NORTH-WESTERN SAHARA AQUIFER SYSTEM

For a Better Valorization of Irrigation Water in the SASS Basin

Diagnosis and Recommendations

SAHARA AND SAHEL OBSERVATORY

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INTRODUCTION

THE BASIN

The North-Western Sahara Aquifer System, better known under the French acronym "SASS", extends over a total area of one million km2. This transboundary aquifer system is shared by Algeria (700 000 km^2) Libya (250 000 km^2) and Tunisia (80 000 km^2).

The basin's water reserves are estimated at 60 000 billion m^3 distributed over two superimposed aquifers: the Intercalary Continental (IC), with a depth that reaches 3000 m in certain areas, and the Terminal Complex (TC), of a depth comprised between 300 and 500 m. According to OSS and the concerned countries' estimations, the annual recharge of the aquifer amounts to one billion m^3 and estimated withdrawals have increased from 0.6 billion m^3/yr in the early 1970s to 2.7 billion m^3/yr in 2012. In 50 years, the exploitation of the SASS water resources has increased fivefold and driven the basin into a state of overexploitation that exceeded the threshold in the early 1980s.

THE SASS WATERS: VITAL RESOURCES

The SASS basin is highly important at the socio-economic and environmental levels in the three neighbor countries. It represents the unique resource of water to support the economic and social development in the Saharan regions as it fulfills a multitude of needs starting from feeding populations with drinking water, to irrigation and livestock breeding, to meeting the demand of tourism and industrial activities.

On the quantitative level, risks related to water deficit affect agriculture the first. The intensive use of the SASS water resources resulted in a significant drawdown of the two tables and led to the drop of artisianism and depletion of sources, shallow wells and traditional water catchment and distribution systems (Foggaras). In order to bridge this gap of water deficit, there has been a tendency to multiply boreholes and dig deeper drillings. Consequently, the resource mobilization costs (energy bill of water pumping) have become a real constraint.

On the qualitative level, the fact of moving water upwards to the surface and discharging it -- without conducting an adapted drainage -- results in an excessive rise of surface water tables, as the case for Ouargla and El Oued (South-East Algeria), which leads to soil and water salinization.

Combined, the quantitative and qualitative impacts have sound socio-economic effects felt mostly by the populations whose livelihoods depend essentially on agriculture. The salinization of less accessible water and a degraded soil result in lower agricultural yields hence a decrease of farmers' revenues. This dynamic makes the Saharan agriculture less attractive and may lead in some cases to a total abandonment of the agricultural activity.

THE SASS PROJECT

A first study was conducted from 1999 to 2002, within the natural boundaries of the basin, and was only apprehended - until then- at the national level or within the framework of bilateral collaborations. The first results led to a clear enhancement of the hydraulic knowledge of the aquifer system, translated concretely in:

- The creation of a common database comprising about 9000 water points;
- The development of a hydraulic management model to assess the impacts of water withdrawals on the resource;
- The establishment of a consultation structure at the technical level.

In 2003, new studies and agricultural diagnostics aimed at consolidating the knowledge of the basin's hydraulic aspects were launched. They helped to shed light on the inefficiency of irrigation, the inadequate valorization of water and degradation of soil quality. These studies highlighted the fragility and non-sustainability of the agricultural systems prevailing in the SASS basin.

In 2006, and following a process conducted by OSS during the previous study phases, the three countries concerned succeeded in setting up a common management framework, the Consultation Mechanism that had as mission the implementation of a concerted policy for sustainable groundwater management at the basin scale.

The overexploitation of the Aquifer System, with all the environmental and socio-economic impacts it implies, has led the three countries to gather around common objectives with a view to controlling water demand, improving its productivity and protecting the environment. Efforts were focused on the agriculture sector, the first consumer of the basin's groundwater resources.

In 2009, OSS launched the third phase of the SASS project which was structured around two main components:

- A "socio-economics" component that has as objective the analysis and understanding of the irrigator's behavior for a better valorization of water resources;
- A "demonstration pilots" component that aimed to prove the feasibility and acceptability of technical innovations to treat the major issues of the Saharan agriculture.

The third phase of the SASS project led to the elaboration of a number of recommendations for the implementation of a sustainable land and groundwater resources management strategy on the entire basin.

SOCIO-ECONOMIC ASPECTS

This component aimed to describe the operation of the selected pilots and the farmer's (irrigator's) behavior. It allowed to elaborate a quantitative and qualitative baseline on irrigated agriculture in the entire basin. Following a series of consultation between OSS and its partners in the three countries involved, thirteen zones were initially selected as representative of the agricultural, environmental and economic issues on the basin. Only ten zones were finally retained and further surveys were conducted in the three countries:

- Tunisia: 5 zones: Gabes, Kebili, Tozeur, Medenine, and Tataouine
- Algeria: 4 zones : Biskra, El Oued, Ouaegla, Oued el Righ
- Libya : 1 zone : Essouani in the Libyan Jeffara .

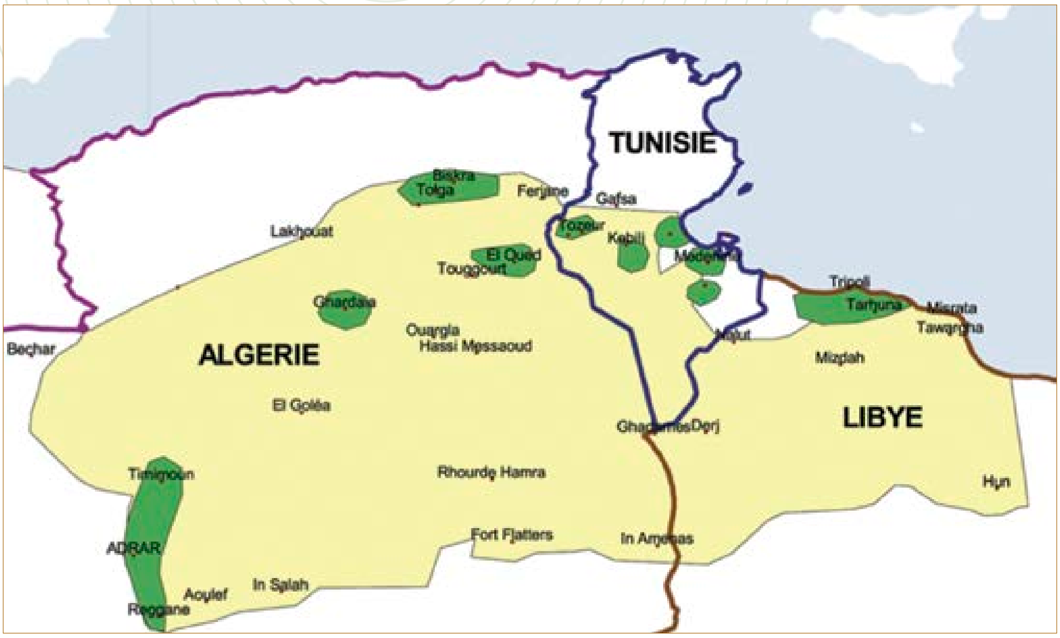


Figure 1. Location of the survey zones.

METHODOLOGY

Out of the ten surveyed zones, a sample of three thousand farms was retained based on various criteria ensuring the sample's representativeness of the whole region, including notably the proportion of irrigated surfaces, the size of farms and the type of access to water.

Two survey campaigns were conducted on this sample (Graphic 1).

The survey's questionnaire was elaborated based on twelve themes covering the quantitative as well as qualitative aspects of the irrigators' activities.

Three categories of access to water were identified:

- *"free" access:* water is considered free when the irrigator does not pay for water pumping or transportation until his plot; (0.004 €/m³ is the average cost declared for the maintenance of irrigation network);
- *"public" access:* the farmer has access to a public subsidized irrigation network;
- *"private" access:* the farmer has a private borehole and takes in charge all costs related to the resource mobilization and network maintenance.

The analysis is based on the following economic variables:

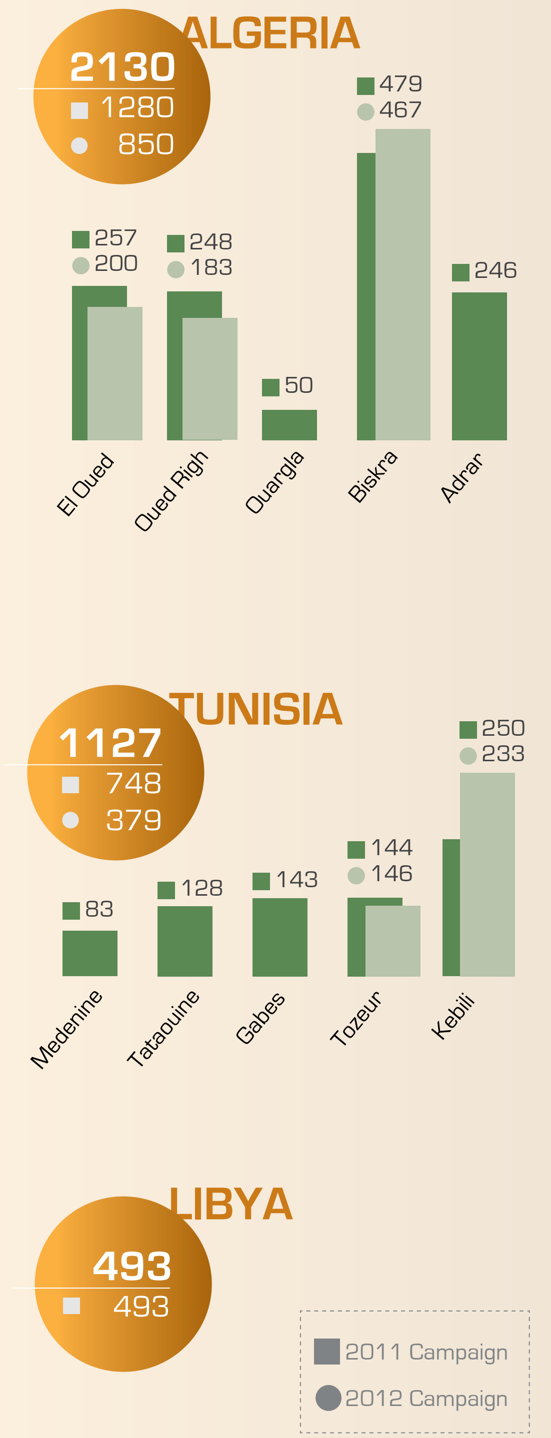
- *water consumption and average irrigated area:* data pertaining to this variable were obtained by combining the responses of surveyed farmers (area, flow, type of irrigation systems …) with the expertise and validation of local water authorities;
- *water cost:* the amount of fees paid by the farmer to mobilize water until the plant;
- *gross margin:* difference between revenues and expenses (workforce, water cost, inputs, fodder);
- *water productivity:* gross margin per m3 consumed for irrigation; it allows to evaluate water valorization;
- *price-elasticity of water demand:* variation of water demand (in %) induced by the change water pricing;
- *salinity-elasticity of water productivity:* variation of water productivity (in %) induced by the change of salinity.

RESULTS OF SURVEYS

Categories of users and profile of consumptions per country

These results allow to describe the irrigator's behavior per country based on the most relevant variables, notably the cost born by the irrigator and the impacts of water salinity on productivity.

The table 1 shows that farmers who have private access



Graphique 1. Spatial and temporal distribution of data retained for the analysis.

Table 1. Summary of results by category of access to water per country.

	Average SASS	Private access	Public access	Free access	Algeria	Libya	Tunisia
Water consumption per hectare et per farmer (m^3/ha)	12 686	10 516	14 746	21 735	13 520	9 134	13 266
Water cost ($/$m^3$)	0.036	0.045	0.028	0.004	0.036	0.028	0.040
Water productivity ($/$m^3$)	0.413	0.484	0.350	0.274	0.405	0.341	0.458
Gross margin per ha	3 909	4 270	3 176	4 683	4 632	2 861	3 478
Importance of breeding (% of the agricultural revenue)	17.72	19.7	12.94	30.85	14.9	27.9	9.4
Average irrigated area (ha)	4.2	6	2.6	0.85	5.1	6	1.8
% of water demand's price elasticity (variation of water consumption when the water price increases by 100%)	-12	-27	-8	-	-45	-25	-33
% of Salinity-elasticity (variation of water productivity when salinity increases by 100%)	-75	-67	-80	-	-53	-52	-35

to water bear a relatively higher cost which leads them, in a first step, to reduce their consumption of water. In order to compensate for this differential in revenue (gross margin), farmers tend, in a second step, to adopt alternative and more profitable agricultural systems, i.e. systems that help to improve water productivity.

In addition, the price elasticity of water demand per country and per category of farmers shows that the higher the cost born by the farmer is, the less water is consumed. To be noted, however, that the fragmentation of agricultural lands considerably reduces the potential for water saving (case of Tunisia where the average irrigated area does not exceed 1.8 ha).

The salinity-elasticity of water productivity calculated per country and per category of farmers indicates in all cases a great vulnerability of farmers to salinity (gross margin). The importance of the results obtained by the analysis lies in the measurement of the economic impacts of salinity, which enables to conduct cost-benefit analyses to evaluate water and soil conservation programmes and thus justify necessary investments (drainage systems, land rehabilitation, demineralization, etc.).

More generally, the set of results included in table 1 could serve as a basis for the elaboration of Saharan development policies based on different instruments as pricing (increasing the cost of water born by the irrigator), land tenure (reducing land fragmentation), or incitements to encourage water and soil conservation investments. Other than the aspects related to water salinity and productivity, it is worth mentioning the positive impacts at the local level: population settlement, preservation of traditional Saharan lifestyle, protection of oases ecosystems, etc.

Water Productivity per agricultural system

Table 2 distinguishes water valorization according to a classification of agricultural systems and shows the most interesting systems to support according to two criteria of water productivity / and gross margin realized by the systems: dense oases, vegetable crops (off-season), and crops/ livestock.

Table 2. Summary of key findings by production system.

	Oasis	Open field	Arbo.	Dense oasis	Vegetable crops	Livestock
Surveyed farmers	994	237	386	1409	459	164
Water consumption (m^3/ha)	10 628	8 371	7 727	16 869	11 920	13 872
Area	3. 9	11. 6	4. 4	2. 57	5. 32	3. 91
Water cost ($/$m^3$)	0. 036	0. 044	0. 046	0. 029	0. 044	0. 035
Water productivity ($/$m^3$)	0. 199	0. 344	0. 456	0. 558	0. 574	0. 769
Gross margin/ha ($)	1 827	3 124	3 271	7 548	7 285	11 841

These results show that increasing revenues is possible by consuming less water by opting for more adapted agricultural systems.

The results obtained could actually inspire an agricultural policy that aims to encourage the most water-valorizing agricultural systems and to reduce areas allocated to less profitable systems.

Results of the socio-economic surveys conducted in Algeria

Agriculture occupies 17.4% of the total area of Algeria and employs 20% of the total active population. The sector's water needs mobilize 65% of the country's water resources (sources: Ministry of Agriculture, Algeria, 2011).

In Algeria, the price paid by the farmer is less than the cost price, which does not help to reduce water consumption. In order to reverse this trend, the Algerian government has been committed since 1994 to an annual increase of water price of 10%/yr over a period of ten years. It is within this objective that Algeria has enriched since 1996 its national water strategy by adapting it to climate change and the socio-economic needs of the country in line with four main principles:

- water is considered as an economic good;
- water resources should be protected quantitatively and qualitatively;
- water management is the concern of all;
- consultation is ensured among the basin's committees.

Table 3. Results per category and per region in Algeria.

	Algeria	Access	Public access	Free access	Biskra	Souf	Righ	Adrar
Water consumption per ha and per irrigator (m^3/ha)	13 432	11	14	22	12 383	13 023	14 218	14 518
Water cost (Algerian Dinar/m^3)	2.60	3.08	1.60	0.39	2.52	3.6	1.8	2.18
Water productivity (AD/m^3)	38.20	35.40	17.77	17.98	36.6	37.4	13.5	26.7
Average irrigated area per ha	4	6.12	3.3	1.01	5.28	3.65	2.15	6.91
% of livestock in the total revenue	14.9	14.38	10.82	33.28	16.9	13.84	19.5	19.6

Analysis of the Algerian surveys

The survey conducted in Algeria showed that 66% of irrigators belong to the "private access" category with a total water consumption of about 65% of the annual withdrawals. One third of the surveyed irrigators belong to the "public access" category with water consumption in the order of 30% of total withdrawals. A small number of irrigators (about 4%) have access to both private and public irrigation systems.

In addition, the results of the Algerian survey indicated regional disparities at the level of consumption: while the regions of Biskra and Adrar represent respectively 42% and 38% of annual water consumption, the regions of Souf and Oued Righ represent only 18% and 2% respectively.

Table 3 shows that farmers with private access to water pay almost twice the cost paid by those connected to a public network (3.08 AD/m^3 against 1.6 AD/m^3) which incites farmers with private access to save more water. For instance, their average consumption of water is 11,000 m^3/ha against 14 000 m^3 /ha for farmers with public access. On the other hand and in order to preserve their incomes, farmers with private access to water valorize the one m^3 of used water much more than farmers with public access. The productivity of one m^3 reaches 35 AD for users of private water while it is in the order of 18 AD for public and free access.

Except for the Adrar region, where water consumption is very high due to an extreme aridity, the differences in water consumptions per hectare in the other regions could be explained by the importance of the collective network in each region (Oued Righ, highly important collective network, high water consumption rate per hectare).

The table also shows that water cost is higher in the regions of Biskra and Oued Souf (2.52 and 3.6 AD/m^3) than in Oued Righ (1.8 AD/m^3) as for the two first regions, most of farmers have private access to water, whereas, for the third region, access to collective water is largely subsidized. The relatively low cost of water in Adrar could be explained by the intensive utilization of the region's "foggaras".

Socio-economic Results in Libya

Jeffara, the survey zone, is the largest irrigated zone in Libya. It represents 70% of the country's total irrigated area. Most of the public hydraulic infrastructures in the study zone are not operational which induced all farmers to turn to private irrigation systems. The proliferation of boreholes leads to an overexploitation of water tables: deeper drillings, sea water intrusion, water table salinization, decline of agricultural yields and abandonment of irrigated agriculture.

Table 4. Results per category and per region in Libya.

	Libye	Private Access	Margueb	Tripoli	Jeffara	Zaouia	Zouara
Water consumption per ha and per irrigator (m^3/ha)	9	9	10	10	9	9	7
Water cost (Libyan Dinar/ m^3)	0.036	0.036	0.027	0.34	0.039	0.041	0.029
Water productivity (LD/ m^3)	0.433	0.433	0.471	0.412	0.449	0.442	0.342
Average irrigated area per ha	5.9	5.9	7.31	5.36	5.95	6.42	4.13
% of livestock in the total revenue	27.9	27.9	20.1	34.6	24.2	31.3	37.4

Analysis of the Libyan Surveys

In Libya, access to water is private. The country is the least consumer of agricultural water

Tunisia

Population	10,980,000 hab.
Area	164,420 km^2
Water demand for all sectors (2012)	11 billion m^3/yr
Renewable water resources	4.38 billion m^3/yr
Non-renewable used groundwater resources	0.65 billion m^3/yr
Total irrigated surface	0.432 million d'ha
Withdrawal for irrigation	2.313 billion m^3/yr
Irrigated area in the SASS*	38,000 ha

** OSS 2012* *Source : MEWINA Report, December 2014.*

Algeria

Population	37,500,000 hab.
Area	2,281,740 km^2
Water demand for all sectors (2012)	10.5 billion m^3/yr
Renewable water resources	13.62 billion m^3/yr
Non-renewable used groundwater resources	2 billion m^3/yr
Total irrigated surface	1.053 million d'ha
Withdrawal for irrigation	6 billion m^3/yr
Irrigated area in the SASS*	202,000 ha

** OSS 2012* *Source : MEWINA Report, December 2014.*

Libya

Population	6,200,000 hab.
Area	1,775,500 km^2
Water demand for all sectors (2012)	6 billion m^3/yr
Renewable water resources	0.625 billion m^3/yr
Non-renewable used groundwater resources	1.79 billion m^3/yr
Total irrigated surface	0.6 million d'ha
Withdrawal for irrigation	6.06 billion m^3/yr
Irrigated area in the SASS*	30,000 ha

** OSS 2012* *Source : MEWINA Report, December 2014.*

Graphique 2. Description of land and water resources in the three countries.

among the three countries sharing the SASS basin. However, the predominance of semi-intensive agriculture makes of water productivity the lowest in the basin.

Table 4 shows that water consumption per hectare in Libya is considerably lower than water consumption in the two other countries of the SASS basin (about 9,000 m^3/inhab/yr), which could be explained, on the first hand, by a far less intensive farming activities in Libya compared to Tunisia and Algeria and by a low water productivity as arboriculture (needs less water than other crops) is the predominating activity in the country. Finally, we can also notice the high contribution of livestock farming in farmers' revenues.

Results of the socio-economic surveys in Tunisia

With a consumption rate that reaches 80%, the agriculture sector is the first consumer of water in Tunisia. *The hydraulic policy adopted in Tunisia since the 1980s was focused on water resources mobilization.*

Table 5. Results per category and per region in Tunisia.

	Tunisia	Access	Public access	Free access	Meta** (Jeffara)	Gabes	Kebili/ Tozeur
Water consumption per ha and per irrigator (m^3/ha)	11	7 171	12 532	15 871	3 696	7 038	16 835
Water cost (Tunisian Dinar/m^3)	0.068	0.088	0.062	0.009	0.096	0.079	0.048
Water productivity (TD/ m^3)	0.691	1.050	0.556	0.047	1.014	0.746	0.494
Average irrigated area per ha	2.07	4.03	1.49	0.71	2.90	4.18	1.01
% of livestock in the total revenue	np	19.1	14.65	14.45	25.8	17.1	8.6

**(NP : not produced)*
*** Medenine/Tataouine*

Analysis of the Tunisian surveys

The "public access" category is the most important in Tunisia as it represents 70% compared to 27% for "private access" and 3% for "free access". Given their frequency, "public systems" consume about 10 million m^3/yr of water, i.e. 57% of the total water consumption in Tunisia, compared to 34% for private access.

Table 5 further confirms the observations made for the two other countries. However, the phenomenon is accentuated for Tunisia. In fact, the difference between private and public water consumption is more important in the case of Tunisia (about 7000 m^3/ha for private access and 12 500 m^3/ha for public access. This could be explained by the different cost allocated to water in the case of private access (much higher than public access to water). Private access to water leads to a better water valorization (1.05 TD/m^3 against 0.556 TD/m^3 for public access and 0.047 D/m^3 for free access).

Water consumption on the other hand differs from one region to another inside the country. In fact, it goes from 3,633 m^3/ha in Jeffara (governorates of Medenine and Tataouine) to 16,813 m^3/ha in the Saharan oasis zone (Governerates of Kebili and Tozeur), i.e. almost fivefold. This could be explained by the high water consumption rates in the Saharan oasis, a region dominated mainly by multi-storey farming systems, especially date palms. In addition, traditional methods of irrigation, namely spray irrigation, are largely used in these regions and contribute to an increase of water consumption. Whereas, in Jeffara (Medenine and Tataouine), water supply represents a supplementary irrigation for rain-fed crops.

On the other hand, water valorization goes from 0.494 TD/m^3 in Jerid to 1.1014 TD/m^3 in the region of Medenine - Tataouine, i.e. more than doubled. This high disparity could be explained by the different specifities of farming systems practiced in the two regions and by the difference in the costs of irrigation networks.

We should finally note that breeding is one important source of revenue for the farmers of the Jeffara region, whereas it only represents a modest supplementary activity in the Saharan oasis region.

HYDRO-ECONOMIC MODEL

A hydro-economic model was elaborated within the framework of the SASS III project in order to provide policy-makers with an appropriate tool to support them in designing and implementing effective agricultural development policies. This tool integrates economic calculation for water resources management through the assessments of goods and services generated by the different agricultural usages of this resource. It also allows to simulate scenarios on an encrypted and quantified basis.

The hydro-economic model was designed and put into operation based on the global and micro-economic data collected and the results obtained through the quantitative analysis. Its application is possible at the regional and local levels and inside the basin.

The hydro-economic model aims to increase the revenue of the irrigation activities conducted under economic and hydrological constraints and enables to obtain for each scenario developed:

- the maximum volume of water to be pumped from the aquifer;
- the maximum income generated.

Depending on the results obtained, the policy maker could hence develop his policy on the relevant scenario.

CONCLUSION

The considerable number of farms surveyed helped to acquire a comprehensive understanding of water usages and users' behavior in the three countries concerned. Data analysis enabled to quantify the impacts of salinization on water productivity and the effect of water pricing on its consumption. The socio-economic component allowed, on the one hand, a better legibility of the agricultural system's viability when the quality of water degrades and to give simple economic indicators that serve to orient policy makers. On the other hand, the socio-economic study highlighted the importance of structural factors to ensure the viability of agricultural systems. It mostly demonstrated the importance of social organization as a key factor in water productivity (involvement of family labor, level of instruction of farmers, previous experience with irrigation, and combination of cultivation/breeding).

The socio-economic component showed that water valorization is possible if key factors related to the user's behavior are taken into consideration: who consumes water, in which order and in what way.

This approach helped also to show that the main users of water in the SASS basin are farmers who have private access to water through private boreholes. This category of farmers has also the highest production percentage. The relatively high productivity of water for the "private access" category could be justified by the fact that paying for water arouses a great concern for efficiency in the farmer. Beyond this conclusion, it would also be extremely important to enhance and deepen the understanding of the farmer's behavior in the SASS region by conducting further studies on water pricing.

DEMONSTRATION PILOTS

The agricultural demonstration pilots aimed to test *technical solutions for a better productivity of water* in the SASS basin.

These solutions were developed taking into consideration the following:

- the economic profitability of hydro-agricultural structures and systems;
- the improvement of irrigation water productivity;
- the increase of farmers' revenues;
- the preservation of the environment.

APPROACH

All the technical innovations introduced in the demonstration pilots were supported by a *participatory approach* that implicates all actors involved in groundwater use and management. Farmers were involved in all stages of the pilots' implementation, starting from the design until the final realization of the pilot. All activities were conducted in a way that ensures the interaction with *the primary actor (farmer)* and tries to convince him that he could produce more with less water. The social acceptability and transfer of the technical innovations introduced were promoted thanks to a *proximity method* that makes of the farmer a mediator for agricultural extension in the rest of the region.

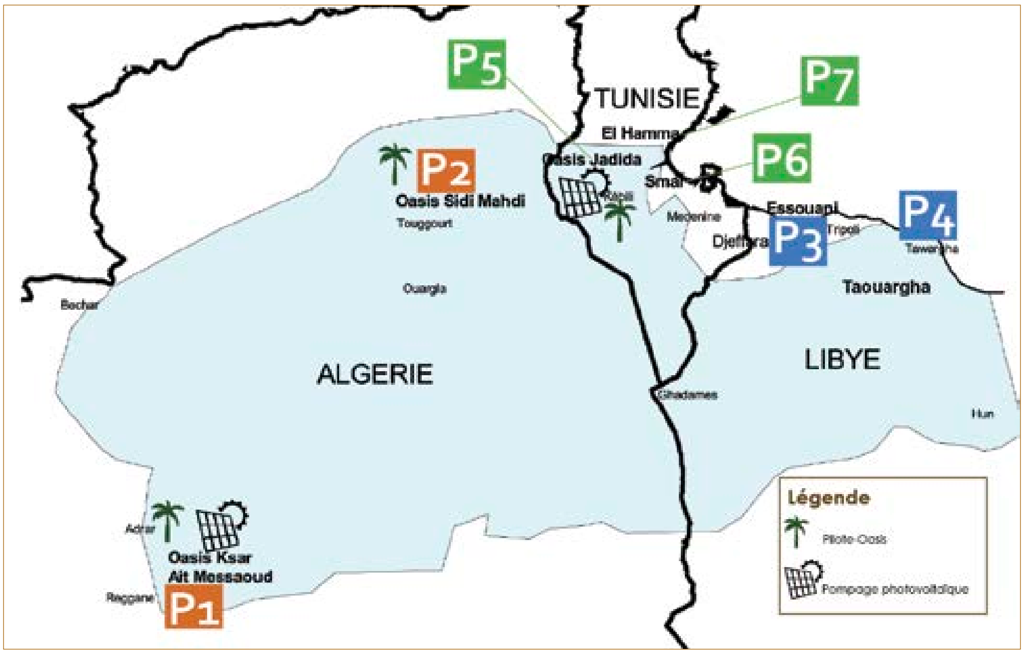


Figure 2. Location of the agricultural demonstration pilots.

ISSUES

Six demonstration pilots, featuring four major problems facing the Saharan agriculture, were selected in close collaboration with institutions in charge of water management in the three countries concerned.

These issues include mainly:

- water deficit;
- water salinization;
- inefficiency of irrigation;
- soil degradation.

The technical innovations adopted at the level of the six pilots to address these issues concern four major themes:

Theme 1: recourse to solar energy

Two photovoltaic solar stations were established within the framework of the "demonstration pilots" component. In Algeria, the solar station installed at the level of Ksar Ait Massaoud oasis, allowed to strengthen the initial flow of the "foggarra" threatened by depletion (Pilot 1), while the second station set up in Tunisia helped to evacuate drainage water and rehabilitate agricultural lands (Pilot 5).

Theme 2: Brackish Water Valorization through demineralization

An experiment conducted in the region of Medenine in Tunisia (Pilot 6) showed that *la groundwater demineralization and use in irrigation is economically profitable for agriculture*. The installation of a demineralization station allowed to improve agricultural yields and to increase the availability of water with a salinity generally adapted to crops by mixing demineralized water with brackish water.

Theme 3: Rehabilitation of lands degraded due to water stagnation

The installation of buried drainage networks at the level of pilot 2 (Touggourt, Algeria) and Pilot 5 (Kebili, Tunisia) helped to reduce soil salinity, decrease the water table level (hydromorphy), and improve agricultural yield.

Theme 4: Irrigation Efficiency and Agricultural Intensification

The efficiency of irrigation was improved, notably at the level of Pilot 4 (Essouani, region of Tripoli, Libya). Adapted agricultural intensification modes allowed to have a better water productivity, improve farmers' revenues and control environmental impacts.

AGRICULTURAL DEMONSTRATION PILOTS

Pilot 1 Reggane, region of Adrar (Algeria)

The overexploitation of groundwater induced by an uncontrolled proliferation of boreholes led to the depletion of most of the foggaras in the region. The "foggaras"'water serves essentially to irrigate date palms and associated crops (olives, fodder, cereal, and vegetable crops). The depletion of fogarras has actually led to a gradual abandonment of irrigation and of traditional oasis systems.

New techniques were used at the level of this pilot including the introduction of solar pumping upstream the "foggara", and modern irrigation techniques downstream.

The success of this operation triggered a series of discussions and exchanges among local actors focusing on prospects for replicating this pilot in other oases according to modalities that fit the social and community network in the region.

	Issue	Main cropping system	Area	Irrigation mode	Socio-economics
Context	Water deficit Foggaras threatened by depletion	Date palms	1 ha	Gravity irrigation / Flood irrigation	Abandonment of irrigated agriculture

Objectives	Implementation means	Results
• Restore the initial flow of "foggaras" to 5 l/s • Save water • Intensify oasis agriculture • Improve revenues	• Allocation of boreholes' water using solar pumping • Water pressurization • Moving from gravity irrigation to drip irrigation	• **Implementation of intercrops between date palms** • **More than 80% of cultivated area** • **Water economy of 40%** • **Increase of agricultural yields** • **Increase of farmers' revenues by 100%**

Before

After

Pilot 2 Oued Righ (Algeria)

In certain oases of the SASS zone, water excess represents a major risk. In fact, the lack of maintenance of drainage networks –after the management of irrigated lands- led to the rise of the water tables level and accelerated soil salinization. This resulted in the degradation of plants and in extremely weak yields which would hinder the future of irrigation in the region.

This pilot yielded positive results starting from its second year of implementation with a significant decrease in drainage water salinity and better soil quality. The improvement of soil and water quality helped to increase the date palms yields. Agricultural intensification, through intercropping, allowed to increase water productivity.

	Issue	Main cropping system	Area	Irrigation mode	Socio-economics
Context	Drainage problems: water stagnation and soil salinization	• Date palms • Subsistence crops	5 ha	Gravity irrigation / Flood irrigation	Palms degradation

Objectives	Implementation means	Results
• Make irrigation more efficient and rehabilitate soil and water • Intensify agriculture • Improve revenues	• Buried drainage system • Conversion of Seguia to PVC canals • Localized irrigation • Intercropping • Off-season high-value-added crops	• **Lowering the level of stagnated water by 1.6 m** • **Reduction of salinity by 40%** • **Intensification of agriculture (intercropping)** • **Increase of agricultural yields by 50% compared to previous years**

Before

After

Pilot 3 Essouani (Libya)

This pilot is located in the agricultural suburban zone of Tripoli. Historically, agriculture was mainly rain-fed. Within the framework of a voluntary policy for food security, the Libyan government has been encouraging for the past years conversion into irrigated agriculture, which led to the proliferation of private boreholes. The visible signs of groundwater overexploitation soon appeared: drawdown of water tables, sea water intrusion, decline of agricultural yields, soil degradation and abandonment of unprofitable irrigated agriculture.

The success of profitable irrigated agriculture helps to revive the sector and create agricultural opportunities for rural populations. This pilot showed the viability of suburban agriculture to supply the local markets of Tripoli as well as other national markets. The performances of this pilot could still be improved in terms of irrigation efficiency, brackish water demineralization, off-season intensification and reduction of soil leaching.

	Issue	Main cropping system	Area	Irrigation mode	Socio-economics
Context	Water deficit and salinization	Vegetable crops	5 ha including 3 permanently irrigated hectares	Gravity irrigation	Abandonment of agriculture

Objectives	Implementation means	Results
• Increase the efficiency of irrigation with brackish water of 1.6g/l salinity and save water • Improve farmers' revenues	• Localized irrigation • Intensification of agricultural systems • Crop rotation irrigated with brackish water • Preventive phyto-sanitary treatment and adapted fertilization • Off-season crops conducted under tunnels and in open fields	• **Yield of 85 tons for 2.8 ha in 2012 compared to 25 tons for the highest production registered in previous years** • **Revenues of 28 225 € compared to 7000 € for the best revenues registered in previous years** • **Intensification of agriculture (intercropping)**

Before

After

Pilot 4 Taouergha (Libya)

The political situation in Libya came against the implementation of this pilot. So, it was replaced by another similar operational pilot in Tunisia in order to facilitate the transfer of know-how to Libyan technicians and farmers.

Like the zone of Taouergha in Libya, Gabes (Tunisia) disposes of important geothermal water resources with a temperature reaching 55 ° C. the main objective of this pilot was to promote the use of geothermal waters in irrigating off-season and greenhouses vegetable crops. This pilot aimed to valorize the dual-use of geothermal water first by taking advantage of its free heat and second by using it in irrigation.

The farm selected for this pilot is important and represents a good example for the double valorization of geothermal waters in hyper-intensive agriculture. It is a Small and Medium-sized Enterprise (SME) of 12 ha exporting its products into Europe. The capital gain of this pilot was demonstrative at the technical level, but it only promoted the transfer of technology and the constitution of a competence network in terms of using geothermal waters in agriculture.

	Issue	Main cropping system	Area	Irrigation mode	Socio-economics
Context	Valorization of irrigation with geothermal (40°C) and desalinated (3 g/l to 0.2 g/l) waters	Vegetable crops	12 ha	• Private borehole in the Intercalary Continental • Localized irrigation	• Development of the farm • Exportation of the entire production • Private Tunisian-Dutch partnership

Objectives	Implementation means	Results
Transfer of knowledge on the use of geothermal waters	• In-field visit with the partners of the three countries concerned • Agro-economic studies	**Competence network and transfer of agricultural technologies**

Pilot 5 Kebili (Tunisia)

The main issue of this pilot relates to soil degradation caused by irrigation with brackish water and hydromorphy.

The drainage and pumping stations installed yielded the expected results. Stagnated water was evacuated which helped to reduce salt in water. Following consecutive leaching operations, water salinity was stabilized with that of the natural salinity of irrigation water. However, in 2012, the main borehole (900 m) feeding the pilot collapsed and a new borehole was constructed in autumn 2014. We should wait until the end of the 2014-2015 agricultural campaign to confirm results.

	Issue	Main cropping system	Area	Irrigation mode	Socio-economics
Context	• Stagnation of irrigation water (-0.7 m below the soil surface • Brackish water of 10.6 g/l	• Date palms • Food crops	1,6 ha	• Public wells • Gravity/flood irrigation	Sustainability of oasis agriculture

Objectives	Implementation means	Results
• Rehabilitation of irrigated lands affected by salinization and water stagnation • Restoration of oases agricultural systems	• Buried drainage network • Solar pumping to evacuate excess water	• **Evacuation of drainage water using solar energy pumping** • **Drawdown of the water table by -1.2 m** • **Reduction of water salinity by 40%**


Before


After

Pilot 6 Medenine (Tunisia)

The region of Jeffara in Tunisia is characterized by extreme aridity and the predominance of rain-fed olives cultivation. The governorate of Medenine includes about 200 000 ha of olives, but, given the lack of precipitation and recurring droughts, yields are generally low.

Family irrigation using saline groundwater does not help to improve agriculture and stabilize rural populations. Thus, the main objective of this pilot is to demonstrate the technical and economic feasibility of brackish water demineralization for family irrigation.

The realization of this pilot required the installation of costly infrastructures, but results showed that these investments were actually profitable for the farmer. The productivity of one hectare of olive trees and vegetable crops, as well as the overall agricultural revenues, increased tenfold.

	Issue	Main cropping system	Area	Irrigation mode	Socio-economics
Context	• Water deficit • Water salinization (4g/l) • Reduction of rangelands	• Olive cultivation • Vegetable crops	1,2 ha	Family wells	• Abandonment of agriculture • Immigration • Rural exodus

Objectives	Implementation means	Results
• Desalinize Water for irrigation • Improve irrigation efficiency • Improve agricultural yields and revenues	• Development of plots • Desalinization station • Construction of a basin • Pressurization pump • Localized irrigation network • Installation of two greenhouses	• **Water saving and water production by mixing treated and non-treated waters** • **Efficiency of the localized irrigation of olives** • **Increase of cultivated area to 1.38 ha** • **Increase of agricultural intensification from 25% to 131.6 %**

Before

After

CONCLUSION

The "demonstration pilots" component had mainly an agro-environmental orientation; however, it is worth mentioning that the adoption of an innovative social approach, realized in consultation with multi-actors, has greatly contributed to the attainment of the component's objectives. Farmers, as primary policy-makers, were highly involved in the implementation of activities within an exemplary synergy with partner research institutions.

The demonstration pilots showed that it had been possible to convince farmers to adopt sustainable water and soil management modes, notably a more efficient irrigation. They also concretely proved to farmers that water valorization is possible while preserving ecosystems.

The recourse to solar energy together with the implementation of buried drainage, demineralization, localized irrigation and agricultural intensification were all profitable technical solutions that clearly contributed to improving water productivity. The introduction of an innovative technological package helped to establish a better valorization of water resources at the pilots' level, as well as a better efficiency of irrigation systems. The proximity method and pragmatic way used in convincing and instructing farmers made them ready to pay for irrigation water and invest for a better efficiency. It is the very perception of the value of water that changed for farmers.

The pilots helped to promote dialogue among farmers and to accomplish its role of agricultural extension and technical dissemination. They also facilitated the social acceptability of the introduced innovations. All these dynamics are promising and could actually revive the interest in irrigated agriculture in certain regions of the basin.

The "demonstration pilots" component paved the way for better livelihoods and stabilization of the region's populations and a better conservation of the basin's resources.

CONCLUSION AND RECOMMENDATIONS

The implementation of the third phase of the SASS project was structured around two distinct but complimentary and firmly convergent components in terms of the insight they both brought and the recommendations they helped to formulate.

One of the converging points that could be mentioned is the possibility of improving water productivity (i.e. the cash income of the farmer per a unit volume of water used for irrigation) while preserving soil and water resources and ensuring their sustainability.

Another point of convergence is that both components showed that farmers are ready to invest in economical and efficient irrigation as long as the reorganization of their irrigation and agricultural calendars help to increase their revenues. This convergence point is important for the construction of an agriculturally sustainable and economically viable alternative in the SASS basin.

The results and conclusions demonstrated by the "demonstration pilots" and "socio-economic" components at the level of the survey zones and plots should in fact be valid for the entire basin given the rigor of the sampling method adopted and the representativeness of the pilots selected of the major agricultural issues in the Saharan regions of Algeria, Tunisia and Libya.

However, the experience and rigor advocate for a larger-scale confirmation of the results obtained at the local level. This issue will be tackled in the next phase of the project.

The next phase would pursue investigations on sustainable groundwater management modes while moving from a small-scale "agricultural system" to a larger scale "integrated production system" in a certain way that takes into consideration the interactions between farmers and different production and commercialization actors. The analysis would also integrate local and regional development strategies.

An efficient and sustainable agriculture in the NWSAS basin is possible.

RECOMMENDATIONS FOR A SUSTAINABLE AGRICULTURE IN THE SASS BASIN

■ Encourage the adoption of technological innovations and good agricultural practices through:

- Large dissemination of the "demonstration pilots" concept as an efficient tool for the extension of good agricultural practices and for accompanying the countries in the replication of these pilots;
- Strengthening the exchange of experiences and results among the concerned countries, through the informational platform that could manage the consultation mechanism with the support of OSS;
- Establishment of a technological watch on the different areas of research in relation with agricultural systems in the Saharan zones;
- Development of public/private partnership to promote the transfer of competences and agricultural technologies among the SASS countries;
- Encouraging consultation between farmers' associations and research institutions at the local and regional levels.

■ Incite a better water valorization and soil preservation through:

- The implementation of an economic policy that aims to establish an appropriate pricing of agricultural water which would highly contribute to controlling water demand and increasing water productivity;
- The design and promotion of an efficient policy for the fight against salinity which would contribute to soil protection and especially to improving water productivity;
- The promotion of an appropriate policy to encourage youths to enter and invest in the agriculture sector as most of the farmers are ageing which would have significant negative impacts on water valorization;
- The inclusion of livestock farming in irrigated agricultural systems in the SASS zone which could improve the productivity of water;
- The recourse to the hydro-economic model to promote the most valorizing agricultural systems and have optimal overall revenue.

NORTH-WESTERN SAHARA AQUIFER SYSTEM

For a Better Valorization of Irrigation Water in the SASS Basin– Diagnosis and Recommendations

The North-Western Sahara Aquifer System (SASS) is a basin which extends over 1,000,000 km2 and is shared by three countries (Algeria, Tunisia, and Libya). The NWSAS water reserves are considerable yet generally of quasi fossil nature.

With the aim of enhancing sustainable development in the region, OSS in partnership with the three countries concerned, conducted, in a first phase, several studies that allowed a better hydraulic knowledge of the basin. However, given the growing water needs, notably relative to the agricultural sector, and the necessity to preserve a little renewable resource, OSS decided to undertake a study on water valorization in the basin.

The study was structured around two components:

• A socio-economic component focusing on analyzing the operation modes of agricultural systems and especially on understanding the irrigator's behavior by conducting several surveys realized with almost 3,000 farmers. This analysis enabled to identify the main constraints to water productivity, to measure their economic impacts and to elaborate operational recommendations for a better valorization of the basin's resources.

In addition, a hydro-economic model was developed with the objective of providing decision makers with an efficient decision-support tool to help them develop and implement agricultural development policies.

• A second "demonstration pilots" component concerned the implementation of six demonstration pilots by the farmers themselves dealing with different issues and problems faced by the three countries. The technical innovations introduced at the pilots level aimed at intensifying cropping systems, saving and valorizing water. The results obtained following two agricultural seasons helped confirm the existence of efficient technical solutions for the renovation and implementation of agricultural systems at the farm level.

The results obtained by the study allowed to conclude a number of recommendations for a sustainable development as well as for a better preservation of the basin's resource.

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