwater potential and makes the water resources limited and thus more expensive to extract. Therefore, all development activities will be constrained by the scarcity of water resources in the area if no appropriate institutional and management strategies are applied.

The first part of this chapter focuses on the Souss-Massa economic potential in relation to water availability. The second part describes water supply management and governance taking into account adaptation to climate change. The third part suggests a new paradigm based on the ecosystem service approach to support the sustainable decision system addressing water scarcity issues. A special emphasis will be put on the Guerdan and Chtouka perimeters and some relevant innovative solutions to mainstream ecosystem services into macroeconomic policies. The last

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part will discuss the institutional aspects of water management and finally some of the key conclusions and the way forward.

Keywords Ecosystem services, Environmental scarcity, Socio-economic, Souss-Massa, Water resources

Contents

1 Introduction

Despite policy of an integrated water resource management, including the mobilization of surface water resources (seven large dams with a total regulation capacity of 364 Mm^3) and the projection of using nonconventional sources of water (desalinization, reusing wastewater), water availabilities are still limited. The Souss and Massa aquifers can hardly offer 318 and 41 Mm^3/year, respectively, in terms of sustainable abstractions. As a result, the balance between supply and demand has toppled; underground water resources are overexploited and the annual water deficit of the groundwater ranges from 100 to 350 Mm^3/year in the Souss aquifer and reaches almost 60 Mm^3/year in Chtouka aquifer. Consequently, the piezometric water line has dropped by several meters, and there are severe risks of saltwater intrusion from the coastal zone. The effect of aquifer drawdown on the agricultural demand is imperceptible in the current situation due to the dichotomy between large, high added value earning farms and smallholdings, since the expansion and intensification of the larger holdings is to the detriment of the smaller ones.

2 Economic Potential of the Souss-Massa region

The Souss-Massa holds significant economic potential based on its natural resources. The agriculture sector, fisheries, tourism, and mining are the most important activities in the region.

Despite its dry climate, the region is experiencing an intensive agriculture. The agricultural area represents 616,500 ha. These lands are mainly in the Souss-Massa plain, where early crops and citrus are the main productions.

Given these constraints and obstacles facing the regional agriculture, especially the climatic conditions and water scarcity, it has many advantages which can ensure a leading position at the national level. The high yields of citrus and vegetables are strong points of this sector. Their annual production usually exceeds 50% of the national total. We should mention that the agricultural sector employs more than 51% of the labor force (HCP 2014).

The Souss-Massa region is characterized by dominant forests, rangelands, and uncultivated lands that occupy around 85%. A large forest area is forming a natural barrier against desertification and erosion.

Despite the high biodiversity of forest areas, the Argan species covers more than 64% and benefits from consistent environmental or socio-economic supporting actions.

In addition, Fishing is a key sector in the region. It employs an important labor and attracts investments and currencies. The region has a large fishing port in Agadir, in addition to a number of small fishing ports reserved for artisanal fishing boats. The fishing activity has contributed to the creation of industrial units and improving export.

Known by its climate, its diverse topography, its historical and cultural heritage, and its wide beaches, the Souss-Massa region represents a unique international destination for tourism. The tourism sector has significant tourism infrastructures. Around 17% of the institutions are classified nationally, with a capacity of 35,500 beds. The region welcomed more than 850,000 tourists in 2012, representing nearly 15% of the national total (CRI 2012).

Agriculture is so far the main economic activity of the Souss-Massa with 143,640 ha of irrigated lands of which about 60% is under modern systems dedicated to market gardening 34%, citrus 25%, cereals 10%, and 28% livestock. The production of citrus and early vegetables contributes over 50% of the volume of national exports.

The global water use of 901 m^3 contributes to only 84% of the global needs (1,068 m^3) underlining a water shortage of 167 m^3. This gap will increase as water demand forecasts for drinking purposes rise from 130 m^3 in 2015 to 197 m^3 in 2030 and the demand for agricultural lands increases from 970 m^3 in 2007 to 825 m^3 in the same timeline [1].

3 Water Supply Management and Governance in the Souss-Massa

The SM region has long been involved in the process of controlling and mobilizing water resources and has adopted an integrated planning and management framework for its water resources. Both the regional water strategy and the Integrated Management Plan of Water Resources in the Souss-Massa basins focus on the management of demand through incentives for water saving and the strengthening of the institutional and regulatory mechanisms.

3.1 The Souss-Massa Strategy for Economic and Social development

Water policy stated in the Souss-Massa Strategy for Economic and Social development (SMSESD) aims to make the SM hydraulic system occupy a position of a national pilot for water management. Three pillar actions were suggested to alleviate key impediments and help meet major water needs [2]:

– Safeguarding conventional water resources and enhancing innovative resources by developing the aquifer contract process, expanding sewage/demineralization of brackish water practices, building hillside reservoirs and appropriate water harvesting structures including artificial rain as well as the optimization of surface water delivery, and the introduction of new generation greenhouses
– Optimization of water consumption by organizing training/awareness campaigns benefiting to small farmers (conversion to drip irrigation, aggregation process, etc)
– Sealing partnerships through a negotiated collective agreement specifying roles and responsibilities of different stakeholders by developing appropriate tools for the Public–Private Partnerships (PPP)

3.2 The Souss-Massa Basins Integrated Water Resources Management

The Souss-Massa area is a dynamic agricultural, industrial, and tourist pole of national importance. The urban expansion reflects the economic development of the region, which tends to become more important in the coming years.

As a result, the Souss-Massa basin is facing today, more than ever, multiple constraints, such as increased overexploitation of aquifers, increasing urbanization, and emergence of new water needs requiring a good governance of water resources management. Moreover, acute structural droughts became a real threat to water resources, particularly in the past three decades.

The PDAIRE was implemented by the ABHSM, starting from 2006, to reflect the major interest of the community in water resource problems and to balance between competing interests of all stakeholders and water users and convene a local consensus for an optimal water resources management.

In terms of managing the offer/demand for water, the PDAIR recommends the following solutions:

– Mobilization of the remaining potential of surface water (30 Mm^3): north coastal basins and tributaries of the Souss watershed not yet regularized
– Investigating additional groundwater resources
– Conversion of 50,000 ha of surface irrigated lands into drip irrigation
– Stopping expansion of irrigated lands and groundwater pumping within public perimeters irrigated from the dams
– Reuse of treated wastewater
– Desalination of 205 m^3 seawater for irrigation and drinking water in 2030
– Reuse of 6 million m^3 of desalinated brackish groundwater in irrigation
– Investigating appropriate rainwater harvesting solutions
– Enhance competitive and water saving crops through awareness programs and scientific research
– Introducing new water technologies both for drinking and irrigation purposes in order to save 162 m^3
– Strengthening the Police Force capacity to provide adequate surveillance of groundwater withdrawal
– Alignment with the national protection program of groundwater resources by developing the process of aquifer contracts

In 2030, the overall water partitioning forecasts are shown in Table 1. The volume of water used in agriculture will decrease from 93% in 2015 to 79%, while a slight increase will be attributed to other public uses.

Table 1 Water partitioning forecasts for 2030

System	Irrigation	Drinking water	Environment	Green spaces	Total
Abdelmoumen Moulay Abdellah – Tamri	83	152	8	11	254
Youssef Ben Tachfine Ahl Souss	93	21	1	2	116
Aoulouz – Mokhtar Soussi – Im El Kheng Sidi Abdellah Lemdad	233	12		4	250
Aquifers and run-of-river withdrawal	440	12	2		453
Total	849	197	11	16	1,074

Source: PDAIR

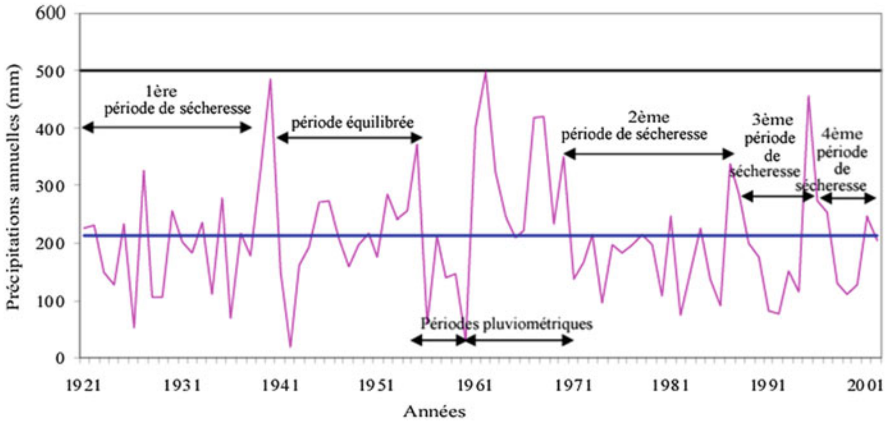

Fig. 1 Annual rainfall between 1921 and 2001

3.3 Water Management in with Regard to Climate Change

In this context of water scarcity strongly affected by the climate change, the Souss-Massa basin already suffering from an acute water deficit is facing an increasing water demand. In fact, forecasts show a decrease in rainfall and surface water up to 4% per year in the southern regions of Morocco. Reduced rainfall will have a direct impact on the hydrologic network of flows and the groundwater recharge. In addition, an alarming water shortage is recorded in this area for irrigated agriculture [3].

Figure 1 gives a first overview of the chronological periods of drought since the early decades of the twentieth century [4]. We notice that there are three different periods: a period of heavy rainfall which lasted about 16 years from 1955 to 1971, a balanced period between 1941 and 1954, and a period of four subperiods of drought during the last three decades. This fact has a considerable impact on water reserves in particular groundwater.

As a matter of fact, water resources management in the Souss-Massa basin is very complex due to several factors. In addition to its natural context especially the arid climate, the Souss-Massa basin is a vulnerable area and difficult to manage. The impact of climate change indicated by the drought that occurred periodically, added to irregular rainfall and floods, explains the scarcity of the resource and the use of massive exploitation of aquifers. This complicated scheme requires an integrated management approach which should ensure, simultaneously, conservation and sustainability of water resources and thus to increase agricultural water productivity, to meet the growing needs of other demands, and contribute to preserve the environment [5]. Figure 2 shows the different factors that influence water management in the area [6].

All models forecasts confirm that there will be a change in agricultural lands and water availability on the long term. Water scarcity will have a negative impact on

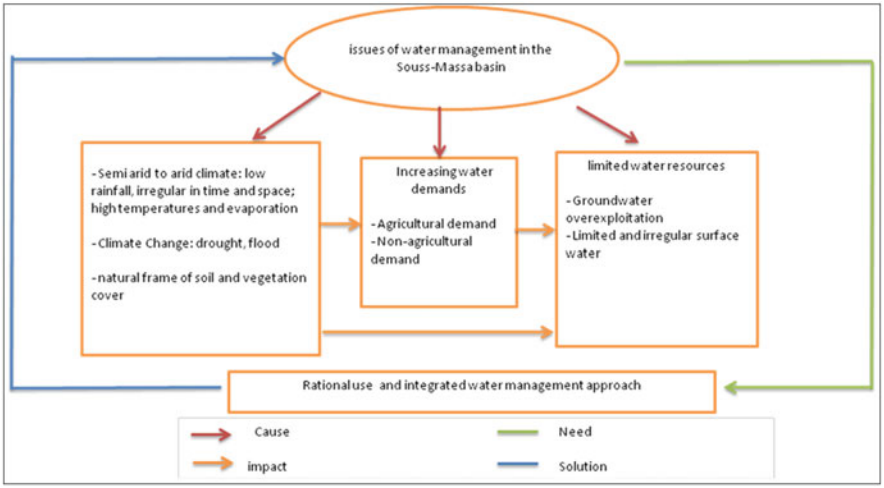

Fig. 2 Issues of water management in the Souss-Massa basin

crop yields especially after 2030 (Requier). Rainfed crops will be most affected. Irrigated crops will also be affected because of the reduction of precipitation and water resources to be mobilized.

Knowing that the agriculture sector is one of the main sectors of employment and income generation (13–23%), the agricultural water use in the Souss-Massa basin will be likely to decrease following the reduction in water supply. This trend will have a tremendous impact on cultivated farmland. Recent studies estimated a decrease of 8% of added values of the agricultural sector in the Souss-Massa basin [5]. Based on this fact, the farmer income will decrease, in particular, small farmers who are the most dominant. In addition, rural unemployment will increase and will encourage migration.

In this context, climate change adaptation strategies are now a matter of urgency. First of all, we need to assess the impact of climate change on natural resources used by agriculture, including water, soils, and rangelands. We need also to assess the vulnerability of small farmers to climate change. These assessments will help identify weaknesses and the main approaches in order to improve the smallholder welfare. The adoption of new technologies and development of crop varieties tolerant to water stress and drought is very crucial. Anticipatory planning among government institutions and important economic sectors will enhance resilience to climate change. In fact, the government should consider the implications of climate change when planning investments for long-lived infrastructure. A participatory approach involving all communities and socio-professional categories likely to suffer the consequences of climate change is needed.

4 Water-Related Ecosystem Services as a New Paradigm to Foster Regional Policies

Despite these government efforts, integrated water management at the regional level still faces key challenges to tackle social and environmental crisis that occurred within the last few decades including political barriers to change, a divergence of understanding of critical water issues among agencies, users, and the public, a seeming disregard for broad approaches to demand management, lack of regional solutions to regional problems, limited capacity of small farmers to adapt to water shortages, and an apparent absence of communications across water managers at the local levels.

Two prominent cases studies are approached to unveil the real impediments for sustainable water management in the Souss-Massa: the Guerdan Build–Operate–Transfer concession mechanism project and the new alternative of water desalination of Chtouka.

In fact, the enhanced discharge of groundwater in modern expanding agriculture along with the risk of the aquifer system being invaded by marine water has been flagged. As a consequence, riots broke out (Guerdane and Chtouka perimeters) and drew national government attention which took urgent measures to mitigate this ecological scarcity.

4.1 El Guerdan Water Irrigation Project

The irrigation water supply project Sebt El Guerdane is a typical example of nature based solution implemented in the framework of a PPP. This approach is based on an exploitation concession mechanism called Build–Operate–Transfer that was applied in the late 1990s when farmers had begun to protest on the decline of underground water table that allowed irrigating some 10,000 ha of citrus.

For this reason, the government authorities decided to build a giant pipe to convey water from the Aoulouz dam 90 km from the area threatened, and then appointed a group designated after a call for tenders for the construction of the structure whose first work began officially in October 2009.

A consortium led by Omnium Nord-Africain (ONA), a Moroccan industrial conglomerate, won the 30-year concession. Other members included Morocco's Igrane Fund and Infrastructure Development and Management (Infra Man), an Austrian firm. By providing half the water needed by the citrus farmers, the Guerdane project reduced the risk of depleting underground water resources and safeguarded an agricultural industry and associated Argan forests which provide a living for an estimated population of 100,000.

The government, being the collective water rights holder, is also responsible to ensure water security. The demand/payment risk was mitigated by carrying out an initial subscription campaign whereby farmers paid an initial fee covering the average cost of on-farm connection. Beneficiaries, organized in a federation, express their willing to pay for incremental costs in order to preserve the upper basin forests. The idea of setting a fund that would be supported by government subsidies is making surface, and suppliers will benefit from conservative activities convened with the federation. The concession, playing a role of intermediation, grants exclusivity to channel and distribute irrigation water in the perimeter while allocating operational, commercial, financial, and environmental risks among the various stakeholders.

Preliminary results of the project highlighted the opportunity to sustain water provisioning services by introducing Payments for Ecosystem Services, strengthen private capacities to integrate ecosystem management into their businesses, and raise funds in a PPP.

In conclusion, the approach of the El Guerdane PPP project confirms several advantages: (1) It saves financial resources of the government that might serve for other environmental activities; (2) it allows to reap the benefits of investments both nationally and internationally (with their positive impact on employment and productivity); (3) and it allows access to a better quality of ecosystem service as part of a comprehensive environment sustainability [7].

4.2 Desalination and Irrigation Project in the Chtouka Area

As surface water mobilization remains insufficient to mitigate water scarcity at the SM region, the government is turning to the sea for a technology based solution (desalination plant) to provide water for irrigation in Chtouka, Morocco's premium agricultural area where groundwater levels have dropped 40 m over the past 20 years [8].

The Ministry of Agriculture estimated the annual water deficit at 58 million m^3. To cover this gap, an agreement bill was reached for the establishment of a desalination plant. The Regional Council, the Wilaya of Souss-Massa-Draa, the regional Chamber of Agriculture, the Inter-professional Fruit and Vegetable Federation, the Regional Office for Agricultural Development, and the Water Basin Agency signed the bill.

Under this agreement, farmers will subscribe to a contract with the operator of desalinated water distribution network for a minimum quantity of 3,600 m^3 per hectare and per year. The final capacity of the unit, which is expected to cost 2.6 billion dirham, was set at 167,000 m^3/day covering 13,600 ha.

The provisioning services will be based on quotas in a way to ensure an effective use of both conventional irrigation water and the desalinized water according to water availability in the dam and the willingness to pay farmers for treated water.

In other words, the environmental service consists of producing water pumped from the sea and treated in order to be used for agricultural purposes and to set standards for surface water use in a way to allow the aquifer replenishment, as well as allow small and medium farmers to practice traditional agriculture.

4.3 Mainstreaming Ecosystem Services into Macroeconomic Policies

Government has certainly managed to overcome these environmental and social crises through development of plans that help meet urgent population well-being needs, but the outlook for natural capital and its sustainability remains bleak, leading to a tangible risk of rapid desertification. Thus, an urgent action is needed to mainstream natural capital into macroeconomic policies.

The United Nations Agencies through the project's circular economy approach based on the introduction of Payment for Ecosystem Services (UNDP) and the UNEP's program to mainstream Ecosystem Services into Country's Sectoral and Macroeconomic Policies and Programs are exploring innovative solutions to support sustainable development in the SM region.

Four major solutions were recommended by the UNEP project recently implemented in close collaboration with the University of Minnesota and the University of Al Akhawayn under the auspices of the Ministry of Environment [9].

Decreasing Water Intensity and Substituting Capital for Water The study undertaken showed that there is an opportunity to increase services of land, surface, and groundwater in irrigated crop production from 5% of value added by primary resources to 15% by helping farmers find those crop production technologies that save the relatively most scarce resource, water.

Also, the study recommended reducing pressure on the costs farmers face in substituting capital for other resources, such as lower cost banking and credit market structures, and introducing farmers to new farming methods that make substitution more profitable.

Reallocation of Surface Water and Adoption of Water Saving Technology The study concluded that food security might be better achieved by a policy which decreases the amount of surface water assigned to produce cereals and pulses and increasing the amount assigned to more competitive crops, such as fruits and vegetables; however, attention or policy emphasis should be given to new water saving technologies.

Aquifer Should Be Used Mostly as a Buffer Stock in the case of surface water shortages and drought periods. Subsidies to groundwater pumping will only speed up the increase in the depth of the water table, a depth that is unlikely to be sustainable in the longer run without subsidies.

The Temporal Rate of Groundwater Withdrawal A policy implication is that public authority or farmers' water association might be delegated with convincing farmers of this possible consequence of their behavior.

5 Institutional Aspects of Water Supply and Governance

For over 50 years, Moroccan government emphasized the need to develop water resources. In 1967, a national goal was established to have one million hectares of land under irrigation before the year 2000. In 1986, the government established a goal to build one dam per year. These goals were both consistent with Morocco's long-term water management strategy of "Not one Drop to the Sea" [10].

At the local level, water rights established before 1914 were traditionally held by communities for irrigation and potable water. During the French colonial period, water ownership by the state was recognized, and intensive irrigation began. Following independence, the Government of Morocco continued to view irrigation development as crucial to the economy and encouraged new developments.

Between 1914 and 1995, more than twenty laws and decrees have been adopted. The first text relating to water was issued as a Dahir in 1914, supplemented by the Royal Decrees of 1919 and 1925. Water legislation was redesigned and unified under Dahir 1-95-154 of 16 August 1995 to improve the legal status of water resources, enhance their development while taking into account socio-economic interests and safeguarding acquired water rights.

Since 1960, the Souss-Massa basin has become the major Moroccan exporter of fruits (50%) and vegetables (45%), in an economy in which agriculture provides 18% of the GDP and 40% of the employment. In addition, the Souss-Massa basin, and Agadir, in particular, has become an international tourist destination. Water use by large hotels and other recreational facilities, such as golf courses, is huge and sure to increase.

The 1995 water law in Morocco (Law 10-95) created the Hydraulic Basins Agencies (ABH) which have a broad mandate for managing the water resources, both surface and ground. Within the new law, well authorizations, allocations of surface water, water quality monitoring and management, and several other aspects of water management were vested in the new ABH. These agencies are expected to be self-sustaining in the longer term, the short run water management problems are still a function of differing – and competing – demands and objectives. For that reason alone, regionalization of decision-making within and among the various agencies with roles to play in water management became an objective of the Government.

Despite the institutional context of the water law 10-95, responsibility for various aspects of water management has been so far fragmented at best. A significant part of the problem of overconsumption is institutional and involves the lack of coordinated planning and policy among the various water managers and consumers.

The regional administrations essentially carried out national policy, with limited discretion. The ABHSM essentially managed surface water supplies, planning and constructing dams, regulating releases and flows, managing flood control, and providing water.

The Ministry of Agriculture, through the SM Regional Office for Agricultural Development (ORMVA), was provided surface flows from storage by the ABHSM, and in turn allocated water (with a minimal price) to the various associations and individual farmers. ORMVA's goal was to expand irrigation, modernize it, and assure that agriculture would continue to provide an economic engine for the Souss-Massa region. ORMVA used also new wells to augment its surface water supply as irrigated perimeters were created and intensive irrigation expanded.

The National Office of Electricity and Potable Water (ONEE) furnished potable water, both in the rural areas and in larger cities, using the same water sources. In addition, the very large cities had quasi-private metropolitan water offices which received water from ONEE and provided it to end users (for example, the Regie Autonome Multi-Services, Agadir – RAMSA). As the cities expanded, both ONEE and RAMSA expanded their groundwater resources (as well as benefiting from new ABHSM storage facilities). Authorization for drilling wells and using groundwater is emanated from ORMVA, and the ABHSM.

Moreover, water quality issues, when even considered, were the responsibility of the ONEE, but came under at least the monitoring auspices of the Ministry of Environment.

Thus, decisions regarding water use and development were primarily single focus. The lines of communications were mainly up and down the chain of command of each ministry and agency, with little horizontal (interagency) exchange.

In addition, the planning and management of water resources in Morocco has been, for the most part, highly centralized. For example, water prices for irrigation were set in Rabat, and vary only slightly among the various river basins, irrespective of water scarcity. Management plans for all the regional agencies were developed at the central level, albeit with considerable cross-agency input at that level.

Given that Morocco in general, and the Souss-Massa in particular, faces limited and exhaustible groundwater supplies in an area with highly variable surface water resources, the results of the emphasis on growth coupled with the institutional "tunnel vision" were predictable.

Augmented surface water supplies could not keep up with demand, pumping increased and the water table fell rapidly in many places. Management prerogatives and politics ensured that the problems of regional integrated conjunctive use and water quality were not going to be solved by one agency acting alone.

Annual declines in the aquifer in the Guerdane area reflect the intensity of farming and pumping. Groundwater levels will be sufficiently deep to make pumping uneconomical in many locations.

It became clear that important changes had to occur. First, emphasis on water management for optimum benefits replaced the expansion of demand as a guiding principle [11]. Next, water managers had to have a broader perspective to plan for the maximum sustainable production from the renewable and nonrenewable water resources. Finally, local water problems had to be met with local solutions and with flexibility.

6 Key Conclusions and the Way Forward

Statistics show a clear downward trend in global water availability in the Souss-Massa basin. In addition to recurrent drought, exacerbated by climate change, the region has experienced over the past three decades an acute pressure on water resources. This tendency is accentuated by a growing demand, notably due to population pressure and the socio-economic development. Indeed, it is a very dynamic area where water resources are very requested by agriculture.

The analysis of the current state of water resources in the area shows that there is a significant imbalance between supply and demand of water with an average annual deficit exceeding 260 million m^3.

The HCP report (2014) projects the SM population to rise to 3.15 million by 2030, or a factor of 1.23. Rising incomes will increase the quantity of food consumed and the animal protein content of diets. Given the relatively high virtual water content of animal protein, water demand will increase in far greater proportion than the increase in food demand. Without efficiency gains, global water withdrawals are projected to increase from 700 million cubic meters to 1,047 million by 2030, leaving most of the population of remote areas afflicted by water scarcity.

Even if the SM region has long been involved in the process of controlling and mobilizing water resources and has adopted an integrated planning and management framework for its water resources, a lot has still to be done to support the sustainable decision system of water management. A clear strategy has to be tuned for an appropriate combination of the technology and/or nature based solutions to deal with environmental scarcities, as it has been proved in the cases of the Guerdan and Chtouka projects.

The production and consumption model adopted since early colonial period was based on abundant natural resources and a linear pattern of extraction, production, consumption, and disposal. This business model has certainly accelerated economic progress of the Souss-Massa region but that was at the expense of natural capital, specifically for water, while aggravating social disparities.

In fact, the landscape of the Souss valley has changed, so that its natural capital has been degraded as a result; 50% of argan forests have been removed, and 50% of underground water stock have been depleted and the Souss River has been modified. Methods to help restore this natural capital will impact positively on future catchment management.

Urbanization has also induced intensive human consumption patterns beyond the ability of the Argan ecosystem to regenerate its resources. Hence, the challenge is to replace this linear model with a circular economy model.

In order to apply the circular economy principles to the water management plan, three major solutions should be undertaken:

- Mainstreaming natural capital into development policies, taking into consideration the shadow price of water in economic transactions
- Rehabilitating the Souss-Massa hydraulic system

- Adopting good governance that shall protect and promote human rights up/downstream the river course

More specifically, a study on watersheds susceptibility to decreasing of their storing capacity, the life of the dams, and the consequent corrective actions is crucial to the effectiveness of corrective measures of the watershed management plan.

Replication of projects based on sustainable water management and water saving agricultural practices will also strengthen the protection of the Souss-Massa water through reduction of soil loss and protection of water reservoirs, and will also provide sustainable income to the local population.

Responsibility for water management and use is a sensitive issue, involving property rights up- and downstream the river remains a controversial issue within the community and the government, and requires delicate negotiations.

Switching towards ecological intensification practices in agriculture by utilizing and enhancing the contribution of ecosystem services on farmland coupled with water saving technologies seems to be an appropriate solution for a responsible investment in this vital sector.

The natural capital approach is not any more a compromise, it can bring multiple benefits and incur arguments to enhance partnership system, but it should be linked back to multiple sources of funding and coordination of the integrated water management.

The concept of natural capital works at the policy level, and in infrastructure planning, water management as well as in environmental rehabilitation; hence:

- There is a need for more integrated and sustainable infrastructure solutions
- The current approach to water management in the Souss-Massa basin needs to be adapted, to include the social and natural benefits that water management measures can provide within the way it carried out its business.
- Effective long-term water management solutions can only be found by fully understanding and valuing social and natural impacts and benefits.

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