SASS III

ELABORATION OF OPERATIONAL RECOMMENDATIONS
FOR A SUSTAINABLE MANAGEMENT OF THE WATER RESOURCES
OF THE NORTH WESTERN SAHARA AQUIFER SYSTEM
July 2010 – June 2014

SOCIO-ECONOMIC ASPECTS OF IRRIGATION IN THE SASS BASIN

A Better Water Valorization for Sustainable Management of the Basin

OSS

SAHARA AND SAHEL OBSERVATORY

SASS III

ELABORATION OF OPERATIONAL RECOMMENDATIONS
FOR A SUSTAINABLE MANAGEMENT OF THE WATER RESOURCES
OF THE NORTH WESTERN SAHARA AQUIFER SYSTEM
July 2010 – June 2014

SOCIO-ECONOMIC ASPECTS OF IRRIGATION IN THE SASS BASIN

A Better Water Valorization for Sustainable Management of the Basin

Drafted by:
Mohamed Salah Matoussi
Regional Consultant

Read by:
Abdelkader Dodo
Water Program Coordinator
Djamel Latrech
SASS III Project Coordinator
Maxime Thibon
Scientific Advisor

Reviewed by:
Khatim Kherraz
OSS Executive Secretary

September 2014

ISBN : 978-9973-856-85-2

Table of Contents

List of Figures and Tables

FIGURES

TABLES

INTRODUCTION

The North-Western Sahara Aquifer System (SASS) covers a total area of one million km^2. This transboundary aquifer is shared by Algeria (700,000 km^2), Libya (250 000 km^2) and Tunisia (80,000 km^2).

The SASS water reserves are estimated at 60,000 billion m^3 distributed over two superposed layers: the Intercalary Continental (CI), with a depth that reaches 3000 m in some areas, and the Terminal Complex (TC) with a depth of 300-500 m. The recharge of the aquifer system is around one billion m^3/year. Estimated withdrawals have increased from 0.6 billion m^3/year in the early 1970s to 2.7 billion m^3/year in 2012. In 50 years, the exploitation of the SASS groundwater resources has passed from a sustainable management situation to over-exploitation.

Promoting the sustainable management of the SASS water resources represents a challenge to the three countries concerned, a challenge that must be met in order to sustain life in one of the most vulnerable regions of the planet. Indeed, this region has been able to maintain a sustainable activity for centuries with an extraordinary ability to adapt to an extremely arid environment by exploiting, in a meaningful way, a transboundary aquifer that contains certainly important yet little renewable water resources. This balance is now disrupted by over-exploitation.

Within the aim of achieving sustainable development in the region, OSS in partnership with the three countries involved, developed over the past decade a number of studies that have allowed a better knowledge of the resources (supply). These studies were followed by the establishment of a permanent Consultation Mechanism with a coordination unit temporarily hosted at the OSS headquarters. The operation of this unit is funded by the three countries.

These studies on water supply alerted all stakeholders on the limits to satisfy water demand expressed by countries to cover the needs of different sectors, particularly irrigated agriculture that consumes more than 80% of the total water demand. The overall balance of the achievements in terms of water supply mobilization is unquestionably positive. However, despite this undeniable success, a gap between available and little renewable resources on the one hand and the growing demand on the other, accentuated by the State guarantees for the accessibility of the resource at a flat rate, can compromise the optimal and sustainable management of the water potential.

Previous studies on the SASS were focused on the characteristics and operation of the aquifer as well as the evolution of withdrawals, but rarely on the valorization of water. The "socio-economics" component of the project aims to fill this gap by a study focused primarily on the impact of the behavior of the primary user on the sustainability of the aquifer. The major objective of this analysis, based both on microeconomic data on appropriate economic and econometric tools, is to provide decision makers with effective instruments for the elaboration of adequate policies that ensure the sustainability of this vital aquifer throughout the region.

This socio-economic study aims primarily at enriching the achievements of the hydrogeological knowledge of water resources by providing socio-economic and environmental data

Figure 1. Map of the SASS basin.

Projet SASS III

The third phase of the SASS project has as final outcomes the elaboration of operational recommendations for the utilization, management, and measurement of water extracted for agricultural purposes, notably in the zones where the water, the soil and/or the ecosystem are most vulnerable.

The project comprises two main components :

1. a component focusing on the realization of a socio-economic study aiming at analyzing the behavior of the user of water in the SASS basin and developing a hydro-economic model which explicitly integrates two main dimensions of a sustainable management of the aquifer, namely its physical behavior and the impacts of the human activity on its sustainability;

2. A second component entitled "Agricultural Demonstration Pilots» aiming at testing the feasibility of the application of technical solutions and technological packages to remedy the major problems noticed in the NWSAS basin, and at demonstrating to the users and decision makers, their adaptability to the diversity of the local situations of the three countries sharing the NWSAS basin.

describing the reality of the farms and especially the actual behavior of the irrigators with particular emphasis on their ability to adapt to the challenges threatening the sustainability of the whole structure. These challenges are diverse; they range from resource depletion due to over-exploitation to the negative impacts of climate change.

Knowing the behavior of the main actor in the life of the oases requires a socio-economic and environmental survey covering exhaustively this important region. The survey, conducted by the project over two campaigns, has helped provide accurate information on all essential aspects of the resource use for about 3000 farms and by processing 4,500 validated questionnaires in a dozen areas spread over an area of about 1 million km2 extending across the three countries. The implementation of such large-scale survey was truly a daunting task that had to be carried out with utmost caution. The second step was to capture, verify and perform a preliminary descriptive analysis of the information thus collected. The third was dedicated to quantitative analysis through econometric tools and the latest optimization techniques. The essential aim of the fourth and final step was to propose operational recommendations to decision makers in the three countries within the framework of the consultation mechanism.

The implementation of this component was conducted as follows:

- designing the survey questionnaire, which was conducted from 1 July 2010 to 31 December 2010;
- identifying the locations where to conduct the field survey for the three countries: This operation was conducted from early November to 31 March 2011;
- developing the survey base: April 2011 - June 2011;
- developing the sample: July 2011 - November 2011;
- completion of the first field survey campaign : December 2011 - September 2012;
- collecting, validating, processing and verifying the data collected in March 2012 - January 2013;
- completion of the second field survey campaign: November 2012 - July 2013;
- collecting, validating, processing and verifying data collected: March 2013 - January 2014;
- Analysis of the data collected by the two campaigns: February 2013 - May 2014.

This report is organized as follows:

- Section I : Developing the questionnaire.
- Section II : Developing the survey base on which is based the preparation of the sample of farmers.
- Section III : Identification of areas selected for the field survey.
- Section IV : Developing the samples of farmers to be surveyed.

- Section V : Verification and validation of questionnaires.
- Section VI : Digital processing of the data collected.
- Section VII : Summary presentation of the tools for the analysis of the data collected.
- Section VIII : Descriptive and quantitative analysis of socioeconomic data. This section is the centerpiece of the report. It is organized into four subsections. The first is dedicated to the presentation of the results of the analysis of the Tunisian sample. The second summarizes the key results of the analysis of the Algerian sample. The results for the Libyan sample are detailed in subsection three, and finally, the last sub-section is devoted to a review of the main results of the analysis of the overall sample of the entire SASS zone.

DEVELOPING THE QUESTIONNAIRE

The basic questionnaire explicitly incorporates all the features and all the criteria to characterize the population of the relevant site and the operation of various types of farms. It was finalized after discussion with the focal points of the three countries.

Emphasis is placed on:

- water and land use as well as different inputs (inputs);
- the role of women in water management;
- constraints faced by the various farmers in the conduct of their activities;
- adaptability of farmers to the challenges of resource scarcity both in quantitative and qualitative terms;
- future prospects.

DEVELOPING THE SURVEY BASE

The socio-economic survey, which represents one of the major pillars of the SASS III project, was designed on sound scientific bases and conducted with the utmost care; so that quantitative analysis, which will be based on econometric techniques and the most advanced operational research, allows obtaining credible results and enables the development of useful operational recommendations to decision makers, it is essential that the sample of farms surveyed be representative of the target population to study. By target population, we mean all the set on whom/which we intend to collect information necessary for the project implementation. This set is nothing in this context that all agricultural water users of the SASS basin.

Statistical theory for the development of representative samples of the population studied is known as the sampling theory. This theory provides that the preliminary step is the definition of a survey base (or plan) which is, by definition, a complete list (file) that is always updated of all the individuals making up the target population. This list must not contain any omissions or double counting.

The ideal would be to have a complete listing of irrigated farms (called survey base) throughout the SASS basin and conduct a random draw of 3000 units to be surveyed. Because this survey base is not available, using the cluster plans or a two-scale surveys, is required.

This method relies on the combination of two simple methods, namely:

- A strata survey (stratification), used in cases where the target population is made up of a small number of homogeneous groups (strata) of large size but different from each other. A stratum is therefore a subset of the target population that is characterized by a greater homogeneity than the entire population.
- A cluster sampling, relevant in the case where the target population consists of numerous groups of rather reduced size where each is characterized by significant internal variability.

The two-scale sampling, which combines these two procedures presented very briefly, will then consist of:

- sampling strata (draw a certain number of units in a target population);
- sampling in each stratum.

The next step in conducting the field survey was therefore adopted:

- First step: choosing the geographical areas to be selected in each country;
- Second step: to establish, in each area, the inventory of existing strata, i.e. existing oasis or, if possible, associations of irrigators, or in some areas, when the choice is wise, the *Daira* (sub-prefectures in Algeria) or the *Shaabia* (in Libya). Retain all strata if their number is reduced, if not develop an adequate sample of the entire strata.

- Third step: develop for each stratum, a suitable sample, including the entire stratum if it is small.

When the strata or clusters consist of geographic features, which is fortunately the case in this context, a substantial saving is generally made of financial and logistical resources and we target better the issues specific to these entities. When the cluster is made up of a specific geographical area, we are dealing with a particular form of cluster survey usually called aerial survey.

The socioeconomic and environmental survey is scheduled over two seasons. The first covers all farms that form the base sample (about 3000), and the second relates to only part of the sample (about 1500), but with a particular focus on the areas of the Pilots in order to better understand their evolution.

This method was adopted for the development of samples relating to all Algerian regions (5 Wilayas of the SASS zone) as well as the governorate of Medenine in Tunisia. For the four other Tunisian governorates, i.e. Gabes, Kebili, Tataouine and Tozeur, which fortunately have complete updated lists of irrigating farmers, the random method was selected (see details in section 5.2.).

IDENTIFICATION OF THE SURVEY ZONES

Following several meetings with the different managers of the resource in the three countries, the sites to be covered by comprehensive socio-economic and environmental surveys have been identified.

The geographical areas selected throughout the SASS basin are:

- five zones in Algeria (Biskra, El Oued, Ouargla, Ghardaia and Adrar)
- three zones in Tunisia (Nefzaoua, Djérid Jeffara and Tunisia); and
- three zones in Libya (Libyan Jeffara, central coastal area and Juffra).

I. ALGERIA

The five geographic areas selected in Algeria include 5 Saharan Wilayas (Adrar, Ouargla, El Oued, Ghardaia and Biskra).

The development of representative samples of all farms of the five Wilayas was completed after:

- the visits have helped collect the preliminary statistical data;
- contacts with the different departments of the National Agency of Water Resources (ANRH) and Directorate of Agricultural Services of the Wilayas (Directions des Services Agricoles -DSA). It should be noted that the heads of statistical offices of the relevant DSAs provided additional information whenever it was needed.

This device allowed the development of samples relating to all areas and sub-areas selected as follows:

- **Wilaya of Adrar**
  - in the subzone of Timimoun, which is the largest in the region, a sample of 140 farms covering the different oasis to be identified was planned at a later stage;
  - in the subzone of Adrar, the sample covered about 65 farms;
  - in the subzone of Reggane, a sample of about 50 farms proved sufficient. One of the two agricultural demonstration pilots of Algeria is located in this area, specifically in the oasis of Ait Messaoud.
- **Wilaya of Ouargla**
  - 110 farmers in the sub-area of Ouargla ;
  - 166 farmers in the sub-region of South Oued Righ around the town of Touggourt.

- **Wilaya of El Oued**
    - subzone of El Oued (250 farmers): This area is known for its wide scale of the original irrigation technique known as the "Ghout"; it is to choose the basin where to plant the palms so that the trees' roots are in direct contact with water. This technique is as important as foggaras and should be preserved as a heritage of humanity.
    - subzone of Oued Righ North (150 farmers): The major issue in this area has focused on the rise of salt following serious drainage problems.

- **Wilaya of Ghardaïa**

Since the irrigated areas in the Wilaya represent only 8% of the area irrigated with the Algerian SASS water resources, the representative sample concerned only 220 farmers. This sample was divided into 5 homogeneous areas according to relevant criteria.

- **Wilaya of Biskra**

The Wilaya of Biskra, which alone accounts for over a third of the areas irrigated with the Algerian SASS water resources (38.4% according to the General Agricultural Census - RGA - 2001), has been the object of privileged treatment when carrying out the field investigation. The representative sample includes at least 450 farmers out of the 1600 allocated to the Algerian side. These farmers are divided according to the dominant activities in the region, namely:

- modern oasis where date palm cultivation, especially that of "Deglet Nour" variety, is performed according to the rules of art by dynamic and highly motivated entrepreneurs;
- vegetable crops under regular and even giant greenhouses by entrepreneurs who use the most modern techniques thanks to substantial financial resources;
- traditional oasis facing challenges and that deserve to be studied seriously.

II. LIBYA

The Libyan part of the SASS involves mainly two regions of the Jeffara and Hamada Hamra.

The Jeffara consists of 4 *Shaabia* (governorates): *Shaabia* Tripoli, *Shaabia* Jeffara, *Shaabia* Zawia and *Shaabia* Zouara.

The central area consists of 5 *Shaabia*: *Shaabia* Juffra, *Shaabia* Misrata, *Shaabia* El Margab, *Shaabia* Jebel Gharbi and *Shaabia* Nalut.

According to the criterion relative to the number of farmers in these regions, the sample of

810 units selected to be surveyed are distributed as follows:

- Jeffara : 595 farms;
- Central area: 215 farms.

Identification of the survey zones and development of the sample of farmers

- **The Jeffara**

The essential elements for the development of representative samples and especially the logistics of in-field collection and monitoring of the survey were gathered:

- thanks to field visits and to the discussion with the farmers and managers of various institutions involved in the mobilization of water resources and the collection of documents and statistics, the sample representative of the Libyan SASS zone was then developed;
- the recruitment of a national consultant of the Jeffara area, as well as other individuals to be in charge of the field survey implementation, made up the logistics capable of completing the process of collecting information under good conditions.

A brief summary of the RGA 2007 has helped identify the sample base clusters and set some criteria for the selection of farms to be surveyed.

The Libyan Jeffara stretches from the Tunisian border to the town of Khoms and consists of four *Shaabia*.

Thus, the survey base to identify the farmers to be surveyed was developed thanks to information collected in the field. The four subzone selected correspond to the four *Shaabia* of the Jeffara plain. The number of farmers to be identified for the survey is as follows:

- Tripoli : 50 farmers;
- Jeffara : 270 farmers;
- Zawia : 180 farmers;
- Zouara : 95 farmers.

- **The central zone**

The field visit helped select the sub-areas to be surveyed, recruit the national consultant to be in charge of completing the field survey and especially to develop the appropriate logistics.

For three of the five *Shaabia* selected of this vast region (Misrata Margheb and Juffra), the distribution of the number of farmers identified for the survey can be presented is as

Figure 2. Selection of sites with the Libyan team.

Figure 3. Developing the survey base with Libyan partners.

follows:

- Misrata : 65
- Margheb : 110
- Juffra : 40

III. TUNISIA

Three regions were selected for this project after consultation with the managers of the resource in Tunisia. Two risk regions (Jerid and Nefzaoua), which are part of the SASS, suffer mainly from a change in water quality. The third, namely the Tunisian Jeffara was incorporated into the project although located outside the SASS area.

III.1. The chotts regions

- **The oases of Jerid**

The oases of Jerid suffer from insufficient water flow and increasing pumping costs.

- **The oases of South Nefzaoua (The region of Douz)**

The most acute problem of this region is the salinity of water used that exceeds 5g/l in some oases.

- **The oases of North Nefzaoua (the region of Jedida – Mansoura)**

The oases are old and experiencing increasing degradation, a drainage problem that is more and more acute and high palm tree density. Salinity, which is of the order of 2.5 g/l, remains good. Although heavily used, the water resources of the oases of Nefzaoua are still sufficient.

III.2. The Tunisian Jeffara

This region consists of three sub-regions:

- **The oases of Gabes**

This region is characterized by a significant drop in the water table level and an increasing salinization of soil and water. Water demand, increasing considerably because of crop intensification, far exceeds the available supply.

- **Region of El Abbabsa (located upstream the GP1)**

This region, which is booming, still disposes of sufficient resources despite increasing water demand.

- **The maritime Jeffara region (located between the sea and the GP1)**

This part of the Jeffara is suffering from acute salinity problems affecting both the soil and water, which challenges the sustainability of a fragile agriculture. In fact, conflicts over the use of the increasingly saline water resource (surface water of 3 to 8 g/l, groundwater from 5 to 6 g/l) are already quite numerous.

III.3. Final selection of regions to be used for socioeconomic and environmental survey

During the meeting held on 14 March 2011 at the Institute of Arid Regions in Medenine, the list of regions and the sample size in each governorate were established and are detailed in Table 1.

Governorate	Size of the sample	Base of survey
Kebili	250	Base list
Tozeur	150	Base list
Gabes	150	are-frame sampling
Medenine	80	No list
Tataouine	120	No list
Total	**750**	

Table 1. breakdown of the Tunisian sample according to the 5 governorates retained.

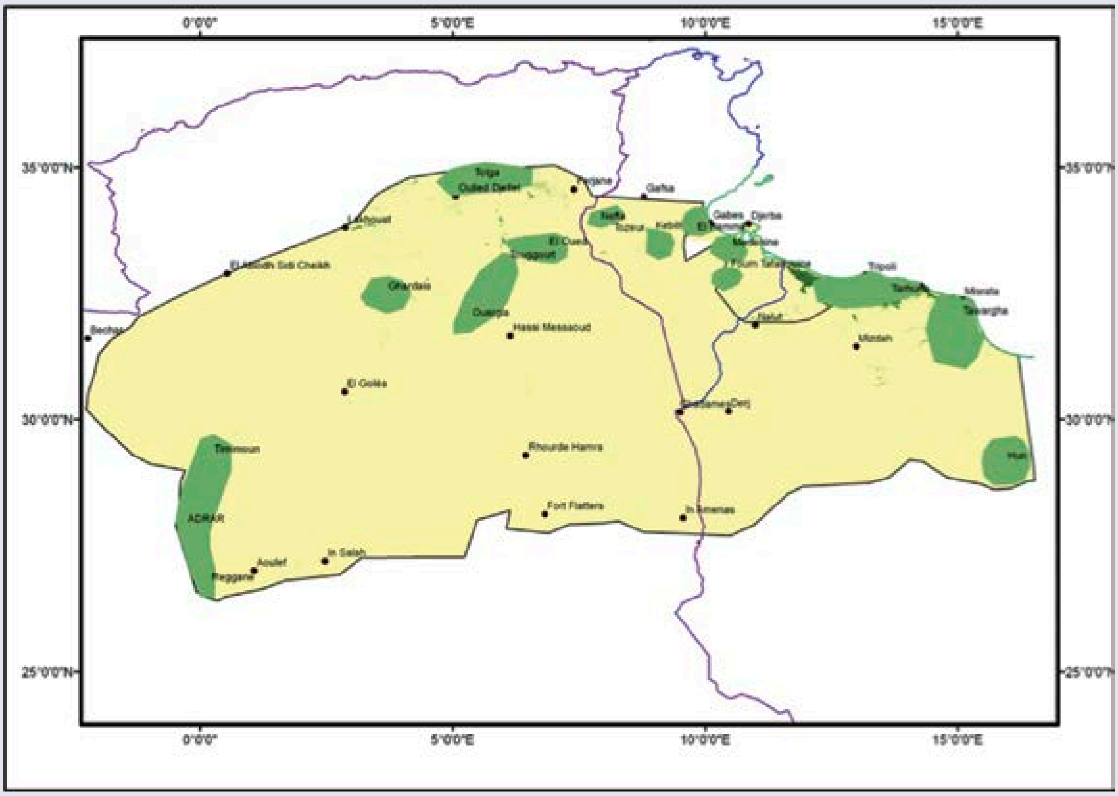


Figure 4. Map of the SASS survey zones.

DEVELOPING SAMPLES OF FARMERS TO BE SURVEYED

I. DEVELOPING THE ALGERIAN SAMPLE

The development of this sample is divided into two stages:

- breakdown of the overall Algerian sample among the large regions selected;
- for each region selected, the development of homogeneous areas based on objective criteria determined in advance. This step has two parts:
  - choice of homogeneity criteria;
  - division into homogeneous areas.

I.1. Breakdown of the Algerian sample among the large areas selected and the development of homogenous zones

A- The breakdown of approximately 1600 farms of the Algerian overall sample was made on the basis of two major criteria, namely:

- the total irrigated area in the Wilaya;
- the number of irrigation farmers in the Wilaya.

Table 2 shows the irrigated area and the number of farmers per Wilaya. The percentages represent the importance of the total of the relevant column. Example: the irrigated area in the Wilaya of Adrar represents 11.9% of the irrigated area of the Algerian SASS zone. In the last column, the numbers in parentheses reflect the importance of the size of the sample of the Wilaya concerned compared to the overall Algerian sample.

Wilaya (1)	Irrigated areas		Farms		Breakdown by sample
	(2) in ha	(3) %	(4) Number	(5) %	
Adrar	28 228	11,9	27 460	17,0	255 (15,9)
Biskra	98 478	41,5	56 797	35,2	460 (28,7)
Ouargla	29 488	12,4	30 163	18,7	270 (16,8)
El Oued	60 850	25,6	33 451	20,7	400 24,9)
Ghardaïa	20 441	8,6	13 635	8,4	220 (13,7)
TOTAL	**237 485**	**100**	**161 506**	**100**	**1 605 (100)**

Table 2. Breakdown of the Algerian sample among the Wilayas concerned.

B- Developing homogenous zones

- Selection of criteria and breakdown into homogenous zones

The current breakdown of each Wilaya (Prefecture) into Daïra (district) and then into municipality (commune) takes into consideration mainly political and administrative criteria. The division of the population of farmers in each Wilaya into homogeneous areas to develop representative samples to be field surveyed must meet hydro-agricultural criteria and other criteria related to the resource use. The approach was then to establish these criteria initially and then move to the breakdown into homogeneous areas at a second phase.

- Selection of criteria for the identification of objectives

In this context, the entire population is the population of irrigation farmers in the Wilaya. The selected regions will be the Wilayas. In each region (Wilaya), we will have the strata that will be demarcated areas here.

We must also remember that the main objective of the socioeconomic component is to understand two essential dimensions of the project, namely:

- the actual behavior of the irrigator in the use of an increasingly scarce water resource in terms of both quantity and quality;
- ingenuity the irrigator develops to adapt to the new reality.

In order to understand this behavior, it is important to explain the following characteristics:

- the nature of the irrigation source used. For example: wells, boreholes, dams, foggaras, the Ghout, etc.;
- the type of main cropping practiced: Permanent crops (date palm, olive, other tree plantations), herbaceous crops (cereals, fodder), vegetable crops, industrial crops, etc.;
- the legal status of the farm: in Algeria, there is a variety of legal forms of farm ownership.

I.2. Developing samples for the 5 regions selected

The development of appropriate homogeneous areas for each of the five selected Wilayas was possible thanks to the basic statistical information obtained with the invaluable assistance of the heads of departments of the relevant Wilaya DSA and especially the sustained effort of the director of the ANRH Ouargla.

The ideal would be to have reliable, consistent and especially comparable statistics for all the selected Wilayas. Unfortunately, it was impossible to do so despite efforts by both the regional consultant and the project coordinator. So we had to work with the available statistics for each Wilaya. For the most important Wilayas (Biskra, El Oued and Ouargla), which together account for over 70% of the entire number of irrigators in the Algerian SASS area, the collected statistics were quite rich and relatively homogeneous. But it was not possible to develop samples for the Wilayas of Adrar and Ghardaia using the same approach.

2.1. Developing the sample for the Wilaya of El Oued

Breakdown of El Oued region into homogenous zones

The region of El Oued was divided into nine homogeneous areas according to the following criteria:

- the nature of the soil;
- the irrigation water source used;
- the main crops.

Breakdown according to area of the farms

For each of the nine areas, the number of farms to be selected was calculated according to the following areas:

- very small farms with an area less than 0.5 hectares;
- the small farms covering between 0.5 and 1 hectare;
- medium-sized farms covering between 1 and 5 ha;

Zone	Common	Nature of the soil	Water source	Main crops
Zone 1 Souf South	El-Oued - Kouinine - Mih Ouensa - Oued Alenda - Robbah - Nakhla - Ogla -Bayada - Ouarmes	Sandy	*Water table *Wells (60 m)+Ghott	Palm tree cultivation Veg. cropping (esp potato) Olive
Zone 2 Souf North East	Debila - Hassani Abdelkrim - Hassi Khalifa - Trifaoui - Magrene - Sidi Aoun - Guemar - Taghzouf - Reguiba	Sandy gypseum	*Water table *Wells (60 m)+Ghott	Palm tree cultivation Veg. cropping (esp potato) Ind. Cul (artichokes, Tobacco) olive trees, fruit trees
Zone 3 Border 1	Ben Ghecha	Sandy clay - Limoneux	*Water table (120 m)	Palm tree cultivation Olive Cereals
Zone 4 Border 2	Taleb Larbi Douar El-maa	Sandy	*Terminal Complex	Palm tree cultivation Olive
Zone 5 Chott Melghir	Hamraia - Still - Oum Tiour	Slaked-lime-saline gypseum	*Water table (120 m) *Terminal Complex	Palm tree cultivation
Zone 6 Djamaa	Djamaa - Tendia - Sidi Amrane	Slake-lime-gypseum	*Terminal Complex *IC	Palm tree cultivation
Zone 7 El-Meghaier	El Meghaier - Sidi Khalil	Slake-lime-gypseum	*Water table (120m)	Palm tree cultivation
Zone 8 M'arara	M'arara	Sandy clay of alivionious origin	*CI	Palm tree cultivation Veg. cropping (greenhouses mainly)
Zone 9 Barghageia	Barghageia	Sandy clay	*Water table (120 m) *Terminal Complex	Palm tree cultivation Veg. cropping Cereals

Table 3. Breakdown of El Oued region into homogenous zones.

- large farms covering between 5 and 20 ha;
- the very large farms with an area exceeding 20 hectares.

Table 4 shows the number of farms by area and size. A simple illustration, 4951 farms in Zone 1 are smaller than 0.5 hectare.

Table 5 shows the distribution of the sample of farms to investigate the field according to the criterion of the number of irrigated farms. Let's consider the following example for a better explanation of the procedure: in the sample of the Wilaya of El Oued, which includes a total of 400 farms, 58 farms whose area is less than 0.5 ha were selected in Zone 1, which represents approximately 69.1% of all farms in the area.

The figure 58 is obtained:

- in zone 1 illustrated by line 1 of table 4, we retained 4,951 farms of an area ≤ to 0.5 ha over a total number of 7,168 farms; A simple calculation give us 4,951/7,168 = 0.691
- starting from line 1 of table 5, we have 85 x 0.691 = 58.

Breakdown according to the source of irrigation water

Table 6 shows the number of farms by area according to the water source criterion. Three main sources of irrigation water were retained in the Wilaya of El Oued, namely:

- irrigation wells using groundwater, which alone account for about 2/3 of the total irrigated area in the province, with over 37,266 hectares out of a total of 60,850 ha;
- irrigation wells from CI and CT;
- Irrigation according to the *Ghout* technique. This technique, although it concerns only 3.7% of the total irrigated area with only 2,225 ha, is of great importance in the region and is a cultural as well as a historical heritage, to be preserved for its originality and uniqueness in the world.
- Table 7 shows the breakdown of the sample selected for the survey according to the water source criterion. Take an example for illustration: in zone 1, out of the 85 surveyed farms, 3 (3 %) are supplied with boreholes, 68 (80 %) with wells and 14 (17 %) by the *Ghout* system.

Breakdown according to the legal status

Table 8 shows the number and percentage of farms by area according to legal status. The most important legal status, which represents 97.4% of all the farms that have been selected are:

- Private collective farm (EAC - "*Exploitation agricole collective*");
- Access to agricultural land ownership ("*Accession à la propriété foncière agricole* " -AALO)

Zones	< 0,5 ha	0,5 to 1 ha	1 to 5 ha	5 to 20 ha	> 20 ha	Total	%	Size of the sample
Zone 1	4,951	428	1 612	165	12	7,168	21.4	85
Zone 2	3,502	2,469	4627	1,103	20	11,721	35.0	130
Zone 3	394	10	25	107	115	651	1.9	10
Zone 4	953	382	191	45	01	1,572	4.7	20
Zone 5	453	790	755	47	03	2,048	6.1	25
Zone 6	1,304	1,777	3,102	311	841	6,535	19.5	75
Zone 7	410	593	1,680	284	08	2,975	8.9	35
Zone 8	50	187	321	01	0	559	1.7	10
Zone 9	16	66	122	18	0	222	0.7	10
Total %	12,033 (36.0)	6,702 (20.0)	12,435 (37.2)	2,081 (6.2)	200 (0.6)	33,451 (100.0)	100	400

Table 4. Breakdown of the farms according to the area of irrigated zones.

Zones	< 0.5 ha & %	0.5 to 1 ha	1 to 5 ha	5 to 20 ha	> 20 ha	Nb. farm/ zone	%	Size of the sample
Zone 1	58 (69.1)*	5 (6.0)	19 (22.5)	2 (2.3)	1 (0.2)	7 168	21.4	85 (100)
Zone 2	39 (29.9)	27 (21.1)	51 (39.5)	12 (9.4)	1 (0.2)	11 721	35.0	130 (100)
Zone 3	6 (60.5)	0 (1.5)	0 (3.8)	2 (16.4)	2 (17.7)	651	1.9	10
Zone 4	12 (60.1)	5 (24.3)	2 (12.2)	1 (2.9)	0 (0.0)	1 572	4.7	20
Zone 5	6 (22.1)	9 (38.6)	9 (36.9)	1 (0.2)	0 (0.0)	2 048	6.1	25
Zone 6	15 (20.0)	20 (27.2)	35 (47.5)	4 (4.8)	1 (0.6)	6 535	19.5	75
Zone 7	5 (13.8)	7 (19.9)	20 (56.5)	3 (9.5)	0 (0.3)	2 975	8.9	35
Zone 8	1 (8.9)	3 (33.4)	6 (57.4)	0 (0.0)	0 (0.0)	559	1.7	10
Zone 9	1 (7.2)	3 (29.7)	5 (55.0)	1 (8.1)	0	222	0.7	10
Total %	143 (36.0)	79 (20.0)	147 (37.2)	26 (6.2)	5 (0.6)	33 451 (100.0)	100	400

** The figures in parentheses represent the % of farms in the zones under study with the indicated area.*

Table 5. Breakdown of the sample according to the number of irrigated farms.

Zone	Boreholes		Wells		Ghout		Total	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Zone 1	255	3,2	6 367	80	1 379	17	8 001	13,1
Zone 2	600	3,0	21 869	94,6	586	2,5	23 115	38,0
Zone 3	288	5,6	4 817	93,0	74	1,.4	5 179	8,5
Zone 4	413	36,5	533	47,1	186	16,4	1 135	1,9
Zone 5	1 338	45,9	1 579	54,1	0	0	2 917	4,8
Zone 6	12 080	100	09	0	0	0	12 086	19,8
Zone 7	5 608	77,8	1 604	22,2	0	0	7 212	11,9
Zone 8	683	100	0	0	0	0	683	1,1
Zone 9	34	6,5	492	93,5	0	0	526	1,0
Total	**21 359**	**35,1**	**37 266**	**61,2**	**2 225**	**3,7**	**60 850**	**100**

Table 6. Irrigated area and breakdown according to the irrigation water sources in El Oued zone.

Zone	Boreholes		Wells		Ghout		Total	
	Number	%	Nb	%	Nb	%	Nb	%
Zone 1	3	3,2	68	80	14	17	85	13,1
Zone 2	4	3,0	122	94,6	4	2,5	130	38,0
Zone 3	1	5,6	8	93,0	1	1,4	10	8,5
Zone 4	7	36,5	9	47,1	4	16,4	20	1,9
Zone 5	11	45,9	14	54,1	0	0	25	4,8
Zone 6	74	100	1	0	0	0	75	9,8
Zone 7	27	77,8	8	22,2	0	0	35	11,9
Zone 8	10	100	0	0	0	0	10	1,1
Zone 9	1	6,5	9	93,5	0	0	10	1,0
Total	**138**	**35,1**	**239**	**61,2**	**23**	**3,7**	**400**	**100**

Table 7. Breakdown of the sample according to the water source.

- Private collective farm + individual farm ("*Exploitation agricole individuelle*" - EAI).

Table 9 shows the number of farmers to be included in the total sample of the area by region and by selected legal status. It should for example be integrated into the overall sample of 70 farmers in zone 1 enjoying the legal status of private Collective Property.

Breakdown according to the type of crops practiced

Table 10 shows the breakdown of farms by type of crop. Two main categories are used:

Zones	PCF		AALO		CF+IF		Total	
	Number	%	Number	%	Number	%	Nb. of farms	% included
Zone 1	5 815	83,5	1 147	16,5	01	0,0	6 963	97
Zone 2	7 305	63,7	3 771	32,9	393	3,4	11 469	98
Zone 3	0	0	651	100	0	0	651	100
Zone 4	0	0	1 445	100	0	0	1 445	92
Zone 5	861	44,7	794	41,2	273	14,1	1 928	94
Zone 6	4 113	64,4	1 289	20,2	984	15,4	6 383	98
Zone 7	1 790	60,7	591	20,0	570	19,3	2 951	99
Zone 8	0	0	224	40,1	335	59,9	559	100
Zone 9	0	0	222	100	0	0	222	100
Total	**19 884**	**61,0**	**10 134**	**31,1**	**2 556**	**7,9**	**32 574**	**97,4**

Table 8. Breakdown of the farms according to the criterion of the legal status of the farms.

Zones	PCF		AALO		CF+IF		Nb. of farms of the sample in the zone
	Number	%	Number	%	Number	%	
Zone 1	70	83,5	14	16,5	01	0,0	85
Zone 2	82	63,7	43	32,9	5	3,4	130
Zone 3	0	0	10	100	0	0	10
Zone 4	0	0	20	100	0	0	20
Zone 5	11	44,7	10	41,2	4	14,1	25
Zone 6	48	64,4	15	20,2	12	15,4	75
Zone 7	21	60,7	7	20,0	7	19,3	35
Zone 8	0	0	4	40,1	6	59,9	10
Zone 9	0	0	10	100	0	0	10
Total	**232**	**61,0**	**133**	**31,1**	**35**	**7,9**	**400**

Table 9. Breakdown of the sample according to the legal status of the farms criterion.

- permanent crops mainly include:
  - palm trees,
  - olive trees,
  - various;
- herbaceous crops mainly include:
  - cereals,
  - fodder,

- vegetable crops,
- industrial crops.

Permanent Crops (Arboriculture)			Herbaceous crops		
Types	**Area**	**%**	**Types**	**Area**	**%**
Date palm	35 700	58,7	Cereals	3 635	6,0
Olive trees	2 913	4,8	Fodder	1 154	1,9
Misc.	633	1,04	Veget. crop Ind. crop	15 025 1 790	24,7 3,4
Total	39 246	64,5	Tot.	21 604	35,5
General Total					**60 850 ha (100,0)**

Table 10. Breakdown of the irrigated areas according to the type of crops.

Table 11 shows the breakdown of the sample of the region of El Oued according the crops practiced. For example, the overall sample should include 235 farms that practice mainly date palm cultivation.

Permanent crops (Arbo)			Herbaceous crops		
Types	**Nb. farmers**	**%**	**Types**	**Nb. farmers**	**%**
Date palm	235	58,7	Cereals	24	6,0
Olive trees	19	4,8	Fodder	08	1,9
Misc.	04	1,04	Veget. crop Ind. crop	99 13	24,7 3,4
Total	258	64,5	Total	142	35,5
Total size of the sample					**400**

Table 11. Breakdown of the sample according to the type of crops criterion.

2.2. Developing the sample for the Wilaya of Adrar

Breakdown of the Wilaya of Adrar into homogenous zones

- Zone 1 : Timimoun, Charouine, Talmine, O. Aissa, O. Said
- Zone 2 : Aougrout, Metarfa, Deldoul, Tsabit, Sbaa
- Zone 3 : Tinerkouk, Ksar Kadour
- Zone 4 : Adrar, Timi, Bouda, Fenoughil, Tamentit,Tamest
- Zone 5 : Reggane, ZT Kouta, Inzegmir, Sali

Developing the sample of farms to be field-surveyed

- The overall area of the sample is 255 farms.
- In order to avoid the possibility of not finding some farmers on site during the visits, it was essential to develop a waiting list of alternative farmers that included around thirty farmers (10%) that is proportional to the area selected.
- As the problem of foggaras is crucial to this project, it was necessary to consider this criterion in the selection of farmers. The selection procedure was as follows: calculate the proportion of farmers using foggaras as the main source of irrigation in the Wilaya and ensure that this proportion is respected. If this proportion is about 15%, for example, the bulk sample will have to use 38 (255 x 0.15) farms irrigated by foggaras to be divided proportionally.
- For each zone, ensure that all the relevant communities are concerned.
- Include in the sample some large farms practicing cereals irrigated by pivots and some large farms practicing vegetable cropping especially giant greenhouses.

Breakdown of the sample for the Wilaya of Adrar per selected zone

This Wilaya had reliable statistics for three selection criteria (distribution of farms by area, type of oasis according to legal status), and it was therefore possible to retain these three distribution keys provided in Tables 12 and 13.

Figure 5. Foggara in Timimoun.

2.3. Developing the sample for the Wilaya of Ouargla

Developing the sample must strictly observe the following criteria:

Breakdown of farms by size

For each of the 5 selected areas, the number of farms was calculated using the following sizes:

- soil-less farms;
- the small size of farms covering between 0.5 and 1 hectare;
- medium-sized farms covering between 1 and 5 ha;
- large size farms covering between 5 and 20 ha;
- The very large farms with area exceeding 20 hectares.

	Oasis Farms (Old palm groves)		Farms developed (Developed oasis)			Size of sample per zone
	< 0,5 ha	0,5 to 1 ha	1 to 5 ha	5 to 20 ha	> 20 ha	
Zone 1	42	4	14	0	0	60
Zone 2	27	5	10	0	3	45
Zone 3	29	2	4	0	0	35
Zone 4	30	16	11	5	3	65
Zone 5	31	6	6	2	5	50
Total	**159**	**33**	**45**	**7**	**11**	**255**

Table 12. Number of farms per zone, per area according to the type of oasis of the sample to be surveyed.

	Size of the sample	Number of farms in one individual irrigation zone	Number of farms in the collective areas
Zone 1	60	31	29
Zone 2	45	27	18
Zone 3	35	25	10
Zone 4	65	24	41
Zone 5	50	9	41
Total	**255**	**116**	**139**

Table 13. Breakdown of the sample according to the legal criterion .

Table 14 shows the number of farms by area and size. A simple illustration, 5748 farms in Zone 1 are less than one hectare.

Table 15 shows the breakdown by region and by size as the sample to be taken into consideration by the field survey. For example, in the sample of the Wilaya of Ouargla, which includes a total of 276 farms, 50 farms with area less than 1 ha represent approximately 62.3% of all farms in the zone.

Breakdown according to the irrigation technique

Table 16 provides the number of farms by area according to the water source criterion. Three irrigation techniques were selected in the Wilaya of Ouargla, namely:

- traditional irrigation, using the technique of gravity, which alone accounts for about 4/5 of the total irrigated area in the province with over 16.505 hectares of a total of 18.977 ha, or 87% of the total;

Zones	Soil-less	0,5 to 1	1 to 5	5 to 20	> to 20	Tot.	%	Size of sample
Zone 1	269 (2.9)	5,748 (62.3)	3,048 (33.1)	125 (1.4)	30 (0.3)	9 220	32.3	89
Zone 2	154 (2.9)	3,283 (62.3)	1,748 (33.2)	72 (1.4)	15 (0.3)	5 272	18.3	50
Zone 3	146 (2.9)	3,166 (62.3)	1,706 33.2)	69 (1.4)	17 (0.3)	5 104	17.7	49
Zone 4	196 (2.9)	4,135 (62.3)	2181 (33.0)	92 (1.4)	21 (0.3)	6 625	23.0	63
Zone 5	76 (2.9)	1,629 (62.2)	867 (33.1)	36 (1.4)	09 (0.3)	2617	9.1	25
Total	841	17 961	9 550	394	92	28 838	100	276
%	2.9	62.3	33.1	1.4	0.3		100	

Table 14. Breakdown of farms according to size criterion.

Zones	Soil-less	0,5 to 1	1 to 5	5 to 20	> to 20	%	Size of sample
Zone 1	04	50	29	03	0,3	32,2	89
Zone 2	0,3	27	16	02	02	18,1	50
Zone 3	03	26	16	02	02	17,8	49
Zone 4	03	35	21	02	02	22,8	63
Zone 5	02	13	08	01	01	9,1	25
Tot.	**15**	**151**	**90**	**10**	**10**	**100**	**276**
%	**5,4**	**54,8**	**32,6**	**3,6**	**3,6**	**100**	**100**

Table 15. Breakdown of the sample according to number of irrigated farms criterion.

- irrigation using the drip technique representing 10% of the total;
- irrigation using the sprinkling technique that represents only 3% of the total.

Table 17 shows the number of farmers to be included in the total sample of the region, by area and according to the irrigation technique. It should for example be integrated into the overall sample of the region, 78 farmers of zone 1 that still use the technique of irrigation by gravity.

Breakdown according to legal status

Table 18 shows the number and percentage of holdings by area according to the criterion of their legal status. In the wilaya of Ouargla, there are only two types of status, namely:

- PCF,
- AALO.

Zone	Gravity	Drip	Sprinkler	Tot (ha)	% of the total zone
Zone 1	5 463	1,268	360	7 091	37,4
Zone 2	1,360	332	130	1 822	9,6
Zone 3	4,394	97	0	4 491	23,7
Zone 4	4,994	173,4	0.	5,167,4	27,2
Zone 5	294	22	90	406	2,1
Tot.	**16,505**	**1,892,4**	**580**	**18,977,4**	**100**
%	**87**	**10**	**3**	**100**	

Table 16. Breakdown of the areas according to irrigation technique.

Zone	Gravity	Drip	Sprinkler	Total	%
Zone 1	78	17	8	103	37,3
Zone 2	18	5	3	26	9,4
Zone 3	60	5	0	65	23,6
Zone 4	70	5	0	75	27,2
Zone 5	4	1	2	7	2,5
Total	**230**	**33**	**13**	**276**	**100**
%	**83,3**	**12**	**4,7**	**100**	

Table 17. Breakdown of the sample according to gravity irrigation technique.

Zones	Private CPF	AALO	Tot.	%	Size of sample
Zone 1	8,821 (93,2)	642 (6,8)	9,463	33,1	91
Zone 2	2,528 (99,)	02	2,530	8,8	24
Zone 3	5,401 (98,8)	62	5,463	19,1	53
Zone 4	9,112 (94,4)	534	9,646	33,7	93
Zone 5	1,528	0	1,528	5,3	15
Tot.	**27,390**	**1,240**	**28,630**	**100**	**276**
%	**95,7**	**4,3**	**100**		

Table 18. Breakdown of farmers according to legal status.

Table 19 shows the sample distribution for the 5 areas of the Wilaya of Ouargla according to the criterion of the legal status of farms. In this sample, it would take, for example, 64 farms in Zone 1 having the legal status type EAC Private.

Zones	Private collective farm	AALO	%	Size of sample
Zone 1	84	7	33,1	91
Zone 2	23	1	8,8	24
Zone 3	50	03	19,1	53
Zone 4	87	06	33,7	93
Zone 5	15	0	5,3	15
Tot.	259	17	100	276
%	95,7	4,3	100	

Table 19. Breakdown of sample according to legal status.

Breakdown according to type of crops practiced

Table 20 shows the distribution of irrigated area in hectares according to the criterion of the main crops. Three types of culture were used, namely:

- Herbaceous crops;
- Fruits;
- Vegetables.

Zones	Herbaceous crops	Fruits	Vegetables	Tot. (ha)	%	Size of sample
Zone 1	7.283 (50.)	6.904 (47.3)	87 (0.7)	14.590	41.9	115
Zone 2	1.900 (52.)	1.660 (45.5)	92 (2.5)	3.652	10.5	29
Zone 3	1.823 (36.3)	3.197 (63.7)	0	5.020	14..4	40
Zone 4	4.077 (38.5)	6.506 (61.5)	0	10.583	30.4	84
Zone 5	313 (32.7)	330 (34.5)	313 (32.7)	956	2.7	08
Tot.	15.396	18.597	492	34.801	100	276
%	44.6	53.9	1.4	100		

Table 20. Breakdown of irrigated areas according to main crop criterion (ha).

Table 21 shows the breakdown of the sample in the region of Ouargla according to the criterion of crops grown. For example, the overall sample will have to include 57 farms that practice mainly herbaceous crops in zone 1.

Zones	Herbaceous crops	Fruits	Vegetables	%	Size of sample
Zone 1	57	54	4	41.7	115
Zone 2	15	13	1	10.5	29
Zone 3	15	25	0	14.5	40
Zone 4	32	52	0	30.4	84
Zone 5	02	03	03	3.0	08
Tot.	**121**	**147**	**08**	**100.1**	**276**
%	**43.9**	**53.3**	**2.9**		

Table 21. Breakdown of the sample according to the main crop criterion (ha).

2.4. Developing the sample for the Wilaya of Ghardaïa

Also, for the wilaya of Ghardaïa, there are no reliable statistics available for the three selection criteria (Breakdown by farm size, type of oasis and type of plantation), and therefore were obliged to keep the following three breakdowns only shown by tables 22 and 23, namely:

- breakdown according to farm size;
- breakdown according to type of oasis;
- breakdown according to plantation (arboriculture or bare field).

	Oasis farm (old palm groves)		Valorized farms (advanced oasis)			Size of sample per zone
	< 0,5 ha	0,5 to 1 ha	1 to 5 ha	5 to 20 ha	> 20 ha	
Zone 1	14	8	20	5	3	50
Zone 2	12	7	14	5	3	42
Zone 3	24	8	20	3	3	58
Zone 4	2	5	18	3	3	31
Zone 5	11	7	17	4	1	40
Total	**63**	**35**	**91**	**20**	**13**	**220**

Table 22. Number of farms per zone, by size and according to type of oasis of the sample to be surveyed.

	Bare land	Land planted trees	Total
Zone 1	16	34	50
Zone 2	09	32	41
Zone 3	11	47	58
Zone 4	14	17	31
Zone 5	11	29	40
Total	**61**	**159**	**220**

Table 23. Breakdown of sample according to criterion of the plantations.

2.5. Developing the sample for the Wilaya of Biskra

For this wilaya, as important for the project as El Oued, rich statistical data were available which allowed keeping a large number of criteria to develop a real representative sample of the overall population of irrigators.

Breakdown into homogenous zones

The wilaya of Biskra is divided into 10 standard zones as follows:

Zone	Main crops
Zone1 : (Steppic) Ras El Miad, Besbes, Ech Chabia	Livestock, date palm Vegetable cropping
Zone 2 : Sidi Khaled, Ouled Djellel	Date palm, vegetable cropping Cereals, industrial crops
Zone 3 : Doucen, El Ghrous	Date palm (D.N) Cropping in greenhouses Cereals, livestock (bovines)
Zone 4 : Piémont Nord El Kantara, Ain Zaatout, Djemorah, Mchouneche	Date palm (regular varieties) Arbo (olive), beekeeping
Zone 5 : Tolga, Lichana, Foughala, Borj B. Azzouz	Date palm (Deglet Nour) Veget. Cropping
Zone 6 : Biskra El Hadjab	Date palm Veget. Crops
Zone 7 : Lioua, Mekhadma, Ourlal, Mlili, Oumache, Bouchagroun	Date palm Veget. crops Livestock, bovine
Zone 8 : Plaine d'El Outaya	Cereals, livestock Date palm Veget. Crops
Zone 8 Bis : El Feidh, El Haouch	Cereals, livestock Date palm Veget. Crops
Zone 9 : Chemta, sidi Okba	Veget. crops (in greenhouses) Date palm Cereals
Zone 10 : Ain Naga, Mziraa, Khanget Sidi nadji, Zribet El Oued	Veget. crops Cereals, Date palm Livestock, industrial crops

Developing the sample of farms to be field surveyed was carried out on the basis of three criteria:

Criterion 1 : Farm size

Table 24 shows the number of farms to be included in the overall sample by area and size. For example, for Zone 1, which includes the towns of Ras el Miad, Besbes and El Chabia, 13 farms of 1 to 5 ha will be included.

1,905 farms out of 24,860 irrigated farms have no area which gives 7.7% of the total. That is why 37 farms without land will be included in the sample (37/465 = 7.9%).

Zones	< 0.5 ha	0.5 to 1	1 to 5	5 to 20	> 20	Total	%	Without area	% (Without area)
Zone 1	3	10	1,761 (68.4)	752 (29)	47 (1.8)	2,573	4.7	1,509	79.2
Zone 2	351 (9.1)	1,007 (26.0)	1,952 (50.1)	524 (13.5)	19	3,853	7.	80	4.2
Zone 3	47 (0.9)	353 (6.9)	2,947 (58.)	1,652 (32.5)	80 (1.6)	5,079	9.3	11	0.6
Zone 4	1,141 (28.)	1,254 (31)	980 (24.2)	662 (16.3)	13 (0.3)	4,050	7.4	34	1.8
Zone 5	748 (7.8)	3,249 (33.9)	5,144 (53.9)	406 (4.2)	30	9,577	17.4	20	1.
Zone 6	265 (5.6)	683 (14.4)	3,094 (65.2)	686 (14.4)	20	4,748	8.6	24	1.3
Zone 7	761 (6.6)	2,372 (20.6)	6,143 (53.4)	2,138 (18.6)	85 (0.7)	11,499	20.9	31	1.6
Zone 8	628 (17.9)	223 (6.4)	1,313 (37.4)	1,210 (34.6)	133	3,507	6.4	01	0.
Zone 8bis	13 (0.4)	162 (5.5)	466 (16.)	1,882 (64.8)	382 (13.1)	2,905	5.3	37	1.9
Zone 9	5 (0.2)	194 (6.6)	1,195 (40.7)	1,446 (49.3)	95 (3.2)	2,935	5.4	143	7.5
Zone 10	145 (3.5)	231 (5.5)	342 (8.2)	2,752 (66.)	696 (16.7)	4,166	7.6	15	0.8
Total	**4,107 (7.5)**	**9,738 (17.7)**	**25,337 (46.2)**	**14,110 (25.7)**	**1,600 (2.9)**	**54,892**	**100**	**1,905**	**100**

Table 24. Breakdown according to farm size.

Zones	< 0,5 ha	0,5 to 1	1 to 5	5 to 20	> 20	Without area	%	Sample without area.	Size of sample
Zone 1	1	1	13	5	2	22	5.1	26	48
Zone 2	4	8	13	5	1	31	7.2	2	33
Zone 3	1	3	21	12	2	39	9.1	1	40
Zone 4	8	9	7	5	2	31	7.2	1	32
Zone 5	6	24	38	4	2	74	17.3	1	75
Zone 6	3	6	21	6	1	37	8.6	1	38
Zone 7	6	18	45	16	3	88	20.6	1	89
Zone 8	5	2	9	9	3	28	6.5	0	28
Zone 8bis	1	2	4	13	3	23	5.4	1	24
Zone 9	1	3	8	9	2	23	5.4	2	25
Zone 10	2	3	4	17	6	32	7.5	1	33
Total	**38**	**79**	**183**	**101**	**27**	**428**	**100**	**37**	**465**

Table 25. Breakdown of the sample according to the farm size criterion.

Criterion 2 : Legal status of the farms

Table 26 shows the breakdown of the sample according to the legal status. For instance, we have to take the global sample of 15 farms in zone 1 with private status.

Table 27, the breakdown of farms according to the legal status.

Zone	Private	Public	AALO	Other	Sample
Zone 1	15	14	13	6	48
Zone 2	7	17	7	2	33
Zone 3	27	4	7	2	40
Zone 4	23	4	2	3	32
Zone 5	30	28	15	2	75
Zone 6	19	14	4	1	38
Zone 7	39	30	16	4	89
Zone 8	8	14	4	2	28
Zone 8bis	5	13	5	1	24
Zone 9	11	9	3	2	25
Zone 10	2	18	12	1	33
Total	**186**	**165**	**88**	**26**	**465**

Table 26. Breakdown of the sample according to the legal status of the farm.

Zone	Private	Public	AALO	Other	Total	Sample.
Zone 1	2,978 (32.3)	2,794 (30.3)	2,510 (27.2)	942 (10.2)	9,224	48
Zone 2	1,406 (22.6)	3,174 (51)	1,285 (20.6)	358 (5.8)	6,226	33
Zone 3	11,450 (70)	1,543 (9.4)	2,689 (16.4)	755 (4.6)	16,437	40
Zone 4	3,705 (73)	637 (12.5)	299 (5.9)	435 (8.6)	5,076	32
Zone 5	3,544 (39.8)	3,379 (38)	1,869 (21)	110 (1.2)	8,902	75
Zone 6	3,542 (51.3)	2,538 (36.7)	742 (10.7)	85 (1.2)	6,907	38
Zone 7	10,026 (43.6)	7,933 (34.5)	4,009 (17.4)	1028 (4.5)	22,996	89
Zone 8	4,647 (27.2)	8,826 (51.7)	2,642 (15.5)	962 (5.6)	17,077	28
Zone 8bis	6,889 (23.3)	16,646 (56.3)	5,671 (19.2)	340 (1.2)	29,546	24
Zone 9	6,571 42.7)	5,571 (36.2)	2,101 (13.7)	1,140 (7.4)	15,383	25
Zone 10	1,775 (3.7)	27,287 (57.2)	18,052 (37.8)	590 (1.2)	47,704	33
Total	**56,334**	**80,327**	**41,869**	**6,743**	**185,473**	**465**

Table 27. Breakdown of farms according to the legal status.

Table 28 shows the sample breakdown according to the criterion of the water source. For example, 43 farms in zone 1 using boreholes as a source of irrigation will be included in the sample. Table 29, breakdown of farms according to water source .

II. DEVELOPING THE TUNISIAN SAMPLE

II.1. Introduction

Developing the Tunisian sample was much easier than the Algerian sample, for the following reasons:

- the statistical offices of five governorates concerned, with the exception of Medenine, provide comprehensive updated list of farmers who use the water resource;.
- teams, which are responsible for carrying out the field survey, have a long experience in the development of representative samples according to the rules of art and especially to conduct surveys of the same scale as the project's;

	Surface resources			Groundwater resources			Total
	Dams & artificial ponds.	Tapping from water course	Spate irrigation	Boreholes	Wells	Sources	
Zone 1	0	0	0	43	5	0	48
Zone 2	0	0	0	28	5	0	43
Zone 3	0	0	0	36	4	0	40
Zone 4	0	0	0	29	2	1	32
Zone 5	0	0	0	55	20	0	75
Zone 6	0	0	0	22	16	0	38
Zone 7	0	0	0	58	31	0	89
Zone 8	9	12	0	5	1	1	28
Zone 8bis	0	0	0	24	0	0	24
Zone 9	11	0	0	14		0	25
Zone 10	0	3	0	30	0	0	33
Tot.	20	15	0	344	84	2	465

Table 28. Breakdown of the sample according to the water source criterion.

	Surface resources			Groundwater resources			Total
	Dams & artificial ponds.	Tapping from water course	Spate irrigation	Boreholes	Wells	Sources	
Zone 1	0	0	0	2,166 (90)	237 (10)	0	2,363
Zone 2	0	0	0	4,213 (83.8)	816 (16.2)	0	5,029
Zone 3	0	0	0	9,480 (90.8)	955 (9.2)	0	10,435
Zone 4	0	0	0	2,659 (95.2)	126 (4.8)	8	2,793
Zone 5	0	0	0	6,288 (74.2)	2,185 (25.8)	0	8,473
Zone 6	0	0	0	2,936 (58.6)	2,070 (41.4)	0	5,006
Zone 7	0	0	0	10,543 (65)	5,664 (35)	0	16,207
Zone 8	1,500 (32.2)	2,120 (45.6)	0	947 (20.4)	75 (1.6)	5 (0)	4,647
Zone 8bis	0	0	0	13,739 (100)	0	0	13,739
Zone 9	2,250 (42.8)	0	0	3,003 (57.2)	0	0	5,253
Zone 10	0	1,580 (6.4)	0	22,956 (93.6)	0	0	24,536
Total	3,750 (3.8)	3,700 (3.8)	0	78,887 (80.1)	12,128 (12.3)	13 (0)	98,478

Table 29. Breakdown of farms according to water source.

- geographical conditions of the Tunisian SASS area are more favorable (reduced distances, areas of selected zones are smaller, etc.), which made the task much easier.

II.2. Breakdown of the Tunisian sample among the large areas selected

The breakdown of approximately 750 farms in the overall Tunisian sample was carried out on the basis of two major criteria, namely:

- the total irrigated area in the wilaya;
- The number of irrigation farmers in the governorate.

Governorate	Nbr of farmers	Irrigated area in (ha)	Size of the sample	Base of the survey
Gabès	21,931	16,461	150	List available
Kébili	33,046	23,837	250	List available
Tataouine	2,627	5,393	120	List available
Médenine	3,453	2,473	80	List available
Tozeur	8,050	8,363	150	Partial lists available
Total	69,107	56,547	750	

Table 30. Breakdown of the global sample per selected governorates.

2.1. Developing the samples for the Governorate of Gabès

The size of the Gabes governorate sample was 150 farmers. The breakdown of these farmers by stratum was carried out as shown in the following table, based on the area of each stratum.

Stratification

Selected strata	Scope of the Survey		Area covered by the survey (ha) (4)	Rate of coverage by the survey (4/2)	Size of the sample (nbr of farms to be surveyed)
	Area (ha) (2)	Nbr of farms			
Oasis	6,978	18,420	5,646	80.9	**63**
Public Irrigated Areas (PuIA) outside the oasis	4,883	2,441	3,498	71.6	**44**
Private Irrigated Areas (PrIA)	4,600	1,070	4,495	97.7	**43**
Total	**16,461**	**21,931**	**13,639**	**83.0**	**150**

Table 31. Size of the sample of farms to be surveyed in the Governorate of Gabes.

Selection of farmers to be surveyed

The selection of farmers to be field surveyed was carried out on the basis of a draw with equal probability and without replacement on the basis of reason «r» calculated in the following manner:

$$r = \frac{total\ number\ of\ farmers}{total\ number\ of\ the\ sample\ strata}$$

	Total nbr of farmers	Size of the strata sample	r
Oasis	18,420	63	292*
Public Irrigated Areas outside the oasis	2,441	44	55
Private Irrigated Areas	1,070	43	25

** Reason that is 292 is obtained in the following way: 18 420/63 = 292*

Table 32. Calculating « r » by strata.

2.2. Developing the samples for Governorate of Kebili

The sample of 250 farmers was selected in order to accurately represent the different farming systems practiced by the entire irrigated oasis areas of the governorate. The criteria selected for stratification, which explicitly incorporate the heterogeneity of the oasis reality, are: the place of residence of the farmer, the size and the type of the oasis.

	Area in ha	Nbr of farmers		Size of the sample
		Number	%	
Modern oases:				
- public	5,479	10,649	32	81
- private	13,896	7,702	23	58
Old oases	4,471	14,695	45	111
Total	**23,846**	**33,046**	**100**	**250**

Table 33. Breakdown of the Kebili sample according to the selected criteria.

Delegation	Old oases	Modern public oases	Private modern oases
Kebili South	26	21	13
Kebili North	13	16	6
Souk Lahad	43	2	7
Douz	18	21	26
Faouar	11	21	6
Total per strata	111	81	58
General Total	250		

Table 34. Structure and size of the sample by strata and per delegation in the region of Kebili.

2.3. Developing the samples for Governorate of Tataouine

The representative sample of the irrigated agriculture in Tataouine was developed according to the same logic as the other governorates (tables 35 et 36).

Two lists were well developed based on this survey method. The first list of the main sample includes 150 farmers and second list of alternatives includes twenty farmers.

	Area in ha	Nbr of farmers		Size of the sample
		Number	%	
Small and medium intensive irrigators - private - public	2,305 1,875	1,137 1,342	43 51	52 61
Big intensive farmers - private - public	951 262	112 36	5 1	28 9
Total	5,393	2,627	100	150

Table 35. Breakdown of the Tataouine sample according to selected criteria .

Delegation	Nbr
Tataouine North	54
Smar	10
Ghomrassen	22
Remada/Dhiba	35
Bir Lahmar	29
Total	150

Table 36. Survey plan in the governorate of Tataouine.

2.4. Developing the samples for Governorate of Medenine

Corrections for the preparation of a representative sample in the governorate of Medenine were required. Indeed, the exhaustive list of irrigators croppers is incomplete, it was necessary to use more methodologies that were more appropriate to the context in order to develop the sample according to the rules of art.

Regarding private irrigated areas, two cases were considered:

- the case of available exhaustive lists of farmers: the case of PrIA (drilling) and PrIA using surface wells for the delegations of Zarzis and Medenine South. In this case, a choice with equal probability and without replacement was approved. The number of farmers to be surveyed was respectively 5 (6%) and 30 (37%) as shown in Table 37.
- The case of available partial lists of farmers: the case of PrIA using surface well of other regions of the Governorate (except southern Medenine and Zarzis). The sampling method adopted is a two-stage survey:
  - the 1st degree is a proportional stratified survey;
  - the second degree is a judgmental sampling according to 2 criteria:
    - farm size (<1 ha, between 1 and 2 ha, and> 2 ha);
    - the irrigation system (PVC, drip).

The number of farmers to be surveyed within this stratum is 32, distributed according to the criterion of farm size as follows:

- 4 farmers with property disposing of irrigable area not exceeding 1 ha (1 drip and 3 PVC);
- 8 farmers with property disposing of irrigable area between 1 and 2 acres (2 drip and 6 PVC);
- 21farmers with property disposing of irrigable area superior to 2 ha (4 drip and 17 PVC).

Two lists have therefore been developed on the basis of this survey method. The first list of the main sample includes 80 farmers and the second list is a replacement list.

<table>
<tr><th colspan="2">Legal status</th><th>Farm size</th><th>Irrigation system</th><th>Total nbr of farmers (A)</th><th>Total area (B)</th><th>% Total area (C)</th><th>Nbr of farmers to be surveyed (D=C*A)</th></tr>
<tr><td colspan="4">Public Irrigated Areas (PuIA)*</td><td>370</td><td>405</td><td>16</td><td>13</td></tr>
<tr><td rowspan="8">Public Irrigated Areas (PuIA)</td><td colspan="3">Drillings*</td><td>66</td><td>151</td><td>6</td><td>5</td></tr>
<tr><td colspan="3">Surface wells (Zarzis & Médenine South)*</td><td>907</td><td>926</td><td>37</td><td>30</td></tr>
<tr><td rowspan="6">Surface wells (Other delegations)**</td><td rowspan="2">< 1 ha</td><td>PVC</td><td rowspan="6">2 110</td><td>87</td><td>4</td><td>3</td></tr>
<tr><td>Drip</td><td>22</td><td>1</td><td>1</td></tr>
<tr><td rowspan="2">1 to 2 ha</td><td>PVC</td><td>190</td><td>8</td><td>6</td></tr>
<tr><td>Drip</td><td>48</td><td>2</td><td>2</td></tr>
<tr><td rowspan="2">> 2 ha</td><td>PVC</td><td>515</td><td>21</td><td>17</td></tr>
<tr><td>Drip</td><td>129</td><td>5</td><td>4</td></tr>
<tr><td colspan="4">Total</td><td>3,453</td><td>2,473</td><td>100</td><td>80</td></tr>
</table>

** Availability of exhaustive list of farmers ** Availability of partial list of farmers*

Table 37. Breakdown of the sample in the region of Medenine.

2.5. Developing the samples for Governorate of Tozeur

The sample of 150 farmers was selected in order to accurately represent the different farming systems practiced by all the irrigated oasis of the governorate. The criteria selected for stratification, which explicitly incorporate the heterogeneity of the oasis reality, are the place of residence of the cropper, the size and the type of oasis.

Size	Farmers		Area	
	nbr	%	ha	%
0 - 1 ha	4,658	57.9	1,700	20.2
1 - 5 ha	3,272	40.6	5,200	61.9
5 - 20 ha	110	1.4	800	9.5
20 ha or more	10	0.01	700	8.4
Total	8,050	100	8,400	100

Source : Results of the survey on the structures of the agricultural farms 2004-2005.

Table 38. Breakdown of the agricultural farms according to size.

Zone	Public irrigated areas		Private irrigated areas	
	Area	%	Area	%
Tozeur	2,610	89.0	322	11.0
Nefta	1,352	83.4	261	16.6
Dgueche	1,923	86.6	298	13.4
Tameghza	457	77.9	130	22.1
Hezoua	746	73.9	264	16.1
Total	**7,088**	**84.8**	**1,275**	**15.2**

Source,: CRDA Tozeur.

Table 39. Public and private irrigated areas per selected zones.

Zone	Irrigated area		Sample	
	Ha	%	Size	%
Tozeur	2,932	35.0	46	30.7
Nefta	1,613	19.3	32	21.0
Dgueche	2,221	26.6	35	23.3
Tameghza	587	07.0	15	10.0
Hezoua	1,010	12.1	22	15.0
Total	**8,363**	**100**	**150**	**100**

Table 40. Breakdown of the sample according to selected zones.

III. DEVELOPING THE LIBYAN SAMPLE

The statistical basis on which the regional consultant relied to prepare the representative sample of farms to be field surveyed is the Agricultural Census of 2007; it was carried out by the General Information Authority. During the meeting held in Tripoli January 29, 2012, with the Libyan team in charge of carrying out the field survey, it was decided by mutual agreement to restrict the first campaign to the Jeffara region. The central area was temporarily excluded from the first season only for security reasons during the period.

III.1. Farms breakdown

Tables 41, 42, 43 illustrate the breakdown of farms and of their areas per *shaabia* according to the source of irrigation in the entire country, in the SASS zone, Jeffera and the central zone.

Shaabia	Breakdown of farms and their areas according to source of irrigation per *shaabia* (Libya)															
	Non-irrigated		Irrig. Private well		Irrigated dam		Irrigated source		Irrigated public well		Irrig. Other sources		Not indicated		irrigated + non-irrigated	
	Nbr farms	Area	Nbr. Farms	Area	Nbr farms	Area	Nbr Farms	Area	Nbr farms	Area	Nbr farms	Area	Nbr farms	Area	Nbr farms	Area
Batnane	6,195	67,052	394	1,655	8	102	14	39	23	70	25	82	172	1758	6,831	70,758
Darna	1,749	13,930	1,024	2,566	19	48	256	574	118	228	138	318	36	731	3,340	18,395
Djebel Lakhdhar	4,818	26,765	800	2,526	12	35	86	244	295	939	1,184	4,797	262	1,442	7,457	36,748
Marj	5,312	126,236	385	4,410	3	42	7	20	12	75	90	546	289	5,720	6,098	137,049
Benghazi	759	8,785	343	2,045	9	48	0	0	28	67	23	48	91	450	1,253	11,443
Ouahatt	634	2,599	3,365	10,397	10	18	16	71	88	592	5	19	621	1,768	4,739	15,464
kouffra	19	56	1,826	5,067	3	5	1	2	353	21,318	10	18	338	614	2,550	27,080
Syrt	1,966	10,147	1,333	46,019	11	44	3	9	144	818	1,302	5,531	393	1,736	5,152	64,304
Juffra	31	140	1,751	5,414	6	21	13	49	446	1,407	9	34	378	1,216	2,634	8,281
Misrata	14,180	43,521	7,871	17,324	35	85	279	330	225	493	63	101	309	820	22,962	62,674
Marguab	38,779	88,697	11,251	13,902	124	206	16	24	119	186	416	702	3,419	12,652	54,124	116,369
Tripoli	1,479	2,845	5,676	7,601	13	27	6	12	2	2	17	16	812	1,224	8,005	11,727
Jeffara	7,008	14,643	35,033	51,220	61	107	21	34	109	252	428	567	3,321	6,540	45,981	73,363
Zawiya	688	1,635	24,216	36,308	43	58	16	22	23	3,062	40	308	1,015	2,066	26,041	43,459
Zouwara	10,839	25,505	12,015	19,063	31	38	7	14	12	4,169	38	49	1,309	2,912	24,251	51,750
Djbel Gharbi	24,507	63,889	1,576	6,270	22	118	43	44	128	1,171	7	32	575	1,829	26,858	73,353
Nalut	4,500	12,923	1,382	4,425	7	47	78	85	105	91	7	7	397	1,934	6,476	19,512
Sebha	12	27	5,219	12,393	8	20	1	1	128	495	5	21	282	1,102	5,655	14,059
Oued Chott	50	212	3,703	6,954	6	15	305	396	585	1,307	8	3	189	377	4,846	9,264
Murzak	15	25	8,784	15,902	7	15	7	162	566	6,473	2	2	130	890	9,511	23,469
Oued Hayet	13	15	6,497	8,694	12	15	1	3	114	195	9	14	744	1,498	7,390	10,434
Ghat	7	15	771	1,066	14	21	15	10	431	1,320	9	11	131	184	1,378	2,627
Total pf the republic	**123,560**	**509,662**	**135,215**	**281,221**	**464**	**1,135**	**1,191**	**2,145**	**4,054**	**44,730**	**3,835**	**13,226**	**15,213**	**49,463**	**283,532**	**901,582**

Table 41. Breakdown of farms and their areas according to source of irrigation per shaabia countrywide.

Shaabia	Irrig. Private well		Irrigated dam		Irrigated source		Irrigated public well		Irrigated other source		Not indicated		Total irrigated & non-irrigated		Tot irrigated	
	Nbr	Area	Nbr	Area	Nbr	Area	Nbr	Area	Nbr	Area	Nbr	Area	Nbr	Area	Nbr	Area
Marguab	11,251	13,902	124	206	16	24	119	186	416	702	3,419	12,652	54124	116,369	11,926	15,020
Tripoli	5,676	7,601	13	27	6	12	2	2	17	16	812	1,224	8005	11,727	5,714	7,658
Jeffara	35,033	51,220	61	107	21	34	109	252	428	567	3,321	6,540	45981	73,363	35,652	52,180
Zawiya	24,216	36,308	43	58	16	22	23	3,062	40	308	1,015	2,066	26041	43,459	24,338	39,758
Zouwara	12,015	19,063	31	38	7	14	12	4,169	38	49	1,309	2,912	24251	51,750	12,103	23,333
Tot Jeffara	88,191	128,094	272	436	66	106	265	7,671	939	1,642	9,876	25,394	158,402	296,668	89,733	137,949
Djbel Gharbi	1,576	6,270	22	118	43	44	128	1,171	7	32	575	1,829	26,858	73,353	1,776	7,635
Nalut	1,382	4,425	7	47	78	85	105	91	7	7	397	1,934	6,476	19,512	1,579	4,655
Juffra	1,751	5,414	6	21	13	49	446	1,407	9	34	378	1,216	2,634	8,281	2,225	6,925
Misrata	7,871	17,324	35	85	279	330	225	493	63	101	309	820	22,962	62,674	8,473	18,333
Tot Central Zone	12,580	33,433	70	271	413	508	904	3,162	86	174	1,659	5,799	58,930	163,820	14,053	37,548
Total SASS	100,771	161,527	342	707	479	614	1,169	10,833	1,025	1,816	11,535	31,193	217,332	460,488	103,786	175,497
Total Libya without SASS	34,444	119,694	122	428	712	1,531	2,885	33,897	2,810	11,410	3,678	18,270	66,200	441,094	40,973	166,960
Total Libya	**135,215**	**281,221**	**464**	**1,135**	**1,191**	**2,145**	**4,054**	**44,730**	**3,835**	**13,226**	**15,213**	**49,463**	**283,532**	**901,582**	**144,759**	**342,457**

Table 42. Breakdown of farms and irrigated areas of the SASS area per Shaabia according to source of irrigation.

Shaabia	Private wells (ha)	%	Other sources	%	Tot.	%
Marguab	13,902	92.5	1,118	7.4	15,020	100
Tripoli	7,601	99.2	57	0.7	7,658	100
Jeffara	51,220	98.2	960	1.8	52,180	100
Zawiya	36,308	91.3	3,450	8.7	39,758	100
Zouwara	19,063	81.7	4,270	18.3	23,333	100
Tot Jeffara	128,094	92.9	9,855	7.1	137,949	100
Djbel Gharbi	6,270	82.1	1,365	17.9	7,635	100
Nalut	4,425	95.1	230	4.9	4,655	100
Juffra	5,414	78.2	1,511	21.8	6,925	100
Misrata	17,324	94.5	1,009	5.5	18,333	100
Tot Central area	33,433	89.0	4,115	11.0	37,548	100
Total SASS	**161,527**	**92.0**	**13,970**	**8.0**	**175,497**	**100**
Total Libya excluding SASS	119,694	71.7	47,266	28.3	166,960	100
Total Libya	281,221	82.1	61,236	17.9	342,457	100

Table 43. Breakdown of the irrigated areas per Shaabia according to source of irrigation (Jeffara & central area).

III.2. Sample construction

The sample construction conducted using the same method used for Algeria's sample was established based on the three following criteria:

- irrigated surface;
- farm size;
- irrigation source.

The total number of surveyed farms amounted to 500 distributed over 5 *shabiaa.*

Shaabia	Area irrigated in ha	%	Size of the sample
Marguab	15,020	10.9	54
Tripoli	7,658	5.6	28
Jeffara	52,180	37.8	189
Zawiya	39,758	28.8	144
Zouwara	23,333	16.9	85
Tot. Jeffara	**137,949**	**100**	**500**

Table 44. Breakdown by global sample to be surveyed in the Jeffara according to the size of the irrigated farms.

Shaabia	Number of farmers	%	Size of the sample
Marguab	11,926	13.3	67.0
Tripoli	5,714	6.4	32.0
Jeffara	35,652	39.7	198.0
Zawiya	24,338	27.1	136.0
Zouwara	12,103	13.5	67.0
Tot. Jeffara	**89,733**	**100**	**500**

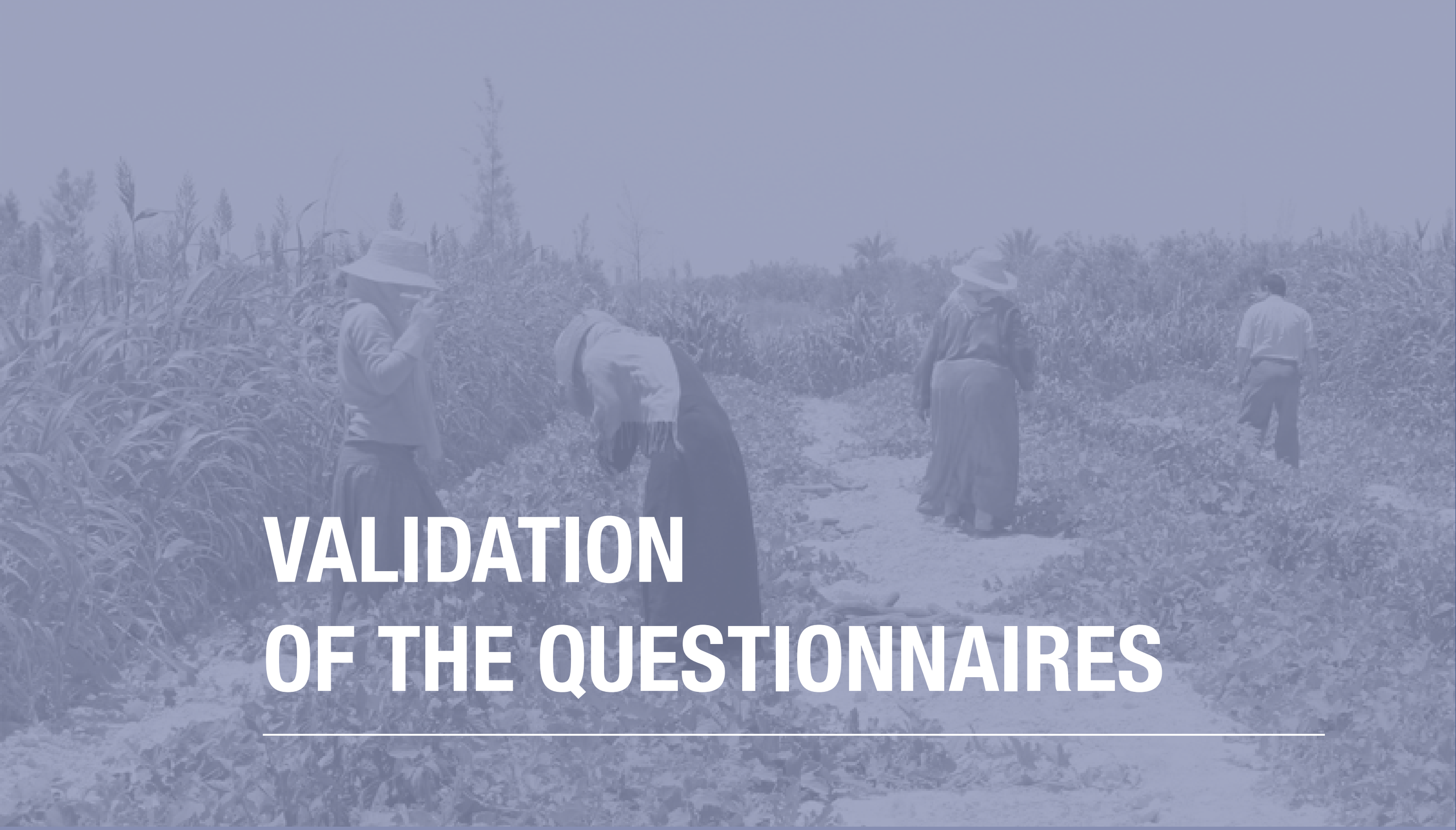
Table 45. Breakdown of the global sample per Shaabia (Jeffara) according to number of farmers.

Shaabia	Irrigated with private wells	Irrigation using other sources	Total of the sample
Marguab	50	4	54
Tripoli	27	1	28
Jeffara	185	4	189
Zawiya	131	13	144
Zouwara	69	16	85
Tot. Jeffara	**464**	**36**	**500**

Table 46. Breakdown of the global sample per Shaabia (Jeffara) according to the size of farms and irrigation source.

Shaabia	Irrigation by private wells	Irrigation using other sources	Total of the sample
Marguab	63	4.0	67.0
Tripoli	30	2.0	32.0
Jeffara	194	4.0	198.0
Zawiya	135	1.0	136.0
Zouwara	65	2.0	67.0
Tot. Jeffara	**487**	**13**	**500**

Table 47. Breakdown of the global sample by Shaabia (Jeffara) according to number of farmers and source of irrigation.



VALIDATION OF THE QUESTIONNAIRES

The questionnaires completed by field surveyors were gathered at Gabes in Tunisia and Ouargla in Algeria, then returned to the OSS headquarters in Tunis. The regional consultant then proceeded with the identification and especially the careful verification of each completed questionnaires.

The validation of each of these questionnaires was a tedious process, repetitive and extremely demanding. However, the whole enterprise of the quantitative analysis of data collected, in order to achieve the development of operational recommendations, closely depends on the conduct of this validation process. ***In fact, any incorrectly completed questionnaire and not corrected in time will have a significant negative impact on the rest of the operations, namely: the numeric processing, quantitative analysis and especially the formulation of proposals for operational recommendations.***

I. DESCRIPTION OF THE VALIDATION PROCESS

The validation operation of each questionnaire has to go through the following steps:

- Verification that all the questions were answered: rappelons que le questionnaire comporte au moins 200 questions qui s'étalent sur 24 pages. La lourdeur du questionnaire s'explique tout simplement par la volonté de collecter une information exhaustive sur tous les aspects socio-économiques et environnementaux afin de saisir au mieux le comportement réel de l'usager primaire de la ressource SASS.
- Consistency of deferred responses: in designing the questionnaires, several consistency tests were introduced to help the respondent provide the required information. Indeed, several questions were designed to obtain important information; they were stated in different ways and placed in different parts of the survey. These tests, used to verify the validity of the answer obtained, concern mainly the key variables targeted such as water consumption, labor input, crops grown, production, unit price, gross income, own consumption of each speculation, etc.
- The verification of the validation of quantitative answers: for each questionnaire, the regional consultant must make an approximate manual estimate of income and gross cost. We note that the estimate of the total income requires computing the income of each crop grown, livestock income and income from sources other than the farm. The estimated total cost through a preliminary calculation of the cost of permanent and temporary labor, the cost of water, the cost of all inputs and the cost of livestock feed. If this estimate shows that the costs exceed income, the questionnaire is returned to the base investigator. In addition, the variable water consumption per hectare per crop is also checked to compare consumption standards in the area.

Any questionnaire that does not meet the conditions described above is returned to the investigator concerned in order to makes the correction of anomalies reported; they often require a return to farmer.

II. THE VALIDATION PROCESS

The validation operation of each of the questionnaires began at the end of August. Out of the 773 questionnaires received for five Tunisian areas, 83 were returned to the investigation teams for verification and further information. Several issues were identified for the questionnaires involving some areas in Algeria, particularly Wilaya of Adrar and Ghardaia. The rejection rate following the first validation was 40% in Algeria.

III. ROUGH ESTIMATE OF THE TIME REQUIRED FOR VALIDATION

Table 48 shows the number of questionnaires provided for countries during the first survey campaign, the rejection rate after the validation operation, as well as the total number of questionnaires to verify and validate the three countries concerned.

The average validation operation requires at least 15 minutes per each completed questionnaire. Table 48 shows the total time devoted to the validation operation of all the questionnaires of the first campaign of socioeconomic and environmental surveys.

If the Regional Consultant devotes 5 continuous hours per day and 5days a week for the validation work , the validation operation of the first campaign questionnaires would require at least 8 months and 15 days.

Unfortunately, this validation operation was underestimated in the beginning. This, in addition to the difficulties encountered on ground following the exceptional events that occurred in 2011 in the region, have caused a slight delay in the completion of the first socioeconomic and environmental survey campaign.

	Size of sample (Nbr. Of farms to be surveyed)	Rejection rate	Nbr of surveys rejected	Total nbr of questionnaires to be verified
Algeria	1,616	40	647	2,263
Libya	500	10	50	550
Tunisia	823	10	83	906
Total	**2,939**	**26.5**	**780**	**3,719**

Table 48. Breakdown of questionnaires to be validated by countries.

Total number of questionnaires to be verified	Time required for the validation of a questionnaire in mn	Nbr of questionnaires validated per hour	Total number of hours devoted to the validation operation
3,719	15	4	930

Table 49. Number of hours required for the validation operation.

DIGITAL ENTRY OF COLLECTED DATA

This process is as delicate and tedious as the validation process, and involves several steps, namely:

- classification, identification and photocopy of previously validated questionnaires;
- setting up a processing and verification team;
- the actual input operation;
- the verification process of the data entered.

I. CLASSIFICATION, IDENTIFICATION AND XEROXING THE QUESTIONNAIRES ALREADY VALIDATED

Once the questionnaires are gathered at the OSS headquarters and approved by the Regional Consultant, the processing team photocopies all the questionnaires and classifies them before proceeding to the systematic processing. The identification of the questionnaire helps define the exact location of each survey and facilitates the processing, verification and especially both the descriptive and analytical analysis. Indeed, on each questionnaire exists an identifier taking forms such as: TGABMET01 (T for Tunisia, GAB for Gabes Governorate, MET for Methouia area and 01 is the number of the questionnaire in the area concerned).

II. SETTING UP THE TEAM FOR THE VERIFICATION AND PROCESSING OF DATA ALREADY COLLECTED AND VALIDATED

A consultant in charge of processing and verifying data of the socio-economic and environmental survey in the SASS area was recruited and assigned the following tasks:

- the preparation of the overall input file;
- training of data inputters;
- supervision and control of the entire data entry operation;
- the descriptive statistical processing for a first analysis of data;
- preparation of data for processing with other softwares (SPSS, STATA, etc.); and
- development of a database.

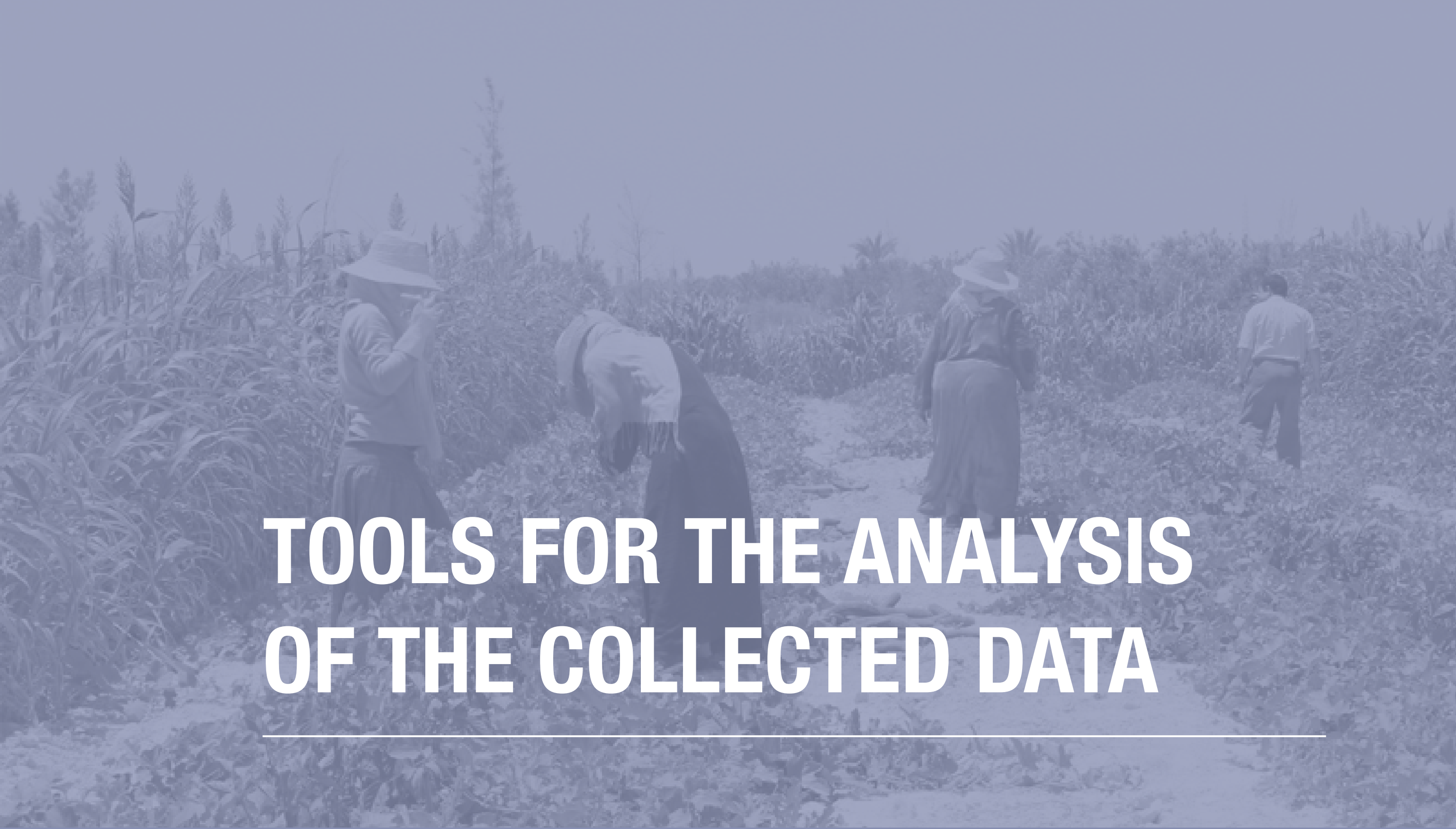
The team responsible for the material processing of data is made up of:

- an entry clerk at the headquarters of the OSS,
- a team of students who carry out the processing at home under the direct supervision of the consultant responsible for data entry.

III. ACTUAL DIGITAL PROCESSING OPERATION

This operation is made up of several stages:

- the actual physical entry by the inputters recruited for this purpose;
- the preliminary verification by both the consultant responsible for the processing and the regional consultant. For this first control, a random draw of some questionnaires is done for each area of the three countries in order to verify them. This control serves to ensure that the processing is successful.
- Systematic verification: this operation is made during the descriptive analysis of data. Its approach is described in detail in the section devoted to the analysis.



TOOLS FOR THE ANALYSIS OF THE COLLECTED DATA

I. DEFINITION OF VARIABLES USED IN OUR ANALYSIS

The total number of both quantitative and qualitative variables that can emerge from the socio-economic and environmental investigation can reach hundreds. Only those deemed most relevant were selected as part of this preliminary analysis and are detailed in Table 50.

Variables selected	Definition of the Variable
WHA	Water consumption per hectare
WCMC	Water cost per m^3 used
RTHA	Total revenue per hectare
Lev.ed	Level of education
AIA	Actual Irrigated Area (ha)
SALI	Salinity of the Irrigation Water Used
WP	Water Productivity
BHA	Net Profit per hectare
FLHA	Family Labor per hectare (men per year)
HLHA	Hired labor per hectare (The cost of wage labor)
WCHA	Water Cost per hectare
INTHA	Inputs per hectare (fertilizers, insecticide, herbicide, manure, etc.)
FEED	Cost of Cattle Feed
SENI	Seniority in the practice of irrigation per year
RHE	RHE1 =0, if the farmer has another activity and 1 if not
WOR	WOR = 0 if water is free, 1 if a public network and 2 if a private network
AWL	% of the total revenue of the farm without livestock breeding

Table 50. list and definition of key variables.

II. BASIC SOCIOECONOMIC CONCEPTS

This section provides a summary presentation of basic socio-economic concepts that support the analysis, both descriptive and quantitative, and feedback of results to achieve operational recommendations proposed for a sustainable management of the relevant aquifer.

1. Cost

The notion of cost is highly complex and especially of paramount importance for any sustainable management of a resource that is very little renewable such as the SASS water resource. For Professor J.M. Clark, "*an economics course would be a success if students succeed to achieve a real mastery of the meaning of cost in all its many aspects*."

A simple definition of such complex concept (cost) is a real challenge.

We offer two tentative definitions:

- cost is the amount of money, time and resources used to produce or acquire an economic good;
- the cost is usually a monetary assessment of current efforts, property used, consumed resources, time and lost utilities, the risk and missed opportunities in the production and supply of goods and services.

In order to properly assess the real cost of water resources, which is the limiting factor in any economic and social development in the SASS region, the ideal would be to have full information on all the elements that explicitly incorporate all the required variables (pumping cost, cost of operations, maintenance of equipment and especially the fixed investment cost). As part of our investigation, only the variable costs of the public network[1] could be collected. However, for private croppers, detailed information on variable costs and fixed costs has been collected. As part of this preliminary analysis, only variable costs have been retained for private farmers in order to compare the two categories of public and private farmers under the same conditions.

2. Marginal cost (MC)

The MC is the cost involved in the production of an additional unit of a good or service. Formally, the MC is calculated by dividing the change in total cost (ΔCT) by the change in the quantity produced (ΔQP) :

$$MC = \frac{\Delta CT}{\Delta QP}$$

[1] A "water points" survey is underway and related to the overall variable and fixed costs of the public and collective irrigation networks.

3. Opportunity cost

The notion of what economists call the opportunity cost is crucial to any process of allocating scarce resources that could be allocated to alternative uses.

Definition: simply put, the opportunity cost the benefit you have been able to receive by choosing the best alternative action.

In the particular case of groundwater resources exploited and especially non-renewable aquifers, two situations should be identified as different:

- that in which the exploitation of renewable groundwater far exceeds the natural recharge rate;
- that of a mining exploitation of the deep aquifers whose stock has been accumulated over thousands of years and whose recharge rate is now negligible.

L'analyse économique dans ces deux cas de figure, qui diffère de celle où la ressource est un flux renouvelable, nécessite l'intégration explicite d'un coût d'opportunité additionnel de la ressource.

The economic analysis in both cases, that differs from that where the resource is a renewable flow, requires the explicit integration of an additional opportunity cost of the resource.

Given that the current uses exhaust the stock and make it unavailable for future use (especially for the future generations), there is an opportunity cost to the non-availability of water for these future users. We will call this cost "an inter-temporal and intergenerational opportunity cost", which should be added to the classical opportunity cost translating the unavailability of the resource to another common usage, could be called the contemporary opportunity cost.

4. Marginal-cost pricing

Modern economic theory teaches us that marginal cost pricing, which stipulates that the price of any scarce resource should be set at the level of marginal cost, leads to an efficient allocation of the resource involved in every process of production.

Achieving the expected optimal allocation requires the integration of multiple types of marginal costs, i.e.:

- the cost of maintenance and ongoing management;
- the future cost of additional investment;
- additional costs for the damage done to the environment.

This orientation leads us directly to the principle of Long Term Marginal Cost (LTMC), which is defined as:

The long term marginal cost is the additional cost incurred by a production company when <u>all factors of production</u> (inputs) are variable. Indeed, when considering the long run, even the fixed investment costs become variables. The LTMC is the additional cost that results when a company increases the scale of its operations, not only by adding more workers in a given factory, but also by building a new plant.

The illustrative example in the context of water resource management would be: the long term marginal cost of an additional mobilized unit of water when constructing a new dam.

We note at the outset that calculating the LTMC implies, by definition, a long-term assessment of the costs; it becomes therefore a method capable of explicitly integrating all aspects of environmental management and especially any expected related climate-change related phenomena.

5. Gross margin

This concept is generally used by agricultural economists instead of the concept of profit dear to orthodox economists. The Gross Margin (GM) of a farm, defined as the difference between its income and variable costs, is usually the variable used in commercial discussions concerning the branch. However, it should be noted that the gross margin is not profit. The topics of major commonly known variable costs are:

- the cost of wage labor;
- the cost of water resources for irrigated agriculture (again we must distinguish between the cost incurred by the farmer and the actual cost to the community);
- the cost of fertilizers, seeds and insecticides;
- the cost of feeding livestock.

<u>Note</u> : These are the four types of variable costs that we retain as part of this analysis.

6. *Economic Water Productivity*, EWP

Economic water productivity is defined as the value, in monetary terms, derived from the use of a unit of the resource. In this context, it will be the value in dinars obtained for the use of one m^3 of water in the production of irrigated agriculture in the SASS zone.

The expressions “more nutrition per drop” or “more job per drop” are common in the literature. As part of our analysis, we use EWP to refer to Economic Water Productivity.

Calculation of gross economic water productivity (GEWP):

$$GEWP\ per\ m^3 = \frac{gross\ margin}{total\ volume\ of\ used\ water}$$

In calculating this productivity, it is assumed that the entire gross margin by the farmer comes only from the water used. When in reality, it is also the result of other factors of production, namely labor, land, seeds, fertilizers, etc. In the context where the water is a factor of production among others, that is to say, a factor of production that obeys the classical substitution rule which states that any factor can be substituted (replaced by) another, this definition is biased. However, in an environment where water is a factor (without it no production is possible), as is the case in the SASS area, this definition is acceptable.

Important Note: To calculate the net economic water productivity (NEWP), we must replace the formula above, gross profit by net margin. However, the passage of the gross margin and net margin is unfortunately not an easy operation. Indeed, this passage requires the availability of data that do not exist currently.

Among the data needed to calculate the net margin, we must at least have:

- the cost of investment in the mobilization of resources;
- the amount of all grants that the state grants to the sector;
- the various taxes imposed on the sector.

7. The Willingness to Pay (WTP)

The WTP is a method which is generally used to evaluate (approximate) property prices in cases where it is almost impossible to know the price otherwise. This approach is common to estimate the price of an environment good that has no classical market (non-market good). This method tries to determine the price that people are willing to pay for the property.

Calculation of the WTP in our context:

Annual WTP for water = Total gross return (return of arboriculture+ return of intercropping + return of full field crops + return of greenhouse farming + return of livestock) - cost (wages paid + cost of inputs + livestock feed and maintenance costs).

$$WTP\ per\ m^3 = \frac{total\ water\ WTP}{total\ volume\ of\ used\ water}$$

Note: All the costs except that of the water were retained in this calculation.

Note: the definitions of water productivity (Water Productivity) and the WTP are very close. The only difference lies in the fact that for the WP, we omit the cost of water in the calculation of expenditure for the WP; we consider the gross margin (we take all expenses including the cost of water) . Since these variables are very close, one can use either as an approximation of the price of water. In this presentation, we will rather use the WP.

In the calculation of the WTP, all the distortions caused by massive State intervention in the management and allocation of water resources were ignored..

The distortions in the calculation of gross margin, the economic productivity of water and WTP

We must therefore take into account the subsidies that farmers receive that distort prices and therefore significantly exclude underlying opportunity costs. This distortion while undermine therefore any attempt to correctly estimate the MB, EWP and actual WTP for water. The integration process of these distortions in the calculation of these components is quite complex[2].

[2] In order to estimate the value of subsidies, we must opt for the PSE (Producer Subsidy Equivalent) that is given in the following form:

$$PSE = \frac{(V_m + D - V_w)}{V_m} \qquad (1)$$

Where V_m is the output evaluated at domestic prices, V_w is the output evaluated at world price and D are the direct subsidies.

The water resource WTP

Calculating the maximum water WTP per farmer for each crop is carried out in the following way:

$$TNM_t = \frac{NM/ha}{Y} - PSE_t \qquad (6)$$

Where TNM_t is the net margin per tons, NM is the net margin, PSE_t is the equivalent of subsidies to the producer and Y is the yield per hectare.

The figures of the real WTP should include the amount that the farmer actually pays for irrigation water used.

The actual WTP for water per hectare is therefore:

$$WTP/ha = \frac{TNM_t + WC}{Y} \qquad (7)$$

Where WC is the actual amount the farmer pays for the water used.

This brief analysis shows clearly that the water allocated to irrigation as well as to other uses is actually significantly underestimated (i.e., supplied to users at a cost that is lower than the actual cost of the resource) in the entire SASS region. The direct result of this underestimation is that water is overused in the all the cropping activities. In fact, if irrigation decisions were taken on the basis of real cost of mobilization of the resource, the demand for irrigation would likely decrease for all the crops. Globally, the farmers would adopt the best performing techniques of irrigation and crops that value most the resource.

8. Intensification Rate (IR)

A very restrictive definition has been selected within this framework:

IR = actual irrigated area during the survey year/area equipped to be irrigated.

$$IR = \frac{SEI}{SI}$$

9. Defining the concept of elasticity

General definition: elasticity is the variation in the quantity of a magnitude (in %) given the variation of another magnitude also in %.

The best known elasticity and most commonly used in applications is the elasticity of the price of a good in demand. This elasticity measures the variation of the quantity in terms of percentage of a particular good (for example, in our context the demand for irrigation water), when the price changes (knowing that the income of the farmer remains unchanged).

$$\varepsilon_p^w = \frac{\text{percentage of variation of the quantity demand of a good (in this case the water)}}{\text{percentage of price evolution on the said good}}$$

$$\text{Elasticity of the price of the demand} = \frac{(q_1 - q_0)/q_1}{(p_1 - p_0)/p_1}$$

Where

- q_0 and q_1 are respectively the quantities required during the periods 0 and 1;
- p_0 and p_1 are respectively the prices observed during the period 0 and 1.

In other words, if we take the example of water, this elasticity measures the % of the variation of the volume of water required by the farmer divided by the% of the tariff change (the price of water) imposed by the water authority or by the market in the case of private management.

Comment: This is also called temporal elasticity as opposed to spatial or individual elasticity. In the latter, it is replaced by space-time. Thus the quantities q_0 and q_1 as well as price

p_0 and p_1 become associated respectively with the first and second farmer and not to the temporal periods 0 and 1.

10. Distinction between the different definitions of agricultural water demand

The concepts of the volume of water used in irrigated agriculture are many.

- the resource mobilizer refers to the volume of water produced. This is the volume of water pumped from a well or a surface well, the amount of water released from a dam.
- The agronomist generally talks about the need for water to irrigate a hectare of tomatoes for example in a given geo-climatic zone. In this case, one speaks of the water need. We deal with normative data.
- The economist, however, speaks of water demand by the user. This is the volume of water required by a user to run an irrigated farm.
- For users of the resource, what matters is basically the volume of water that actually reaches the plot. More importantly, the actual volume that reaches the plant or the crop.

The distinction we have just presented between different definitions of the volume of water used in agriculture is of paramount importance to conduct quantitative analysis.

To specify exactly the definition adopted in our approach, it is first necessary to outline the nature of the data collected during field surveys.

The field surveyor collects the following information from the farmer of the area selected:

Water consumption per crop

Crops	Method of irrigation	Total number of irrigations/ Yr.	Number of hours/ Irrigation	Flow L/S	Volume consumed in m^3
Arboriculture	Flooding	52	10	3	5,616

This table shows an example by way of illustration. This is a farmer who cultivates ha of orchards, irrigated by a surface well with a continuous flow rate of 3 liters per second:

- crop: different kinds of fruit trees;
- method of irrigation practiced: In this example, it is the traditional technique of releasing water on a given surface; also known as flood irrigation;

- number of irrigations: the farmer irrigates his plot once a week, which gives 52 irrigations for the whole week;
- the duration of each irrigation is 10 hours.

The produced water, which is the volume pumped from the well, is calculated as follows:

$$(3{,}600 \text{ seconds}) \times (3 \text{ L/S}) \times (10 \text{ hours}) \times (52) = 5{,}616 \text{ m}^3.$$

Evaluation of water loss

The questions addressed to the cropper about the losses between the water source and place of effective irrigation.

Means of water transportation to the farm:

- seguia;
- PVC Pipe;
- Cement pipe.

Are there losses over this course? How much do you estimate in % compared to the initial flow?

Means for distributing water inside the farm:

- Land Seguia
- PVC pipe / Rubber pipe
- Cement pipe

What is the estimated lost water volume in the case of seguias compared to the initial flow?

Thus, thanks to such information, it is possible to calculate the volume of water actually used by the farmer.

Important Note: In this preliminary quantitative analysis, the concept of water demand by the irrigator was used. This is the volume of water produced by the private cropper using his own means (pumping a surface well or drilling) or volume issued by a public or collective network.

11. The median

The median of a set of values is a statistical parameter; it is a value m situated in the middle of a series so that the number of values of the series that are higher or equal to m is exactly equal to the number of values higher or equal to m.

This tool is very useful and gives better information than the conventional average when the available data set available is heterogeneous.

12. The nature of available data

It is essential to know the type of available statistic data to be able to conduct the estimations of the retained specification coefficients through the econometric model presented in annex.

Three major categories of data are generally available:

- the Time Series: this involves disposing of observations over time on a given entity. The annual production of a country over several years, the production of an irrigated farm over a period of 20 years for example. In this category of data, emphasis is placed on the dynamic aspect.
- Cross section data: this information is typically collected through surveying campaign during a given year on irrigated farms for example. In this category of data, however, emphasis is on individual or spatial aspects.
- The panel data: a combination of the two types of data. For example, this involves collecting data on a sample of farmers over several time periods; which means conducting several survey campaigns on a set of irrigators in a given area. This category of data, that combines important aspects of any economic activity, namely the dynamics and spatial, provides a wealth allowing a better estimate of any model chosen.

III. PRESENTATION OF ECONOMETRIC MODELS USED IN THE ESTIMATES

Three specifications of the general econometric model have been selected to estimate the determinants of the three key variables of this analysis, namely:

- Estimate the determinants of the demand for water by farmers of the SASS zone;
- Estimate the determinants of productivity of the water used;
- Estimate the determinants of the production function of the farmers of the SASS zone

1. Water demand estimates

The selected specification is designed to identify the determinants of the key variable expressed in log, which is the consumption of water per hectare per farmer. The WHA variable is well expressed in terms of the set of explanatory variables used in the following specification:

(1) $$lwha = \alpha_0 + \alpha_1 lwcmc + \alpha_2 lAIA + \alpha_3 Rhe + \alpha_4 lsalin + \alpha_5 Awl + \alpha_6 Wor + \alpha_7 Country + \alpha_8 Seniority + \alpha_9 \mathrm{Re}$$

where:

$\alpha_0, \alpha_1, ...\alpha_8$ are the parameters (here elasticities) to be estimated thanks to data collected and the selected model.

The variable to be explained is: Lwha (log of the irrigation water demand by the farmer i).

The explanatory variables are :

- Lwcmc : log of the cost per one m^3 borne by the farmer ;
- LSalin : log of the salinity of the water used by each farmer i ;
- LAIA : log of the actual irrigated area in hectares ;
- Rhe : This variable is set to 0 if the farmer has an activity other than agriculture and 1 if not.
- Re : This variable indicates the region of each farmer i.
- Awl : agriculture without livestock. This variable represents the percentage pf revenue achieved by the farmer i from his agricultural activity excluding revenue from livestock from the total farmer's revenue.
- Country : this variable is 1 if the farmer is Algeria, 2 if the farmer is Libyan and 3 if he is Tunisian.
- Seniority : log of the farmer's experience in the practice of irrigation.
- Wor : This variable is 0 if water is free, 1 if water is supplied by a public network and 2 if water is mobilized by the cropper.

This specification is estimated using the STATA software in the most appropriate manner, i.e., using econometric technique that best suits the reality on the ground.

2. Water economic productivity estimate (EWP)

The specification to estimate the determinants of economic water productivity is as follows:

(2)

$$lwp = \alpha_0 + \alpha_1 lwcmc + \alpha_2 lAIA + \alpha_3 lsalin + \alpha_4 Awl + \alpha_5 Wor + \alpha_6 Rhe + \alpha_7 Country + \alpha_8 lflha$$

Where :

$\alpha_0, \alpha_1, ...\alpha_6$ are the parameters (here the elasticities) to be estimated thanks to data collected and the selected model.

The variable to explain is Lwp : the water economic productivity log by farmer i.

The explanatory variables are:

- Lflha which is the log of the family labor size;
- the rest of variables selected are already defined before.

3. Estimates of the determinants of the total production per hectare

The selected specification to estimate the determinants of total production per hectare:

(3)

$$lrtha = \beta_0 + \beta_1 lflha + \beta_2 lhlha + \beta_3 lwcha + \beta_4 Lintha + \beta_5 Lfeed + \beta_6 Laia + \beta_7 Lsalin + \beta_9 Lseniority + \beta_{10} Wor + \beta_{11} Re$$

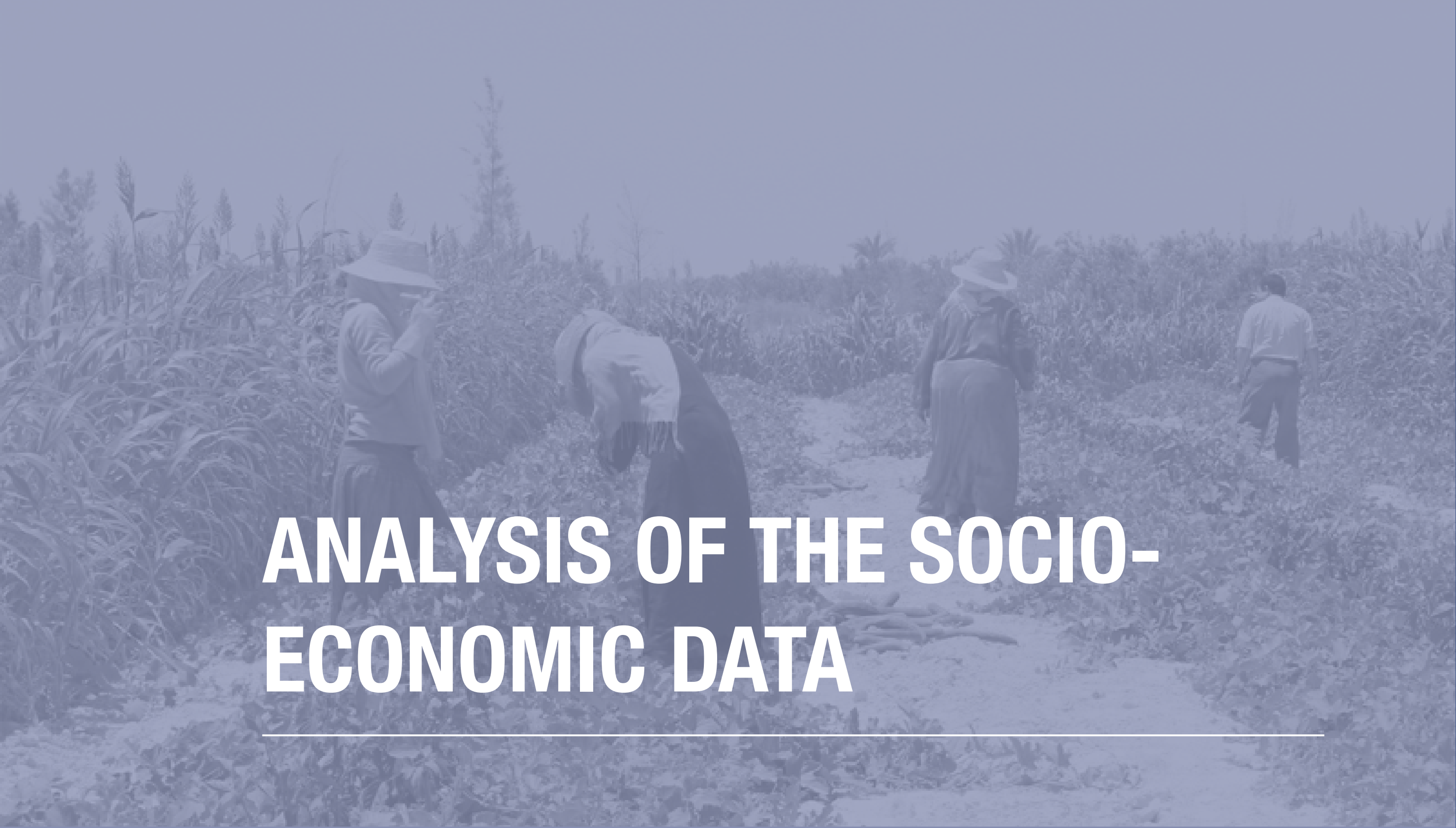
Where :

The variable to be explained is LRTHA : Total agricultural production log of the farmer i.

The explanatory variables are:

- Lflha: log of the family labor size;
- Lhlha: log du total cost of wage labor;
- Lwcha: water cost per ha;
- Lintha: cost of inputs (manure, fertilizers, insecticides, herbicides, etc.);
- Feed: cost of livestock feed.
- The rest of variables are already defined here above.

Note: These different selected specifications are estimated using a STATA software in the most appropriate manner ; i.e., using the econometric technique that best suits the reality on the ground. We mean the use of econometric model that explicitly incorporates all the extensions required to achieve the results that are closest to reality.



ANALYSIS OF THE SOCIO-ECONOMIC DATA

Two types of analysis will be developed out of the data:

- A descriptive analysis, through simple statistics, will generate the most common characteristics;
- A quantitative analysis, using the most recent econometric tools, will reveal the most important features and that are useful for the design of the most appropriate economic policies.

I. TUNISIA

Two types of analyses of the data were carried out:

- A descriptive analysis, thanks to simple statistics, helped reveal the most common characteristics;

- A quantitative analysis, thanks to the most recent econometric tools, will help reveal the most important and useful characteristics for the design of the most appropriate economic policies.

1. Descriptive analysis

The descriptive analysis, which will be the subject of this section will mostly prepare the ground for the quantitative analysis. Indeed, in this context, focus will be on some intuitive results to demonstrate and quantify especially in the next section which is the major contribution of this report.

Table 51, which holds the optical mode of payment of the cost of water, gives the average, minimum, maximum and standard deviation of the key variables in this preliminary analysis to the whole country and the three categories selected. Table 53 focuses on the most important features to be drawn from this table, but first a few remarks are required:

- the average area irrigated by private farmers is higher than that of the farmers of public irrigated areas and especially farmers who receive free water sources (*4 hectares for private, 1.5 hectares for farms supplied by public irrigation and less than one hectare for free water resources*) ;
- With regard to seniority in the practice of irrigation, the private farm is a much more recent phenomenon than the other two types (*17 years on average for private farms and between 28 and 33 years for the other two categories*).

Table 52, that shows the criterion of spatial homogeneity, gives the average, minimum, maximum, and standard deviation of the key variables of this preliminary analysis for the whole country and the three selected regions. Table 53 will focus on the most important features to be drawn from this table, but first a few remarks are required:

Tunisia	AIA/ ha	WCHA (DT/ha)	WCMC (DT/m³)	WHA/ha	MB (DT/ha)	WP (DT/m³)	WTPMC	SALIN	ANCI
Average	2.148	545.484	0.068	11170.325	6149.343	0.691	0.759	2.920	25.297
Min	0.030	0.000	0.000	260.000	-1890.000	-1.275	-1.175	0.300	0.000
Max	45.000	3192.593	1.019	33572.571	38581.250	10.343	10.413	9.000	151.000
E.T	3.683	468.581	0.069	7423.504	5533.511	0.799	0.819	1.085	17.560
FREE									
Average	0.830	28.846	0.003	15871.170	7805.631	0.479	0.482	2.350	33.800
Min	0.090	0.000	0.000	2592.000	-1760.000	-0.127	-0.127	1.600	2.000
Max	2.500	576.923	0.058	25920.000	21333.333	1.317	1.317	3.500	62.000
E.T	0.700	129.004	0.013	6064.888	6772.524	0.413	0.413	0.707	24.039
PUBLIC									
Average	1.493	609.162	0.062	12531.808	6133.387	0.557	0.619	2.902	27.896
Min	0.030	1.200	0.000	480.000	-1530.000	-1.275	-1.175	0.300	0.000
Max	22.600	3192.593	0.617	33572.571	38581.250	4.553	5.142	7.500	151.000
E.T	1.944	470.582	0.054	7183.514	5378.308	0.547	0.557	1.021	17.962
PRIVATE									
Average	3.977	421.395	0.088	7171.095	5922.437	1.050	1.138	3.013	17.379
Min	0.090	34.286	0.004	260.000	-1890.000	-0.517	-0.482	0.600	1.000
Max	45.000	2777.778	1.019	31104.000	35773.333	10.343	10.413	9.000	61.000
E.T	5.975	429.626	0.095	6531.749	5829.095	1.181	1.210	1.248	12.770

Table 51. Breakdown according to the legal status of the origin of the irrigation water.

- The average area irrigated by the farmer in the Gabes area is higher than that of farmers in the Medenine and Tataouine areas; and especially the farmers of the Saharan oases zone (*4.2 hectares for Gabes, 2.9 hectares in the area of the Jeffara and barely one hectare for the Saharan oases*);
- With regard to seniority in the practice of irrigation, the Saharan oases area, with 32 years of average experience in irrigation, is distinguished by the most ancient practices; while in Medenine and Tataouine area, with an average of 16 years, irrigation is a much more recent phenomenon;
- The importance of livestock breeding in the farmers' income is illustrated by the "TCB" column. Breeding, with 36% of total revenue, is a very important source of income for farmers in the area of Jeffara while for the Saharan oases zone, with just 16% of the total revenue, it is a modest supplement.

Tables 53 and 54 show some key variables, of paramount importance to the quantitative analysis, calculated according to two spatial perspective and payment of water cost.

Tunisia	AIA	WCHA	WCMC	WHA	BHA	WP	WTPMC	SENI	TCB
Average	2.148	545.484	0.068	11170.325	6149.343	0.691	0.759	25.297	0.234
Min	0.030	0.000	0.000	260.000	-1890.000	-1.275	-1.175	0.000	-2.733
Max	45.000	3192.593	1.019	33572.571	38581.250	10.343	10.413	151.000	33.000
E.T	3.683	468.581	0.069	7423.504	5533.511	0.799	0.819	17.560	1.348
Médenine-Tataouine									
Average	2.886	301.029	0.096	3632.981*	3934.831	1.014	1.110	16.000	0.362
Min	0.250	0.000	0.000	432.000	-1530.000	-1.275	-1.175	0.000	0.000
Max	34.000	2000.000	0.405	31104.000	35773.333	10.343	10.413	62.000	13.481
E.T	3.458	265.544	0.069	2867.081	4654.990	1.109	1.117	12.706	0.989
Gabes									
Average	4.181	405.977	0.079	7038.004	4194.345	0.746	0.825	21.667	0.239
Min	0.060	0.000	0.000	260.000	-3.125	-0.001	0.004	0.000	0.000
Max	45.000	2500.000	1.019	19008.000	38581.250	5.655	5.794	61.000	3.906
E.T	6.496	334.835	0.106	4159.085	5041.923	0.876	0.922	15.263	0.530
Kebili-Tozeur									
Average	1.007	730.470	0.048	16812.869	8075.217	0.494	0.542	31.726	0.161
Min	0.030	0.000	0.000	1335.484	-1890.000	-0.137	-0.079	1.000	-2.733
Max	6.000	3192.593	0.284	33572.571	22396.000	4.553	4.620	151.000	33.000
E.T	1.050	516.621	0.038	5030.000	5454.515	0.416	0.419	17.995	1.682

** The low quantity of water consumption per ha could be explained by the predominance of arboriculture which only requires a supplemental irrigation.*

Table 52. Breakdown according to the 3 zones considered.

Some preliminary results could already be developed from Table 53 that shows the optical mode of payment of the cost of irrigation water:

- Water consumption (or demand) per hectare per cropper:
  - private farmers, who bear most of the cost of water mobilization, use this resource sparingly with an average of 7,171 m^3 per hectare;
  - those who are connected to a public network and pay only a small part of the actual cost, use more resources, with 12,532 m^3 (75% more than the private);
  - farmers, who have the chance to dispose of free water, use this resource at will. Indeed, with 15,871 m^3 per hectare on average, they consume twice times more than the private farmer.

This result by itself demonstrates with no ambiguity whatsoever the importance of the cost of mobilization in any rationalization policy and especially the conservation of this rare and valuable resource in these largely poor countries.

- The cost of water per m^3:

The cost of one m^3 of water directly paid by the farmer is 62 millimes/m^3 (0.028 €) for the cropper connected to a public network, while the private spends at least 88 millimes/m^3 (0.04 €), or about 1.5 times the charge of the public irrigator. Incidentally, the actual cost borne by the private cropper is much higher than this amount if we integrate set costs.

We will see the importance of this difference in costs paid by the public sector and the private sector croppers in the conservation of the scarce resource demonstrated by quantitative analysis, which will be detailed in Section 4.

- Water Productivity:

Table 53 provides an interesting result on the valuation of water resources by the various categories of water users:

- farmers benefiting from free water value the least this valuable resource with only 478 millimes/m^3 (€ 0.217);
- farmers are supplied by a heavily subsidized public network, value this resource at a rate of 556 millimes/m^3 (€ 0.252), slightly higher than the previous;
- however, farmers who bear the bulk of the cost of the resource mobilization, i.e. private, valorize much better the water used than the previous two categories with 1,050 millimes/m^3 (€ 0.477).

This result on the productivity of one m^3 allocated to agricultural production is diametrically opposed to that obtained for consumption. Indeed, the private cropper uses less resources and values them much more than the two categories that do not pay the real cost of the required water. The farmer, who has access to a free resource, paradoxically gets the poorest results with only 478 millimes/m^3 (conversion base: 1 € = 2.2DT = 2,200 millimes).

- Willingness to pay per m^3:

As the definitions of Water Productivity and the WTP are close enough (the only difference lies in the fact that the cost of water has been cut off from WP and not WTP), their Interpretation is also quite similar in this context. Indeed, the private cropper who bears the greatest burden for the mobilization of his own irrigation water is most willing to pay a high price (TND 1.138); it is followed by the cropper receiving water from a public network largely subsidized by the community (TND 0.619). The cropper currently with a quasi-free water resource is himself willing to pay only 0.478 DT/m^3.

- Intensification rate:

It is an average of 0.98 respectively for the farmer having a free resource, 0.94 for the public cropper and finally 0.76 for the private cropper. It is very likely that the private cropper, handicapped by the lack of resources and the exorbitant cost, must consent

	Tunisia	Free network	Public network	Private network
Number of farmers	761	22	538	206
Water consumption per hectare and per cropper (m^3/ha)	11,170	15,871	12,532	7,171
Water cost (TND/m^3)	0.068	0	0.062	0.088
Water Productivity (TND/m^3)	0.691	0.478	0.556	1.050
WTP (TND/m^3)	0.759	0.585	0.619	1.138
Intensification rate (super. irrigate/ sup. Irrigable)	0.90	0.98	0.94	0.76

Table 53. Breakdown according to the type of water pumping network (public, private, free).

to mobilize. These two reasons explain their inability to irrigate the entire irrigable area available.

Some preliminary results could be already cleared from table 54 that holds the optical space division of the Tunisian SASS area into three homogeneous sub-regions.

- The use (or demand) water per hectare per farmer and area

The consumption of water per hectare is very different from one area to another. Indeed, it varies from 3,633 m^3/ha in the area of Jeffara (governorate of Medenine and Tataouine) to 16,813 m^3/ha in the Saharan oases zone (governorates of Kebili and Tozeur), almost 5 times more. This difference is explained simply by the fact that in the Saharan oasis, where multi-level cropping and date palm prevail, water consumption is huge. This exorbitant consumption per hectare can also be explained by the ancient irrigation techniques still widely used in these oases, namely flood irrigation. While in the Jeffara, where irrigation is mostly complementary and is rather semi-intensive, consumption is moderately low. The Gabes area, with 7,038 m^3/ha, is in an intermediate range. Indeed, this area is characterized by two types of oasis agriculture, such as Jerid and semi-intensive as found in Jeffara.

- The cost of water per m^3

The cost of water paid by the farmer is more important in both zones of Medenine-Tataouine and Gabes with respectively 96 and 79 millimes/m^3 and (48 millimes/m^3) in the Jerid. This difference, quite significant, is explained by the fact that in the first two areas, there are many private farmers while in the Jerid that is dominated by public irrigated area, water is heavily subsidized.

- Water Productivity

The valorization of the resource ranges from 494 millimes/m^3 in the Jerid to

1,014 millimes/m^3 in the Medenine-Tataouine region, which is the double. This significant difference is explained by the specificity of farming systems practiced in the two regions, and the difference in costs of irrigation networks. The Gabes region, that disposes of both cropping systems, namely the oasis system and semi-intensive field crops, is characterized by a median valorization (DNT 0.746).

- WTP per m^3: the same comment also applies to the WTP.
- Intensification rate: The Kebili-Tozeur region is characterized by its pure oasis system where farmers practice a highly intensive agriculture, characterized by a relatively high IR (0.98). The Medenine-Tataouine region, which is characterized by a rather semi-intensive irrigated agriculture in a steppe environment has a lower IR (0.76). The Gabes region, with its IR of 0.89, ranks midway between the two distinct zones.

	Tunisia	Medenine-Tataouine	Gabes	Kebili-Tozeur
Number of farmers	761	219	144	383
Water consumption by hectare and per cropper (m^3/ha)	11,170	3,633	7,038	16,813
Water cost (DT/m^3)	0.068	0.096	0.079	0.048
Water Productivity (DT/m^3)	0.691	1.014	0.746	0.494
WTP (DT/m^3)T	0.759	1.110	0.825	0.542
Intensification Rate (super. irrigated/ sup. Irrigable)	0.90	0.77	0.89	0.98

Table 54. Breakdown by geographical region.

2. Quantitative analysis and commentary on the results

This quantitative analysis, whose main purpose is to demonstrate and quantify the above proposed operational recommendations to be submitted to decision makers, will be conducted in three levels:

- the first level will be based on the basis of the bulk sample of the whole of Tunisia;
- the second, which will focus on the dimension of the resource cost, will keep the breakdown of the entire sample in three large groups according to the cost of mobilizing water resources borne directly by the farmer:
  - "Free group" farms profiting from free water resources;
  - "Public group": farms supplied by a public network;
  - "Private group" farms irrigated through a private network;
- the third level will explicitly consider the *spatial breakdown* that will provide a special focus on regional specificities:

- the Jeffara (Medenine Tataouine)
- marine oasis (Gabes);
- the Saharan or continental oasis (Kébili-Tozeur).

For each level, we will keep the analysis criteria that seem most relevant to this preliminary phase, namely:

- Water consumption per hectare per cropper (WHA)
- Water productivity (WP);
- The net margin per hectare or the profit from one m^3 of water used;
- Total production per hectare.

2.1. Comprehensive quantitative analysis across the Tunisian SASS

As explained above, our overall analysis will be conducted according to the criteria of the consumption of water per hectare per farmer, economic productivity of water, the gross margin and total production.

Water consumption per hectare and per farmer (WHA)

The selected specification is designed to identify the determinants of the key variable expressed in log, which is the consumption of water per hectare per farmer.

The WHA variable is well expressed in terms of the set of explanatory variables used according to specifications (1).

(1)

$$lwha = \alpha_0 + \alpha_1 lwcmc + \alpha_2 lrtha + \alpha_3 laia + \alpha_4 rhe1 + \alpha_5 lhlha + \alpha_6 llev.ed + \alpha_7 Awl + \alpha_8 Wor$$

Where:

$\alpha_0, \alpha_1, ...\alpha_8$ are the parameters (here elasticities) to be estimated thanks to data collected and the model selected.

- Lwha: log of the demand for irrigation water by farmer i;
- Lwcmc: log of the cost of one m^3 borne by the farmer;
- Lrtha: log of the total production of the farmer i per hectare;
- Laia: log of the actual irrigated area in hectare ;
- Rhe1: This variable is set to the value 0 if the cropper has an activity other than agriculture and 1 if it is not the case;
- Lhalha: log of the wages paid to both temporary and permanent laborers;

- Llev.ed: log of the farmers' level of education;
- Awl: % of the global revenue excluding livestock;
- Wor: this variable is set to 0 if water is free, 1 if water is supplied by a public network and 2 if mobilized directly by the farmer.

Table 55 summarizes the results for all farmers of the Tunisian sample, provided by the output of the computer and that concerns all the selected irrigators. This table shows the same results with the overall sample excluding the irrigators that receive free water (column 3):

- The variables selected, namely the price of water, total revenue per hectare, the actual area irrigated, revenue excluding the farm, the salinity of the water used, the wage labor, the level of education , farming without livestock, the origin of the water source and seniority in the practice of irrigation, explain at least 52% of the variability in water consumption per hectare per farmer. According to the performance of the model chosen for spatial data, the result is excellent.
- Price elasticity is very significant and has the appropriate sign.

To estimate this key parameter, we will adopt two criteria: the first is to approximate the variable price by the cost paid by the farmer. The second, that we give as an indication, keeps the WTP as an approximation of the resource's price. The analysis will be based, in this context, mainly on the first option.

- Water resource price approximated by the cost paid by the farmer: When the price of water (here the cost paid by the farmer) is twice in the Tunisian SASS area, consumption (water demand) per ha decreases by 16%. When we remove from the sample farmers who do not pay water (column 3), this elasticity goes to 33%, i.e. for a variation of 100% the price of the resource consumption (water demand) per hectare decreases by 33%. **This result is very important**. Indeed, it shows that the price of water has a significant impact on the demand for irrigation water. Appropriate pricing of agricultural water would contribute significantly to master the demand and thus encourage irrigators to better allocate and especially preserve this scarce resource.
- Water resource price approximated by the farmer's WTP: the price elasticity of water demand for the whole of Tunisia password from 0.16 to 0.42 when retains the WTP as a proxy for prices instead of raising costs. This result, which is shown in Table 56, further supports the role played by the price of water in the management of this scarce and valuable resource in this fragile environment.
- The impact of the farm size effect on water demand: the result shows that when the size of irrigated farm increases, consumption per hectare decreases. This would be the consequence of two effects. The first result of the decline intensified following

	Global sample	Global sample (excluding the farmers that receive free water resources)
Variable explained	**Water consumption per hectare per farmer (WHA)**	
Explanatory Variables		
Lwcmc	- 0.16 (0.000) ***	- 0.33***
Lrtha	0.13 (0.000) ***-	0.12***
LAIA	- 0.27 (0.000) ***	-0.27***
Rhe1	0.24 (0.000) ***	0.21***
Lsali	- 0.39 (0.000) ***	-0.30***
Lhlha	0.03 (0.000) ***	0.03***
Llev.ed	0.10 (0.015) ***	0.11***
Awl	0.20 (0.000) ***	0.23***
Wor	- 0.18 (0.002) ***	-0.10***
Lseni	7.62(0.000) ***	6.90***
Cte	7.62 (0.000) ***	-
N	761	744
Adj R-squared	0.52	0.57
F	92.88	109.57

*The P-values are in parentheses. ***, **, *: statistically significant at levels 1, 5 et 10%.*

Table 55. Water consumption per hectare per farmer (WHA).

the extension of irrigated areas. The second is due to improved irrigation techniques.

- The impact of revenue from sources other than the farm: This result clearly shows that when the farmer has no secondary activity, it's even more intense and requires more irrigation water per hectare.

Table 57 shows the cost of water as the sole explanatory variable of the demand for irrigation water. This result illustrates in a clear and unambiguous the paramount importance of the variable cost of water in the allocation of this resource. Indeed, when one considers the overall sample without farmers benefiting from free water, water demand is considerably reduced at the rate of 47% for a 100% price increase (column 3). It is also important to note that the only variable cost of water would explain at least 20% of the variability of the total water demand in Tunisia SASS region.

Variable explained	Tunisia	
	Water consumption per hectare and farmer (LWHA)	
Explanatory variables		
Lwcmc	- 0.16 (0.000) ***	
Lwtpmc		-0.42 (0.000) ***
Lrtha	0.13 (0.000) ***	0.14 (0.000) ***
Laia	- 0.27 (0.000) ***	-0.22 (0.000) ***
Rhe1	0.24 (0.000) ***	0.22 (0.000) ***
Lsalin	- 0.39 (0.000) ***	-0.81(0.000) ***
Lhlha	0.03 (0.000) ***	0.02 (0.000) ***
Llev.ed	0.10 (0.015) ***	0.09 (0.012) ***
Awl	0.20 (0.000) ***	0.83 (0.060) **
Wor	- 0.18 (0.002) ***	-0.12 (0.014) ***
Lseni	7.62(0.000) ***	0.08 (0.000) ***
Cte	7.62 (0.000) ***	7.78 (0.000) ***
N	761	761
Adj R-squared	0.52	0.61
F	92.88	118.82

*The P-values are in parentheses. ***, **, *: statistically significant respectively at levels 1, 5 et 10%.*

Table 56. Water consumption per hectare and cropper (WHA) (replacing LWCMC by LDAPMC)

	Tunisia	Tunisia (without free water)
Variable explained	Water consumption per hectare per cropper	
Explanatory variable		
Lwcmc	-0.28***	- 0.47***
Cte	8.11***	7.56***
N	761	744
Adj R-squared	0.15	0.20
F	130.41	188.74

*The P-values are in parentheses. ***, **, *: statistically significant respectively at levels 1, 5 et 10%.*

Table 57. Water consumption per hectare per cropper with focus on the water price only.

Water productivity (WP)

We previously presented gross output of the estimates using the STATA software for the global Tunisian sample excluding the irrigators benefiting from free water.

The specification estimated is the following:

(2) $$lwp1 = \alpha_0 + \alpha_1 lwcha + \alpha_2 lrtha + \alpha_3 lsali + \alpha_4 lflha + \alpha_5 laia + \alpha_6 Wor$$

Where:

- Lwp1 : log of the economic productivity of irrigation water per cropper;
- Lflha : log of the number of family members that work full time on the farm;
- The remaining selected variables have already been defined.

Table 58 provides a synthetic summary of the results of the computer output.

- The independent variables (determinants) selected explain 55% of the variability in the productivity of the water resource (independent or explanatory variable). The F-test is highly significant for the selected specification.
- Elasticity of the resource price (here, the cost of water per hectare borne by the farmer) is highly significant and is characterized by a negative sign. When the cost of water per hectare borne by the farmer increases by 100%, productivity per unit of resource used (here m^3) decreases by 30% for the whole of the Tunisian SASS zone. This result is quite difficult to explain intuitively because it is the combined product of two effects that work in opposite directions and thus compensate:
  - normally, when the cost of the resource increases, the demand decreases. This effect would result in a decrease in the volume allocated per hectare and a decrease in expenditure per hectare and normally would have a positive impact on the productivity of the allocated resource.
  - The decrease in the volume allocated per hectare produces a decrease in production per hectare, which would lead to a decrease in revenue per hectare (equally applicable to all other aspects). The decline in revenue per hectare in turn would cause a decrease in productivity per allocated m^3. This effect would obviously have a negative impact on the productivity of the allocated m^3.
  - The final result, the model estimates, depends on the relative importance of these two effects. In this context, the second effect is therefore higher and dominates the first; that is why the result is negative. We'll see when estimating the determinants of net margin per hectare (net revenue per hectare), the importance of the effect of the increase in water consumption per hectare on the significant improvement in the net margin per hectare.
- The elasticity of salinity is highly significant for the global sample. When salinity

	Tunisia Global (without irrigators benefiting from free water)
Variable explained	Log of the Water Productivity (LWP1)
Explanatory variables	
Lwcha	- 0.30 (0.000) ***
Lrtha	0.51(0.000) ***
Lsalin	- 0.35 (0.000) **
Wor	0.30 (0.003) ***
LFLHA	0.04 (0.000) ***
LAIA	0.10 (0.004) ***
Ct	- 3.86 (0.000) ***
N	744
Adj R-squared	0.55
F	150.66

*The P-values are in parentheses. ***, **, *: statistically significant at the levels 1, 5 & 10%.*

Table 58. Water Productivity (global sample).

increases to 100%, the water productivity decreases by 35%.

- The elasticity of total production is highly significant and is characterized by the appropriate sign. When production per hectare increases 100%, the water productivity increases by 51% globally Tunisia.
- The elasticity of the impact of the water source (private or public). At the global scale of Tunisia, this variable is significant and has the appropriate sign. Indeed, when we move from free water to highly subsidized water (public sector), and from there to a slightly subsidized water source (private sector), water productivity increases by 30%.
- The elasticity of the impact of family labor. This variable has a positive and significant impact on the productivity of water. However, this impact is rather low.
- The elasticity of the actual irrigated area. The elasticity of this very important variable is characterized by a significant and positive impact on productivity. Indeed, when the actual irrigated area increases by 100%, the water productivity increases by 10%. This result is very important and needs to be further expanded. We know that there is a broad debate on the impact of farm size on their productive performance. The question that is still debated in the economic development literature, can be summarized briefly as follows: developing countries, where agriculture still plays a leading role in employment and in improving the nutrition and especially alleviating the scourge of poverty, should they opt for small sized farms that hold abundant

family labor or rather promote large farms through a proactive agrarian reform? This question is of crucial importance for decision makers in the field. However, to answer this question, it is necessary to solve another underlying issue that could be raised as follows: does the expansion of the size of the farm have a positive or negative impact on the productive performance? Our empirical study already gives us some interesting elements of strong responses to address this critical issue.

The gross margin per hectare or the profit per one m^3 of water used for irrigation

The specification used to estimate the determinants of the net margin are:

$$lbha1 = \alpha_0 + \alpha_1 lwha + \alpha_2 lsali + \alpha_3 lflha + \alpha_4 laia + \alpha_5 Awl \quad (3)$$

Where:

- Lbha1: log of profit per m^3 and per hectare;
- Awl: agriculture without livestock.

Table 59 provides a synthesis of the results.

Variable explained	Log of the gross margin per hectare (lbha1)
Explanatory variable	
Lwha	0.92 (0.000) ***
Lsalin	-1.51 (0.000) ***
LFLHA	0.04 (0.000) ***
LAIA	0.12 (0.106) *
AWL	-0.86 (0.000) ***
Cte	1.06 (0.292)
N	744
Adj R-squared	0.23
F	45.40

*The P-values are in parentheses. ***, **, *: statistically significant respectively at the levels 1, 5 et 10%.*

Table 59. Gross margin per hectare.

The most important result to emerge from this estimate is the one given by the salinity elasticity. According to the results shown in Table 22, when the salinity increases by 100%, the profit generated by irrigated hectare would decrease by at least 150%. This high sensitivity of the valorization of water salinity must be seriously taken into consideration by the decision-makers. The fight against this “scourge in these highly sensitive areas is to put in the priority.

Total production per hectare

The specification used to estimate the total production estimates per hectare is:

$$rtha = \beta_0 + \beta_1 flha + \beta_2 hlha + \beta_3 wcha + \beta_4 intha + \beta_5 alim + \beta_6 sei + \beta_7 sali + \beta_8 niv + \beta_9 anci + \beta_{10} ase + \beta_{11} Rhe1 \quad (4)$$

Where:

- INTHA: The cost of inputs (manure, fertilizers, insecticides, herbicides, etc.) ;
- FEED: The cost of animal feed;
- Lev.ed: The level of education.

The rest of the variable has already been defined here above.

Table 60 shows the results of estimating the determinants of total production per hectare for the whole of Tunisia.

Variable explained	Total production per hectare (RTHA)
Explanatory variable	
FLHA	186.7 (0.000) ***
HLHA	1.5 (0.000) ***
WCHA	1.4 (0.000) ***
INTHA	1.8 (0.000) ***
FEED	0.6 (0.000) ***
AIA	-246.0 (0.000) ***
SALIN	-5352.4 (0.000) ***
Lev.ed	167.7 (0.113) *
SENI	24.0 (0.015) ***
AWL	-1095.3 (0.000) ***
RHE1	780.4 (0.002) ***
CTE	14021 (0.000) ***
N	761
Adj R-squared	0.62
F	112.6

*The P-values are in parentheses. ***, **, *: statistically significant respectively at levels 1, 5 et 10%.*

Table 60. Total production per hectare (RTHA).

All the results obtained are relevant:

- All of the variables explain 2/3 of the variability of the total production;
- The F test is highly significant;

- The impact of all inputs on production [cost of family labor per hectare (men per year), the cost of wage labor per hectare, cost of water per hectare, inputs per hectare (fertilizer, insecticide, herbicide, manure, etc.) and cost of livestock feed] is positive and highly significant.
- The Farm size (AIA) has the expected sign and impact. In fact, the smaller the irrigated area, the higher the production per hectare is. This result is simply due to the scarcity of the resource. Indeed, when the actual irrigated area is high, the farmer is forced to practice a rather semi-intensive farming.
- The impact of salinity on production is negative and highly significant: when the salinity of irrigation water increases, output per hectare decreases significantly. **This result is very important because it illustrates the negative consequences of the increasing salinization of the resource due to overexploitation**.
- The impact of the farmer's level of education on production is positive and significant at the level of the overall sample. When the education level of the main farmer rises, total production per hectare increases significantly.
- The impact of seniority in the practice of irrigation is also positive on production and significant across Tunisia.
- The impact of revenue from sources other than the farm is positive and highly significant across the overall sample. Indeed, when the main farmer has a non-agricultural activity, production per hectare decrease significantly.
- The impact of livestock on global production is characterized by the appropriate sign for the overall sample. The production per hectare for farmers who do not practice livestock breeding to supplement their agricultural activities decreases significantly.

2.2. Disaggregated quantitative analysis according to the water cost borne by the farmer

This analysis, that shows the breakdown based on actual cost borne by the irrigator, will be carried out according to the water consumption criteria per farmer, the water productivity, the net margin of production.

Water consumption per hectare per farmer (WHA)

Specification (1) is now estimated thanks to samples of public and private irrigators.

Table 61 gives estimates of the determinants of water consumption per hectare per farmer respectively for:

- the overall sample of Tunisia (Column 2);
- the overall sample of Tunisia without farmers who have free water (column 3);
- the sample of farmers who have private pumping equipment (column 4);

- the sample of farmers who are connected to a public water distribution network (column 5).

The elasticity of the cost of water demand. This estimate confirms the essential results at the global level of Tunisia. However, spotlighting the terms of payment of irrigation water brings new and interesting strong elements for analysis. Indeed, for private farmers, this elasticity (column 4) climbs to 45%, while that of farmers benefiting from the public network (column 5) goes down to 26%. This result confirms and quantifies the intuition of all experts, that the irrigators enjoying a highly subsidized resource are less price sensitive than private irrigators who bear the actual cost of the resource. It is found that the elasticity of demand from private irrigators is well above that of the public irrigators (45/26 = 1.73).

Table 62, which focuses solely on the price of water as a factor in explaining the variation in water demand, further illustrates this dimension. Indeed, the results of columns 4 and 5 clearly demonstrate the significant difference between the price elasticity of water demand of the private farmers and of those who are connected to the highly state-subsidized public network. The price elasticity of the private farmer is very significant and high enough to -0.61 (1.6 times higher than that of the public farmer -0.38). Note also that the variable cost of water in the case of private farmers, explains by itself 35% of the variability of water demand of all private irrigators of the Tunisian SASS area.

Water productivity (WP)

The specification (2) is estimated on the basis of the sample of framers of the Public Irrigated Areas (PPI) and the Private Irrigated Areas (PIA).

Tables 61 and 62 give estimates as produced by the software for the two selected categories of farmers. Table 63 gives a synthetic summary of the results.

- The independent variables selected (determinants) explain the variability in the productivity of the water resource (dependent or explanatory variable) between 42% and 63% of depending on the sample. The F-test is highly significant for the three selected specifications.
- Elasticity of the resource price (here the cost per hectare of water borne by the farmer), estimated on the basis of the sample of PPI farmers, is very similar to that obtained for the entire sample. However, for the sample of farmers of the private irrigated areas, although this elasticity is characterized by a negative sign, it is not significant. The result for private irrigators could be explained as follows: the resulting estimate is the result of two impacts of opposite signs. For this sample, the two impacts could be of the same weight and therefore would be canceled, so the estimate obtained is not significant.
- The elasticity of salinity is highly significant and is characterized by the appropriate sign for the sample of public farmers. This elasticity is even greater than that obtained

	Tunisia	Tunisia (excluding free water)	Private	Public
Variable explained	Water consumption per hectare per farmer (LWHA)			
Explanatory Variables				
Lwcmc	- 0.16 (0.000) ***	- 0.33***	-0.45***	-0.26***
Lrtha	0.13 (0.000) ***	0.12***	0.07***	0.14***
Laia	- 0.27 (0.000) ***	-0.27***	-0.36***	-0.19***
Rhe1	0.24 (0.000) ***	0.21***	0.20***	0.24***
Lsalin	- 0.39 (0.000) ***	-0.30***	-0.42***	-0.34***
Lhlha	0.03 (0.000) ***	0.03***	0.13***	0.31***
Llev.ed	0.10 (0.015) ***	0.11***	0.12**	0.10***
Awl	0.20 (0.000) ***	0.23***	0.46	0.25***
Wor	- 0.18 (0.002) ***	-	-	-
Lseni	7.62(0.000) ***	0.10***	0.031	0.09***
Cte	7.62 (0.000) ***	6.90***	6.85***	6.59***
N	761	744	206	538
Adj R-squared	0.52	0.57	0.63	0.52
F	92.88	109.57	40.28	65.42

*Les P-values sont entre parenthèses. ***, **, *: statistiquement significatif respectivement aux niveaux 1, 5 et 10 %.*

Table 61. Water consumption per hectare per farmer (WHA).

	Tunisia	Tunisia (excluding free water)	Private	Public
Variable explained	Water consumption per hectare per farmer			
Explanatory Variables				
Lwcmc	-0.28***	- 0.47***	-0.61***	-0.38***
Cte	8.11***	7.56***	6.79***	8.06***
N	761	744	206	538
Adj R-squared	0.15	0.20	0.35	0.13
F	130.41	188.74	111.86	79.48

*The P-values are in parentheses. ***, **, *: statistically significant at the levels of 1, 5 & 10%.*

Table 62. Water consumption per hectare and per farmer with focus on water price.

	Tunisia	Public	Private
Variable explained	Log of the Water Productivity (LWP1)		
Explanatory Variables			
Lwcha	- 0.30 (0.000) ***	- 0.33 (0.000) ***	-0.11 (0.406)
Lrtha	0.51(0.000) ***	0.49 (0.000) ***	0.55 (0.000) ***
Lsalin	- 0.35 (0.000) **	-0.48 (0.000) ***	0.1 (0.774)
Wor	0.30 (0.003) ***	-	-
LFLHA	0.04 (0.000) ***	0.04 (0.000) ***	0.06 (0.01) ***
LAIA	0.10 (0.004) ***	0.06 (0.046) **	0.24 (0.01) ***
Cte	- 3.86 (0.000) ***	-2.9 (0.000) ***	- 4.7 (0.000) ***
N	744	538	206
Adj R-squared	0.55	0.63	0.42
F	150.66	181.39	30.12

*The P-values are in parentheses. ***, **, *: statistically significant at the levels of 1, 5 & 10%.*

Table 63. Water Productivity (according to the water source perspective).

for the overall sample. The negative impact of salinity on water productivity is more detrimental to irrigators supplied by a public network. As for private irrigators, this elasticity is not significant. This result could be explained by the fact that they have a relatively better water quality and above all, as they rationalize further the use of this resource and apply less water per hectare, they thus reduce its negative impacts.

- The elasticity of total production is highly significant and is characterized by the appropriate signs for farmers of both public and private irrigation. This result confirms and supports the results already obtained from the global sample.
- The elasticity of the impact of the origin of water (private or public). This variable is only relevant for the overall sample.
- The elasticity of the impact of family labor. This variable has a positive and significant impact on water productivity for both public and private irrigators. However, this impact is still quite low, as was the case for the overall sample.
- The elasticity of effectively irrigated area. The elasticity of this very important variable is characterized by a significant and positive impact on the productivity of water in the both categories of private and public water users. This finding would support the arguments already developed for the global sample. It should be added that the disaggregated estimation helps highlight the importance of the area dimension in the context of private irrigation schemes. Indeed, when the actual irrigated area increases by 100%, the water productivity would increase by only by 6% for public

irrigators and would rise to 24% for private irrigators. This significant difference between the two categories of irrigators could be explained as follows: The AIA sample of private farmers has a CV (coefficient of variation) of 1.5, while that of public irrigation farmers is only 1.3. The greater variability of the AIA of private irrigators helped provide a more accurate estimate of the phenomenon studied.

	Tunisia	Free	Public	Private
Coefficient of variation	1.72	0.84	1.30	1.50

Table 64. Coefficient of variation of the AIA.

Gross margin per hectare or profit per one m^3 of water used for irrigation

Specification (3) is estimated from the samples of PuIA and PrIA farmers.

We previously presented gross outputs of the estimates provided by STATA software according to the global Tunisia breakdown without irrigators receiving free water, irrigators of the public areas and private sector. Table 65 provides a synthetic summary of the results.

The estimates of the net margin per hectare determinants according to public/private disaggregation essentially confirm the results obtained in the previous section that focused on economic productivity of the water resource. The main difference to note is the importance of the highly negative impact of salinity on the net margin per irrigated hectare. We notice that an increase in the salinity of the water by 100% would cause a significant decrease of 128% of the net income per hectare in public irrigation areas and even lead to a catastrophic drop of 272% in private irrigated areas.

	Tunisia	Public	Private
Variable explained	Log of the net margin per hectare (lbha1)		
Explanatory Variables			
Lwha	0.92 (0.000) ***	1.06 (0.000) ***	0.40 (0.186)
Lsalin	-1.51 (0.000) ***	-1.28 (0.000) ***	-2.72 (0.000) ***
LFLHA	0.04 (0.000) ***	0.05 (0.003) ***	0.04 (0.495)
LAIA	0.12 (0.106) *	0.73 (0.328)	0.22 (0.273)
AWL	-0.86 (0.000) ***	-0.54 (0.001)	-1.97 (0.000) ***
Cte	1.06 (0.292)	-0.52 (0.604)	6.44 (0.024)**
N	744	538	206
Adj R—squared	0.23	0.30	0.18
F	45.40	47.50	9.90

*The P-values are in parentheses. ***, **, *: statistically significant at the levels of 1, 5 & 10%.*

Table 65. Gross margin per hectare (according to the water source perspective).

Total production per hectare

Specification (4) is estimated on the basis of the samples of the PPI and PIA farmers.

Table 66 shows the results of estimating the determinants of total production per hectare for Tunisia as a whole (column 2) for farmers of the public sector (column 3) and the private sector (column 4).

All the results obtained are relevant:

- all of the variables selected explain 2/3 of the variability of the total production for the three categories of farmers (the whole Tunisia 0.62%, public 0.68% and private 0.66%);
- the F-test is highly significant for the three categories of farmers.
- The impact of all the production inputs, [cost of family labor per hectare (men per year), the cost of wage labor per hectare, cost of water per hectare , input per hectare (fertilizers, insecticides, herbicides, manure, etc.) and cost of feed] is **positive and highly significant**.
- Farm size (AIA) has the expected sign and impact. Evidently, the larger the irrigated area, the higher the production per hectare is. This result is simply due to the scarcity of the resource. Indeed, when the actual irrigated area is high, the farmer is forced to practice a rather semi-intensive farming and therefore use less water per irrigated hectare.
- The impact of salinity on production is negative and highly significant. Indeed, when the salinity of the irrigation water increases, the yield per hectare decreases significantly for the three categories of farmers. **This result is very important because it illustrates the negative consequences of the increasing salinization of the resource due to overexploitation.**
- The impact of the farmer's level of education is positive and significant at the level of the global sample. When the level of education of the main farmer rises, total production per hectare increases significantly. When we consider the smaller samples of public and private farmers, this impact becomes insignificant.
- The impact of seniority in the practice of irrigation also impact positively production and is significant across the whole of Tunisia and for private farmers. This impact is not significant for farmers benefiting from public irrigation network.
- The impact of income from sources other than the farm on total production is positive and highly significant across the overall sample. Indeed, when the main farmer has a non-agricultural activity, production per hectare decreases significantly. This impact is not significant when we consider the reduced samples of public and private farmers.

- The impact of livestock on global production is significant and is characterized by the appropriate sign for the overall sample and for private farmers. Production per hectare of farmers who do not practice farming as a supplement to their agricultural activities declines significantly.

	Tunisia	Public	Private
Variable explained	**Total production per hectare (RTHA)**		
Explanatory Variables			
FLHA	186.7 (0.000) ***	153.3 (0.000) ***	286.2 (0.000) ***
HLHA	1.5 (0.000) ***	1.2 (0.000) ***	2.2 (0.000)** *
WCHA	1.4 (0.000) ***	1.02 (0.012) ***	2.4 (0.000) ***
INTHA	1.8 (0.000) ***	1.8 (0.000) ***	1.8 (0.000) ***
FEED	0.6 (0.000) ***	1.5 (0.000) ***	0.3 (0.000) ***
AIA	-246.0 (0.000) ***	-449.4 (0.000) ***	-148.6 (0.000) ***
SALI	-5,352.4 (0.000) ***	-5,505.3 (0.000) ***	-551.2 (0.000) ***
Lev.ed	167.7 (0.113) *	2.1 (0.985)	508.6 (0.000) ***
SENI	24.0 (0.015) ***	19.3 (0.062) *	62.5 (0.000) ***
AWL	-1,095.3 (0.000) ***	348. (0.373)	-2,235.3 (0.000) ***
RHE1	780.4 (0.002) ***	444.6 (0.221)	294.3 ( )
CTE	14,021.0 (0.000) ***	14,800 (0.000) ***	115,003 (0.000) ***
N	761	538	206
Adj R-squared	0.62	0.68	0.66
F	112.6	106.9	36.9

*The P-values are in parentheses. ***, **, *: statistically significant at the levels of 1, 5 & 10 %.*

Table 66. Global production per hectare (RTHA) (according to the water source perspective).

All important results obtained across the entire Tunisian SASS area are confirmed by the two sample components, namely all public and private farmers. Still, all the key variables used by the specification (1) explain better the variability of total output when the overall sample disintegrates into two private and public components. Indeed, the adjusted R2 passes from 0.62 in the overall case to 0.66 for private farmers and even rises to 0.68 for irrigators of the public sector. These scores are exceptional in modeling that uses survey data where the effect of the temporal dynamics is absent.

2.3. Quantitative analysis according to the spatial perspective

The preceding analysis has retained the criterion of payment for the cost of water mobilization at farm scale and the type of irrigation system used by the farmer. Indeed, this criterion focuses primarily on the cost of irrigation water borne directly by the farmer. Moving on to another criterion as important as the previous one, that places special focus on the regional specificities of the great Tunisian SASS zone.

The Tunisian South (part integrated in the SASS zone) could be subdivided into three fairly homogeneous large regions:

- The Jeffara that concerns in this context the two governorates of Medenine and Tataouine. This area is of a steppe nature and predominated by rangelands. Much of the agriculture is rather extensive and dry arboriculture, relying on the olive, is the dominant practiced rule. Irrigated agriculture is a recent activity over very small areas that still do not exceed 10,000 hectares in both governorates. However, livestock is an important activity and is a quite old practice.
- The area of maritime oasis (mainly the governorate of Gabes). This region, very dynamic, is undergoing major structural changes. Agriculture, which was mainly based on arboriculture (palm and pomegranate) practiced in rather old oasis (multi-level cultivation) is undergoing profound changes with the growth of intensive and semi-intensive farming outside the traditional oasis . These traditional oases, which were the backbone of farming, are now in decline in favor of modern agriculture outside the oasis.
- The area of Saharan oases or continental oases (governorates of Kebili and Tozeur). We will call this oasis the continental zone. It is based primarily on oasis farming where the palm (especially the variety of Deglet Nour) dominates. This region owes its existence to the totally dependent intensive SASS little renewable irrigation groundwater. This resource is currently the most threatened by overexploitation and hence the continued deterioration of this vital aquifer.

The same criteria of analysis in the previous section are used, namely:

- Water consumption per hectare per farmer (WHA);
- the economic productivity of water per m^3 (WP);
- the net margin per hectare or the profit per one m^3 of water used.

Water consumption per hectare per farmer (WHA)

Specification (1) is estimated on the basis of samples of farmers in the three selected zones, namely Medenine-Tozeur, Gabes and Kebili-Tozeur.

Table 67 provides a synthetic summary of the main results obtained thanks to an appropriate econometric estimation and illustrated by the output above:

- Price elasticity: This elasticity is significant and negative for the three areas. Although the regional criterion is selected, the price of water has a significant impact on demand. However, this impact is quite significant in the region of Gabes. Indeed, if

	Tunisia (without free water)	Medenine-Tataouine (Jeffara)	Gabes (Maritimes Oasis)	Kebili-Tozeur (Continental Oasis)
Variable explained	Water consumption per hectare per cropper (LWHA)			
Explanatory Variables				
Lwcmc	- 0.33***	- 0.19 (0.000) ***	-0.76 (0.000) ***	-0.16 ***
Lrtha	0.12***	0.06 (0.000) ***	0.22 (0.003)***	0.06 **
Laia	-0.27***	- 0.23 (0.000) ***	-0.26 (0.025)**	0.02
RHE1	0.21***	0.19 (0.000) ***	0.54 (0.021) **	0.02
Lsalin	-0.30***	- 0.73 (0.000) ***	0.35 (0.920)	-0.22 ***
Lhlha	0.03***	0.01 (0.000) ***	0.03 (0.10) *	0.01 ***
Llev.ed	0.11***	-	-	0.01
AWL	0.23***	-	-	0.04
WOR	-	0.20 (0.000) ***	-0.11 (0.691)	-0.005
Lseni	0.10***	-	-	0.02
Cte	6.90***	7.1 (0.000) ***	4.3 ***	8.61 ***
N	744	219	144	383
R-squared	0.57	0.32	0.40	0.25
F	109.57	15.73	14.74	13.55

*The P-values are in parentheses. ***, **, *: statistically significant at the levels of 1, 5 & 10%.*

Table 67. Water consumption per hectare per farmer (WHA).

	Tunisia	Medenine-Tataouine	Kebili-Tozeur	Gabes
Coefficient of variation	1.02	0.72	0.79	1.34

Table 68. Coefficient of variation of the cost per m^3 of water paid directly by the farmer per region.

the cost of water varies by 100%, demand shows a significant decrease of 76%. However, in the other two regions, although it is still significant, it is rather quite low. It is 19% In the Jeffara and 16% in the Jerid.

This very significant difference between the three regions can be explained at least partially by the difference between the variability of the cost paid by the farmer as shown by the CV (see table 68).

- The impact of production on water demand: as expected, the impact is positive and significant for all zones. When production per hectare increases, the demand for water per hectare also increases significantly in all three areas.

- Elasticity of the area: this elasticity is significant and negative for both areas of Jeffara and Gabes. However, it is not significant for the Jerid area. When the area of the farm increases, the water demand per hectare decreases substantially in the Jeffara and the Gabes region. This is explained by the fact that when the farmer extends the irrigated area, this lowers the intensity of cropping. In the Jerid area, such farms are already relatively small, intensification is already quite high. *We note that in this area the analysis should be conducted more by palm tree and not according to the criterion of the area,* given the advanced state of fragmentation and the intensification of the oasis culture in this area.

Water productivity (EWP)

The outputs of the estimation of the determinants of irrigation water economic productivity through specification (2) by STATA 11 for the three zones (Kebili-Tozeur, Tataouine and Medenine-Gabes) are presented below:

Table 69 provides a synthetic summary of the main results obtained by appropriate econometric estimation and illustrated by the outputs above:

- Elasticity of the area: this elasticity, when considering the criterion of regional breakdown, is of paramount importance to this analysis. With this estimate, based on a database that is both rich and original, it is possible to give some answers to a crucial question that concerns all development economists, namely:

  To improve the food balance in poor countries, should we promote large farms through supportive land reform or opt for smaller farms to occupy a maximum of people in the rural areas?

  According to the results shown in the first line of the table above, the elasticity of the area is highly significant and positive for both the Jeffara and Gabes areas; however, it is negative for the Jerid area. In the areas of Jeffara and Gabes, water productivity increases as the size of the farms increases. Indeed, while the irrigated area of a farm doubles, its productivity increases by 36% in the area of Jeffara and 22% in the zone of Gabes. In both areas, the results call for a supportive agrarian reform that puts an end to the fragmentation that characterizes estates in Tunisia. However, the result for the Jerid area seems at first paradoxical. Nonetheless, if one carefully examines the situation in this area, the result could be justified. In the Jerid area, where the counting unit is rather the palm tree, the area is not relevant to the analysis of the productivity of the resource. The latter should rather be conducted on the basis of the palm tree rather than the area. We'll return to this point with a more detailed analysis of our data.

- Elasticity of the salinity: This elasticity is highly significant and a negative sign as expected. This result confirms and amplifies even the one obtained by the cost perspective estimate. When the salinity of the irrigation water increases, productivity is considerably reduced in the three areas. If the salinity of the water increases by

	Medenine-Tataouine (Jeffara)	Gabes (Maritime Oasis)	Kebili-Tozeur (Continental Oasis)
Variable expliquée	Productivité de l'eau (LWP1)		
Explanatory Variables			
LAIA	0.36 (0.008) ***	0.22 (0.013) ***	-0.12 (0.009) ***
LSALIN	- 2.03 (0.000) ***	-1.13 (0.003) ***	-1.33 (0.000) ***
LFLHA	0.08 (0.002) ***	0.071 (0.003) ***	0.003 (0.730) ***
AWL	-1.25 (0.000) ***	-0.74 (0.001) ***	-0.10(0.314) ***
TI	-0.80 (0.086) *	-0.08 (0.862)	-0.69 (0.156) ***
Cte	1.74 (0.000) ***	0.32 (0.519)	0.21 (0.659)
N	219	144	398
R-squared	0.23	0.30	0.25
F	14.09	13.14	27.91

*The P-values are in parentheses. ***, **, *: statistically significant at the levels of 1, 5 & 10%.*

Table 69. Water Productivity.

100%, productivity drops at a rate of 203% in the area of Jeffara, 113% in the governorate of Gabes and 133% in the Nefzaoua and Jerid areas. This result is of paramount importance as it demonstrates the urgent need to combat it in order to ensure the sustainability of any irrigated agriculture in this strategic region for the three countries concerned.

- Elasticity of family labor: this positive and significant elasticity for the three zones shows the importance of family labor in the management of water resources. When the family labor per irrigated hectare increases, the productivity of water resources also increases.
- Elasticity of breeding: this is as significant as positive elasticity that shows the importance of livestock in the farmer's revenue and especially the valorization of the scarce resource in the three areas. However, it should be noted that the importance of this activity is clear for the Jeffara area where livestock is an essential component to the farmer's income. However, in Jerid and Nefzaoua where oasis irrigation is highly intensive, breeding becomes much less important, while remaining a significant contribution.

Gross margin per hectare per one m^3 of water used

The outputs of the estimation of the determinants of the net margin of one irrigated hectare, with the specification (3), by STATA 11 for three zones (Kebili-Tozeur, Tataouine and Medenine-Gabes) are presented below:

	Tunisia (excluding free)	Medenine-Tataouine (Jeffara)	Gabes (Maritime Oasis)	Kebili-Tozeur (Continental Oasis)
Variable explained	Gross margin per hectare (Lbha1)			
Explanatory Variables				
LWHA	0.92 (0.000) ***	1.47 (0.000) ***	0.92 (0.000) ***	0.56 (0.19)
LAIA	0.12 (0.106) *	0.57 (0.018) ***	0.16 (0.184)	-1.31 (0.192)
LSALIN	-1.51 (0.000) ***	-2.46 (0.014) ***	-1.15(0.028) **	-1.68 (0.028) **
LFLHA	0.04 (0.000) ***	0.12 (0.012) ***	0.08 (0.010)***	-
AWL	-0.86 (0.000) ***	-2.04 (0.000) *	-0.76 (0.008)	-0.19 (0.250)
Cte	1.06 (0.292)	-2.43 (0.426) ***	1.03 (0.207)	3.92 (0.095)
N	744	219	144	398
R-squared	0.23	0.28	0.45	0.18
F	45.40	17.51	24.79	23.4

*Les P-values sont entre parenthèses. ***, **, *: statistiquement significatif respectivement aux niveaux 1, 5 et 10 %.*

Table 70. Gross margin per hectare or profit generated per one m3 of irrigation water used.

The estimates of the determinants of the net margin per hectare depending on the spatial disaggregation of the overall sample into three zones (Medenine Tataouine, Gabes and Kebili, Tozeur) confirm the main results obtained in the previous section that focused on the economic productivity of the water resource. The main difference to note is the importance of the highly negative impact of salinity on the net margin per irrigated hectare i. There is an increase of 100 % in the water , which would cause a significant decrease of in 115% of the net profit per hectare in the governorate of Gabes, 168% in the Jerid and even lead to a catastrophic drop of 246 % in irrigated areas of Jeffara.

3. Summary of the main results and some recommendations

Preliminary results obtained through quantitative analysis based on the sample of Tunisian farmers are very encouraging and confirm the relevance of the approach adopted within this project. Indeed, the huge effort to collect actual data on the scale of the primary user of the resource has been useful and conclusive. In addition, the use of the latest software designed specifically to treat individual survey data as well as the most appropriate econometric tools have yielded valuable results for both the economic analysis and decision makers in the sustainable management of this vital resource for the whole SASS zone.

The major objective of this brief review is to focus on the essential results of the analysis of the information gathered in the Tunisian SASS zone.

- The cost of water borne by the farmer: all the results obtained, regardless of the selected breakdown criterion (type of network used, method of payment of the cost of the resource used, spatial dimension) show that when the cost paid by the irrigator increases, water demand decreases substantially. The elasticity of water demand price varies depending on the category of selected farmers (public, private), the geographical area concerned (Jeffara, maritime oasis, continental oasis) and the chosen specification, 0.16 to 0.75 *(when the price of water increases by 100%, the demand falls from16 to 75%).* This result demonstrates the major importance of the dimension "**pricing**" of the resource in the control of its demand. This control would induce resource conservation and thus help to ensure its durability and sustainability for future generations and especially for the survival of a region that is vital to the entire country.

- The salinity of the resource: the results obtained, that demonstrate and quantify the most negative impact of salinization of the resource on the production of irrigated agriculture and the productivity of the most limiting input, that is water, confirm and support results obtained by agronomists. *Not to forget that according to our estimates, the production of an irrigated hectare would decrease by 150% for an increase in the salinity of the water used by 100%*. Our results demonstrate unambiguously that the salinity of the resource due to over-exploitation is a pandemic that must be fought by all means possible.
- The fragmentation: the results show that when the area of the irrigated farm increases, profitability improves and so does water productivity that increases significantly. This is evident across the overall sample, the public and private sectors and in the regions of Jeffara and Gabes.
- The origin of the resource (private or public). On the level of Tunisia, this variable is significant and has the appropriate sign. Indeed, when we move from free water to highly subsidized water (public sector) and from there to a slightly subsidized water source (private sector), water productivity increases by 30%. This result is quite important in the debate on the choice between centralized management by the state (public management of irrigation water) and decentralized management either by the market or use through a participatory management.
- Seniority in the practice of irrigation: according to estimates made, it appears that the older is the practice of irrigation, the better are the efficiency and productivity of water resources used.
- The level of education: when the level of instruction of the farm head increases, the valuation of water resources improves.
- The role of livestock: in the Jeffara and Gabes, livestock play a significant positive role in enhancing the value of water resources used by irrigated farms.
- Encouraging farmers to focus more on their farms: All estimations show that when the farmer is fully dedicated to the farming, the productivity of the water resource

increases significantly. This result argues against a policy of encouragement, by appropriate means, to set more farmers in farming.

II. ALGERIA

Two types of data analysis will be carried out:

- A descriptive analysis, through simple statistics, will help generate the most common characteristics;
- A quantitative analysis, using the most recent econometric tools, will reveal the most important and useful characteristics for the design of the most appropriate economic policies.

1. Descriptive analysis

The descriptive analysis will mainly prepare the ground for the quantitative analysis. Indeed, in this context, the focus will be on some intuitive results to be demonstrated and especially quantified in the next section.

1.1. Size of the sample selected for analysis

Table 71 describes the planned sample as well as the sample developed in the field.

Despite all the difficulties, mainly due to the area covered and the distances between the farms surveyed, the rate of production of 96% is fairly good.

Thus, on a planned sample of 1,605 farms, the first campaign conducted 1,535 surveys, a coverage rate of 96%.

In the validation process, which consisted in checking the quality of the information collected by the field survey, 220 surveys were rejected. The rejection rate of about 14% was justified in part by the significant rejection in the Wilaya of Ghardaia. Indeed, if we exclude the wilaya of Ghardaia, the rate drops to 3%, which is an excellent result. The rejection rate of about 50% in the wilaya of Ghardaia is due to the poor performance of the investigators in charge of the field survey.

Out of the 1,315 surveys validated, only 1,213 were selected for both quantitative and descriptive analysis, a percentage of 92%. Indeed, the sample of Ghardaia, which is made up of only 100 farms after validation, is no longer representative of all farms in the Wilaya according to predetermined criteria. Keeping this truncated sample would bias the entire analysis; this is why it is better to exclude it. Fortunately, this wilaya represents only 7% of all irrigated areas of the Algerian SASS (16,431 ha out of actual irrigated area of 234,834 ha across the 5 wilayas).

Wilaya	Planned sample	Realized sample	% of realization
Biskra	460	460	100
El Oued	400	400	100
Ouargla	270	220	81
Adrar	255	255	100
Ghardaïa	220	200	91
Total	1605	1535	96

Table 71. Planned sample and realized sample.

Wilaya	Sample realized	Sample validated	% of rejection	Sample selected in the analysis		Surveys not retained	
				Size	%	Size	%
Biskra	460	410	11	410	100	0	0
El Oued	400	390	2.5	390	100	0	0
Ouargla	220	166	24	166	100	0	0
Adrar	255	247	3	247	100	0	0
Ghardaïa	200	102	49	0	0	100	100
Total	1535	1315	14	1213	92	100	8

Table 72. Size of the sample selected for the analysis.

In summary, out of the 1,605 planned surveys, 1,213 were carried out properly in the field and thus retained as part of this analysis, a coverage rate of approximately 78.2%. Since the planned sample was oversized, coverage is more than acceptable. We have to remember that the samples provided for the three countries of the SASS area were purposely oversized to accommodate the rejection of the surveys that do not comply with the established surveying criteria.

1.2. Appropriate breakdown

The analysis of data collected in the 5 areas of the Algerian SASS has been carried out based on two perspectives:

- the first focuses on the important aspect of the nature of the water resource used and especially on the terms of the payment of the cost of this mobilization.

  The in-field survey distinguished the following modalities for the resource mobilization:

(1) Individual private Drilling	depth	débit (l/s) :
(2) Collective private Drilling	depth	débit (l/s)
(3) Drilling conducted by the State	depth	débit (l/s) :
(4) Private surface well	depth	débit (l/s) :
(5) Collective surface well	depth	débit (l/s) :
(6) Artesian drilling	depth	débit (l/s)

(7) Other (foggaras, Ghout) to be specified:

Based on this distinction, three types of irrigation methods are used:

- "Free": the farmer benefits from free water source. The water used comes from a source, an artesian borehole, foggaras or is provided free of charge by the state. This method contains the types of irrigation practiced according to the methods of irrigation (6) and (7).
- "Collective" the farmer is connected to a collective irrigation network. The public authority supports all fixed investment costs and charges the farmer but a fraction of variable costs of operation and maintenance of the mobilization equipment. This method takes into consideration the irrigation types according to the methods of irrigation (2), (3) and (5).
- "Private": the farmer mobilizes the water used using his own means. Three components that make up the cost of mobilization of resources are considered by the survey: (1) equipment (drilling and pumping equipment and water distribution), (2) the cost of service and maintenance, and (3) the variable cost (cost of electricity and/or diesel). In this preliminary analysis, only the costs of energy and maintenance are retained. This method takes into consideration the types of irrigation made according to irrigation methods (1) and (4).

- The second perspective takes into consideration the spatial dimension that is also as important as the method of payment of the water cost. The Algerian SASS part is subdivided into four homogeneous regions:
  - Biskra region;
  - The region of the Oued Souf;
  - The region of the Oued Righ;
  - The Adrar region.

  These four regions produce most of the irrigated agricultural produce of all the Algerian Sahara and provide over 85% of irrigated agricultural in the Sahara. They also consume most of the SASS water in Algeria. That is why we favor these regions in this preliminary analysis.

1.3. The actual analysis

Table 73, which considers the mode of payment for cost of water perspective, gives the average, minimum, maximum, standard and median deviation of the key variables in this preliminary analysis for the whole country and the three categories.

Table 75 will focus on the most important features to be drawn from this table, but first a few remarks are required:

- - The average area irrigated by private farmers is higher than that of farmers connected to a collective irrigation network and especially that of farmers receiving

	AIA	MBHA	AWL	WP	WTPMC	IR	WHA	WCMC	WCHA
Global without Ghout									
Average	5.02917157	436525.425	0.84803714	29.395807	31.8845086	0.83696735	13431.6825	2.48870155	26512.687
Min	0.05	822.999975	0	0.15875771	1.46407091	0.015	1166.4	3.6075E-10	0.00001
Max	254	12317560	1	633.619342	634.619342	2	39398.4	13.744213	101333.333
Med	2	283866.667	1	25.6397891	28.5952381	1	12960	2	25439.3305
ET	10.8910713	616529.009	0.23340999	28.212917	28.2050864	0.2477283	6506.08987	1.74454538	13843.6139
Global without free of charge									
Average	5.32524457	437207.859	0.86450053	30.2747487	32.9252604	0.83242442	12748.7638	2.65051178	27898.241
Min	0.05	822.999975	0	0.15875771	1.46407091	0.015	1166.4	0.36168981	3110.4
Max	254	12317560	1	633.619342	634.619342	2	39398.4	13.744213	100000
Med	2.5	274546.4	1	26.5078742	29.5552249	1	12441.6	2.08917601	26939.9385
ET	11.2425296	631994.25	0.22002199	28.8767856	28.7894837	0.24980895	6100.18477	1.70082679	12911.5858
Individual									
Average	5.86462324	501526.234	0.84093347	35.4032107	38.4835768	0.80489118	11870.7094	3.08036607	29868.0817
Min	0.06	822.999975	0	0.15875771	3.12945157	0.03888889	1166.4	0.40154951	3110.4
Max	90	12317560	1	633.619342	634.619342	2	39398.4	13.744213	73333.3333
Med	3	323893.333	1	30.462963	33.3777591	1	11108.5714	2.72633745	28853.3333
ET	9.26862949	720894.273	0.23642296	31.8591265	31.4745101	0.2633327	6088.99925	1.79186419	12598.1625
Collective									
Average	4.00956386	280319.113	0.92198656	17.7651357	19.3671244	0.89958493	14890.56	1.60198869	23093.3026
Min	0.05	3200	0.08235725	0.47483381	1.46407091	0.015	1658.88	0.36168981	3666.66667
Max	254	1896000	1	68.5763889	69.3721065	1	31104	7.2337963	100000
Med	2.00	186140.00	1.00	13.74	15.43	1.00	15552.00	1.63	20000.00
ET	14.94	268211.27	0.16	13.13	13.27	0.20	5583.33	0.75	12414.29
Free									
Average	1.18	427661.81	0.63	17.98	18.37	0.90	22301.59	0.39	8516.78
Min	0.06	30250.00	0.00	3.38	3.44	0.15	7488.00	0.00	0.00
Max	10.00	1980000.00	1.00	68.75	70.14	1.00	32400.00	3.52	101333.33
Med	0.80	336200.00	0.66	15.10	15.45	1.00	23040.00	0.24	5000.00
ET	1.33	361947.10	0.29	12.87	12.98	0.21	4927.69	0.49	12978.03

Table 73. Breakdown according to the type of irrigation network.

free water (*6.4 hectares for the first, 4 hectares for the second and 1.7 hectares for the last*).

- With regard to seniority in the practice of irrigation, private farming is a more recent phenomenon than the other two types (*20 years on average for the private, 25 and 22 years respectively for public and free of charge*).

Table 74, that shows the criterion of spatial homogeneity, gives the average, minimum, maximum, standard and median deviation of the key variables of this preliminary analysis for the whole country and the four selected regions. Table 75 will focus on the most important features to be drawn from this table, but first a few remarks are required:

- The average area irrigated by farmers of the Biskra region is higher than that of the farmers of the other three regions (7.2 hectares for Biskra, 4.7 for O. Souf, 3.2 for O. Righ and 3.7 for Adrar). The median area irrigated by farmers of the Biskra region is also higher than those of the farmers of the other two regions (4 hectares for Biskra and only 2 ha for the other three regions).
- With regard to seniority in the practice of irrigation, the area of O. Righ, with an average of 25 years of experience in irrigation, is characterized by the oldest practices.

Tables 75 and 76 show some key variables, of paramount importance to our quantitative analysis, calculated according to the two spatial perspectives and payment of the cost of water.

Some preliminary results could already be developed from Table 73 that shows the type of irrigation system perspective:

- The use (or demand) of water per hectare per farmer:
  - private farmers, who bear most of the cost of mobilizing water, use this resource sparingly, averaging 11,871 m^3 per hectare;
  - those connected to a collective network and pay only a small part of the actual cost, use more resources, with 14,891 m^3 (25% more than the private farmers);
  - farmers who are lucky enough to dispose of free water resources, use this resource at will. Indeed, with an average of 22.301 m^3 per hectare, they use about twice the private farmer.

This result by itself shows unambiguously, the importance of water cost in any policy of rationalization and especially the conservation of this rare and valuable resource in these largely poor countries.

- The cost of water per m^3:

The cost of m^3 of water directly paid amounted to 1.60 AD/m^3 (0.016 € *) for the farmer

	AIA	MBHA	AWL	WP	WTPMC	IR	WHA	WCMC	WCHA
Biskra									
Average	7.25	513447.95	0.93	36.85	39.37	0.80	12383.40	2.52	24121.60
Min	0.20	823.00	0.00	0.16	2.61	0.04	1166.40	0.06	1428.57
Max	254.00	4408461.60	1.00	282.88	289.39	1.00	39398.40	8.96	56164.38
Med	4.00	411527.50	1.00	35.19	37.52	1.00	11722.77	2.02	22308.78
ET	14.39	482770.18	0.18	21.90	21.67	0.26	6747.49	1.58	10403.13
O. Souf									
Average	4.70	606422.83	0.85	37.44	41.05	0.80	13023.02	3.61	36571.24
Min	0.06	2000.00	0.00	0.39	5.12	0.04	2114.26	0.08	1666.67
Max	58.00	12317560.00	1.00	633.62	634.62	2.00	33696.00	13.74	73333.33
Med	2.00	332125.00	1.00	28.00	31.79	1.00	12960.00	3.20	35714.29
ET	8.55	1102206.49	0.28	48.25	47.68	0.29	6455.15	2.14	12494.34
O. Righ									
Average	3.24	191918.66	0.92	13.52	15.32	0.88	14217.88	1.80	22760.71
Min	0.05	3200.00	0.07	0.47	1.46	0.02	3110.40	0.12	2272.73
Max	30.00	945239.47	1.00	44.11	45.21	1.00	31104.00	10.68	100000.00
Med	2.00	151173.64	1.00	10.95	12.58	1.00	14052.96	1.68	20000.00
ET	4.55	155105.79	0.15	9.06	9.37	0.21	5541.84	1.31	12268.17
Adrar									
Average	3.09	406066.39	0.64	26.69	28.87	0.89	14517.71	2.18	25945.91
Min	0.06	9111.11	0.05	3.44	3.44	0.17	2620.80	0.00	0.00
Max	90.00	1980000.00	1.00	103.49	106.59	1.00	32400.00	8.83	101333.33
Med	1.06	318241.03	0.67	24.28	26.01	1.00	12830.40	2.24	24434.72
ET	9.25	353263.30	0.20	15.74	16.14	0.20	6564.65	1.35	16339.27
Adrar sans gratuits									
Average	3.74	379933.73	0.66	28.48	31.16	0.87	11948.08	2.67	30542.55
Min	0.20	9111.11	0.05	3.48	7.38	0.17	2620.80	0.61	4964.29
Max	90.00	1924750.00	1.00	103.49	106.59	1.00	29433.60	8.83	68000.00
Med	1.50	289833.33	0.69	26.04	28.82	1.00	11232.00	2.59	29117.65
ET	10.34	337844.25	0.19	15.82	16.00	0.21	4402.29	1.04	13294.31

Table 74. Breakdown according to the 4 regions considered.

connected to a collective network while the private farmer spends at least 3 AD/m^3 (0.03 €), about twice the charge of collective irrigator. Incidentally, the actual cost borne by the private farmer is much higher than this amount if we integrate fixed costs. (* Conversion base: 1 € = 100 AD).

We will see the importance of this difference in costs paid by the collective sector farmers and private farmers in the conservation of the scarce resource demonstrated by quantitative analysis (detailed in Section 4).

	Algeria (without the ghout)	Algeria (without the free of charge)	Individual network	Collective network	Free of charge (foggaras, artesian boreholes)
Number of farmers	1,189	1,104	783	321	85
Water consumption per hectare per farmer (m³/ha)	13,432	12,749	11,871	14,891	22,302
Water cost (AD/m³)	2.49	2.65	3.08	1.60	0.39
Water Productivity (AD/m³)	29.40	30.27	35.40	17.77	17.98
WTP (AD/m³)	31.88	32.93	38.48	19.37	18.37
Intensification rate (super. irrigated/ sup. irrigable)	0.84	0.83	0.80	0.90	0.90

Table 75. Breakdown according to the water pumping network (collective, private, free).

- Water Productivity:

Table 75 provides an interesting result on the valorization of water resources by the various categories of water users:

- Farmers benefiting from free water and those related to a collective network value the least this valuable resource with only 18 AD/m^3;
- By cons, farmers who bear the bulk of the cost of mobilization of resources, i.e. private, value much better water used with 35 AD/m^3.

This result on the productivity of one m^3 allocated to agricultural production is diametrically opposed to that obtained for consumption. Indeed, the private farmer uses less resources and values it much more than the two other categories that do not pay the real cost of the required water.

- WTP per m^3:

As the definitions of Water Productivity and the WTP are close enough (the only difference lies in the fact that the cost of water has been cut off from WP and not WTP), their interpretations are also quite similar in this context . Indeed, the private farmer who bears the greatest burden for the mobilization of his own irrigation water is most willing to pay a high price (38 AD/m^3), followed by the farmer benefiting from a Collective network that is heavily subsidized by the community (19 AD/m^3) and finally by the farmer currently disposing of an almost free of charge water resource willing to pay only 17 AD/m^3.

- Intensification rate:

The IRs are respectively of 0.9 on average the farmer disposing of a free of charge resource and the one connected to the collective network and of 0.8 for the private farmer. It is very likely that the private farmer is handicapped by the lack of resources and the exorbitant cost he must consent to bear in order to mobilize the resource. These two reasons explain his inability to irrigate the entire irrigable area available.

Some preliminary results that can also be developed from Table 76, which gives the spatial breakdown perspective of the Algerian SASS, are into three homogenous regions.

	Algeria	Biskra	O. Souf	O. Righ	Adrar
Number of farmers	1,189	410	239	244	246
Water consumption per hectare per farmer (m^3/ha)	13,432	12,383	13,023	14,218	14,518
Water cost (AD/m^3)	2.49	2.52	3.6	1.8	2.18
Water Productivity (AD/m^3)	29.40	36.8	37.4	13.5	26.7
WTP (AD/m^3)	31.88	39.4	41.1	15.3	29.4
Intensification rate (super. irrigated/ sup. irrigable)	0.84	0.80	0.80	0.88	0.84

Table 76. Breakdown according to the geographical areas.

- Water consumption (or demand) of water per hectare per farmer and area:

Water consumption per hectare differs from one area to another. Indeed, it ranges from 12,383 m^3/ha in the Biskra region to 14,218 m^3/ha in the area of Oued Righ. This difference is simply explained by the importance of the collective network in each region. Indeed, the Oued Righ, which is characterized by the highest consumption, is the region where the collective network is predominant. The importance of the collective network is rather limited in both areas of Biskra and Oued Souf. The very high consumption in Adrar, which amounts to 14 515 m^3/ha, is certainly due to the extreme aridity of the region.

- The cost of water per m^3:

The cost of water paid by the farmer is more important in both areas of Biskra and Oued Souf with respectively 2.52 and 3.6 AD/m^3 in the Oued Righ (1.8 AD/m^3). This difference, significant enough, is explained by the high number of private farmers in the first two areas while in Oued Righ where there is a predominance of public irrigated areas , water is heavily subsidized. The relative low average cost of water in Adrar is certainly due to the presence of a significant proportion of irrigators using the foggaras.

- Water Productivity:

The valorization of the resource ranges from 13.5 AD/m^3 in Oued Righ to about 37 AD/m^3 in the two regions of Biskra and Oued Souf, an increase of 274%. This significant difference is due to the complex problems currently plaguing the huge palm groves of Oued Righ. Indeed, the significant decline in production in this region is due, at least in part, to the rise in salinity due to excessive irrigation and the dominance of highly subsidized collective irrigation network.

- WTP per m^3: the same comment also applies to the WTP.

2. Quantitative analysis and commentary on the results

This quantitative analysis, whose main purpose is to make proposals for operational recommendations for decision-makers, will be conducted in three levels:

- the first level will be based on the global sample across Algeria;
- the second, which will focus on the size of the dimension of the resource cost, shows the breakdown of the global sample into three main groups according to the cost of mobilizing water resources borne directly by the farmer:
  - "Free of charge group" farms receiving water resources free of charge;
  - "Collective group": farms supplied by a collective network;
  - "Private group" farms irrigated by a private network;
- The third level will explicitly consider the spatial breakdown that will give a special focus on regional characteristics
  - the Wilaya of Biskra;
  - the oasis of Oued Righ;
  - farmers of the region of Oued Souf; and
  - the wilaya of Adrar.

For each of these levels, we use the analysis criteria that seem most relevant in this preliminary phase, namely:

- Water consumption per hectare per farmer (WHA)
- Economic water productivity (WP);
- The gross margin per hectare or gross profit generated by one m^3 of water used;
- Total production per hectare.

2.1. Comprehensive quantitative analysis across the Algerian SASS

As explained above, our overall analysis will be conducted according to the criteria of water consumption by farmer, the economic water productivity, the gross margin and the global production.

Note: The global Algerian sample used in this analysis includes 1,213 farms. Out of this total number, 26 are irrigated using the traditional Ghout system. This system, which uses a natural irrigation directly from the sheet, may be compared to the rainfed production system and thus excluded from our sample of farms supplied by conventional irrigation systems. Thus, once these Ghout-irrigated farms are excluded, the final Algerian sample will be made up of **1,187 farms**.

Water consumption per hectare per farmer (WHA)

The selected specification is designed to identify the determinants of the key variable expressed in log, which is the consumption of water per hectare per farmer.

The WHA variable is well expressed in terms of the entire set of explanatory variables used according to specifications (1).

Table 77 summarizes the results for all farmers of the Algerian sample, provided by the computerized output that concerns all selected irrigators. This table also shows the same results with the overall sample without irrigators receiving free water (column 3).

The passage from the global sample to the sample where we exclude farms receiving free water significantly improves the quality of the estimate. Indeed, the key variable in this model, namely the price of water (LWCMC) passes an almost insignificant elasticity (6%) with a significant elasticity of the order of 45%.

The variables selected, namely the price of water, the actual irrigated area, the salinity of the water used, the family and wage workforces, the origin of the water source and the region explain at least 57% of the variability of water consumption per hectare per farmer. According to the model chosen for performance of spatial data, the result is excellent.

- Price elasticity is very significant and has the appropriate sign.

Two criteria were used to estimate the key parameter:

- the first consists in approximating the variable price by the cost paid by the farmer;
- the second, given just as an indication, will use the DAP as an approximation of the price of the resource.

In this context, the analysis will be based mainly on the first option.

	Global sample (Without the Ghout)	Global sample (Without free of charge)
Variable explained	Water consumption per hectare per farmer (WHA)	
Explanatory variable		
Lwcmc	- 0.06 (0.000) ***	- 0.45 ***
Laia	- 0.12 (0.000) ***	- 0.12***
Rhe	0.02 (0.496)	0.02
Lsalin	- 0.68 (0.000) ***	-0.38***
Lflha	0.02 (0.000) ***	0.02***
Lhlha	0.01 (0.000) ***	0.01***
Wor	0.01 (0.565)	0.05***
Re	-0.06 (0.000)***	-0.04 ***
Cte	10.0 (0.000)***	10.03 ***
N	1187	1104
Adj R-squared	0.46	0.57
F	129.82	180.19

*The P-values are in parentheses. ***, **, *: statistically significant at the levels of 1, 5 & 10%.*

Table 77. Water consumption per hectare per farmer (WHA)

- Water resource price approximated by the cost to the farmer:

When the price of water (here the cost paid by the farmer) ranges from 100% from one farmer to another in the Algerian SASS area, consumption (water demand) per hectare falls by only 6%. This elasticity is very low and justifies the prevailing consensus among policy makers on the matter, that the price variable is not relevant to any policy to control the demand for this resource with specific characteristics. However, this seemingly negative result is simply due to a global and crude analysis. The transition to a more detailed analysis will reveal that the price variable, as advocated by the entire economic literature on this very important subject, shows the true relevance of the price elasticity. Indeed, when excluding the farmers who do not pay water (column 3) from the sample, this elasticity reaches 45%, i.e., for a 100% increase in the price of the resource (water demand), consumption per hectare drops by 45%. This result is very important because it shows that the price of water actually has a significant impact on the demand for irrigation water. Appropriate pricing of agricultural water would contribute significantly to control demand and thus lead irrigators to better allocate this scarce resource and especially to conserve it. This important result will be confirmed by a more detailed analysis based on a more appropriate disaggregation.

- Water resource price approximated by farmer's WTP:

The price elasticity of the demand for water for the whole of Algeria increases from 0.45 to 0.83 when we take the DAP as an approximation of the price instead of the mobilization costs. This result, which is illustrated by the computer output (see annex), further strengthens the role of the price of water in the management of this scarce and valuable resource in this fragile environment.

- The impact of farm size on water demand:

The result shows that when the size of the irrigated farm increases, consumption per hectare decreases. This would be the consequence of two impacts: The first is the result of the decreasing level of intensification following the extension of irrigated areas while the second is due to improved irrigation techniques.

- The impact of the type of irrigation network (Wor) and region :

These two variables are very significant. The result shows the importance of the type of irrigation network and the regional dimension in determining the demand for agricultural water. It fully justifies the approach adopted, namely the disaggregation of the global sample according to two key criteria of the spatial variation and type of irrigation system.

Water productivity (WP)

Specification (2) is adopted to estimate the determinants of the economic water productivity.

Table 78 provides a synthetic summary of the results.

- Independent variables (the determinants) selected explain that 25 % of the variability of water productivity (dependent or explained variable). The F-test is largely significant for the selected specification.
- Elasticity of salinity is highly significant for the global sample. When salinity increases by 100%, water productivity decreases by 53%.
- Elasticity of farm size: when the size of the farm increases, water productivity decreases. This very important result justifies an agricultural reform benefiting small farms in this context of extreme scarcity of the vital resource, that is water.
- Elasticity of the impact of the family labor: this variable has a positive and significant impact on water productivity. However, this impact still quite low.
- Elasticity of agriculture without livestock (AWL): this result shows that when the farmer excludes livestock on his farm, the productivity of allocated water drops by 33%. This important result shows perfectly the dimension of livestock in this region.
- Impact of the availability of the farmer: when the farmer has no other activity besides farming, water productivity increases by 22%.

	Global Algeria (without irrigators receiving free water)
Variable explained	Log of Water Productivity (LWP)
Explanatory Variables	
Lsalin	- 0.53 (0.000) ***
Laia	- 0.05(0.000) ***
Awl	- 0.32 (0.002) ***
LFLHA	0.006 (0.231)
Lhlha	0.013 (0.000) ***
Re	0.20 (0.004) ***
Rhe	0.22 (0.000) ***
Cte	2.97 (0.000) ***
N	1,104
Adj R-squared	0.25
F	51.09

*The P-values are in parentheses. ***, **, *: statistically significant at the levels of 1, 5 & 10%.*

Table 78. Water Productivity (global sample).

Important conclusion: the dimensions that have a significant impact on water productivity are:

- salinity;
- farm size
- family labor;
- availability of the head of the farm ;
- importance of livestock to the farmer's revenue.

Any economic policy that targets the improvement of the current management of this precious resource in a context of high fragility requires measures focused on the key variables.

The gross margin per hectare or the benefit obtained per one m^3 of water used for irrigation

Specification (3) is selected to estimate the determinants of the gross margin.

The two most important results to obtain from this estimate are:

- The importance of the salinity variable. In fact, according to the results shown in

Table 79, when the salinity increases by 100%, the gross margin per hectare irrigated drops by at least 97%. This high sensitivity of the valuation of water salinity should be taken into consideration very seriously by the decision makers.

- The importance of the water price variable. This estimate shows very clearly that this variable has a direct impact on the farm's gross margin. Indeed, when the price of water increases by 100%, the gross margin of the farmer drops by at least 37%, which is far from negligible.

Total production per hectare

Specification (3) is selected to estimate the determinants of total production per hectare.

Table 80 shows the results of estimating the determinants of total production per hectare for the whole of Algeria.

All the results are relevant, meaningful and have an appropriate sign:

- All of the variables account for nearly half of the variability of the total production. The F-test is highly significant.
- The elasticities of all the inputs [cost of family labor per hectare (men per year), the cost of wage labor per hectare, cost of water per hectare, inputs per hectare (fertilizers, insecticide, herbicide, manure, etc.), and the cost of feed] **are positive and highly significant**.
- Elasticity of salinity on production is negative and highly significant. When the salinity of the irrigation water increases by 100%, output per hectare decreases significantly by 103%. **This result is very important because it illustrates the negative consequences of the increasing salinization of the resource due to overexploitation.**
- The impact of income from sources other than the farm on total production is positive and highly significant at the level of the entire sample. Indeed, when the main farmer has an activity other than cropping, production per hectare decreases significantly.
- The impact of the irrigation method on global production is significant and is characterized by the appropriate sign. Indeed, when switching from one highly subsidized irrigation source to one that is entirely the farmer's responsibility, production per hectare increases significantly.
- The regional impact is highly significant and important.
- Elasticity of the area: this elasticity is of paramount importance in this analysis. Indeed, thanks to this estimate based on a database that is both rich and original, it is possible to give some answers to a crucial question:

  to improve the food balance in poor countries, should large size farms be

Variable explained	Log of the net margin per hectare (lnmha)
Explanatory Variables	
Lwcmc	-0.37 (0.000) ***
Lsali	-0.97 (0.000) ***
Wor	-0.002 (0.678)
Lflha	0.01 (0.121) *
Laia	-0.11 (0.000) ***
Re	0.1 (0.000) ***
Awl	-0.37 (0.004) ***
Cte	13.4 (0.000) ***
N	1,104
Adj R-squared	0.33
F	79.61

*The P-values are in parentheses. ***, **, *: statistically significant at the levels of 1, 5 & 10%.*

Table 79. Gross margin per hectare.

Variable explained	The Log of total production per hectare (TPHA)
Explanatory Variables	
Lflha	0.012 (0.014) **
Lhlha	0.03 (0.000) ***
Lwcha	0.54 (0.000) ***
Lintha	0.32 (0.000) ***
Feed	0.12 (0.000) ***
Wor	-0.007 (0.060) *
Re	0.13 (0.000) ***
Lsalin	-0.65 (0.000) ***
Laia	-0.15 (0.000) ***
Cte	7.09 (0.000) ***
N	1,104
Adj R-squared	0.48
F	111.75

*The P-values are in parentheses. ***, **, *: statistically significant at the levels of 1, 5 & 10%.*

Table 80. Total production per hectare (TPHA).

promoted through supportive land reform, or rather opt for smaller farms to occupy as many people as possible in the country?

The elasticity of the area obtained through the global sample is highly significant and negative. Indeed, if the irrigated area on farm doubles, the farm production drops by 15%.

According to these results, illustrated by the above table, it would be wise to opt for land reform focused on **smaller farms to occupy as many people in the country as possible.**

Note: The two most important factors in determining the total variability of the irrigated agricultural production function on a global scale are:

- The water input with an elasticity of about 0.54, which means that for a 100% increase in water costs per ha, the total output would increase by 54%;
- Salinity with an elasticity of around -0.65; indicating that for an increase in the salinity of the water resources of 100%, the overall output would decrease by 65%.

2.2. Quantitative analysis disaggregated according to the cost of water borne by the farmer

This analysis, which shows the breakdown based on the cost actually incurred by the irrigator, will be conducted according to the criteria of the water consumption per farmer, economic water productivity, gross margin and total production.

Water consumption per hectare and per farmer (WHA)

Specification (1) is now estimated based on the samples of irrigators disposing of an individual network and those connected to the collective irrigation network.

Table 81 provides estimates of the determinants of water consumption per hectare per farmer respectively for the total sample of Algeria (column 2), the overall sample of Algeria without farmers who receive free water (column 3), the sample of farmers who dispose of individual pumping equipment (column 4) and the sample of farmers connected to a collective water supply network (column 5).

- The price elasticity of water demand. This estimate confirms the essential findings on a global scale across Algeria. However, clarifications related to the payment for irrigation water provides new elements for analysis. Indeed, for individual farmers, this elasticity (column 4) reaches 57%, while that of farmers benefiting from a collective network (column 5) drops to 20%. This result confirms that the behavior of the irrigators enjoying a resource at highly discounted prices, thanks to a significant public subsidy, are less sensitive than individual irrigators who bear the actual cost of the resource. The elasticity of demand for individual irrigators is well above that of collective irrigators (57/20 = 2.85).

	Algeria (without Ghout)	Algeria (without free water)	Individual	Collective
Variable explained	Water consumption per hectare and per farmer (LWHA)			
Explanatory Variables				
Lwcmc	- 0.06 (0.000) ***	- 0.45 ***	-0.57 ***	-0.20 ***
Laia	- 0.12 (0.000) ***	- 0.12***	-0.14***	-0.06 ***
Rhe	0.02 (0.496)	0.02	0.02)	-0.01
Lsalin	- 0.68 (0.000) ***	-0.38***	-0.30 ***	-0.58 ***
Lflha	0.02 (0.000) ***	0.02***	0.012 ***	0.017 ***
Lhlha	0.01 (0.000) ***	0.01***	0.007 ***	0.01 ***
Wor	0.01 (0.565)	0.05***	-	--
Re	-0.06 (0.000)***	-0.04 ***	-0.06 ***	-0.05 ***
Cte	10.0 (0.000)***	10.03 ***	10.2 ***	10.1 ***
N	1187	1104	783	321
Adj R-squared	0.46	0.57	0.63	0.34
F	129.82	180.19	166.90	23.99

*The P-values are in parentheses. ***, **, *: statistically significant at the levels of 1, 5 & 10%.*

Table 81. Water consumption per hectare per farmer (WHA).

	Algeria	Algérie (without free water)	Individual	Collective
Variable explained	Water consumption per hectare per cropper			
Explanatory Variables				
Lwcmc	-0.08***	- 0.53***	-0.65***	-0.17***
Cte	9.4***	9.8***	9.9***	9.6***
N	1189	1104	783	321
Adj R-squared	0.11	0.35	0.43	0.03
F	153.70	604.58	596.00	10.56

*The P-values are in parentheses. ***, **, *: statistically significant at the levels of 1, 5 & 10%.*

Table 82. Water consumption per hectare per cropper with focus on the water price only.

Table 82, which focuses solely on the price of water as a factor in explaining the variation in the application, further illustrates this dimension. Indeed, the results of columns 4 and 5 clearly demonstrate the significant difference between the price elasticities of demand for water subsidized by the State and the price elasticity of the individual cropper (-0.17 and -0.65 respectively, a difference of 1 to about 4). The variable cost of water in the case of individual farmers alone explains 43% of the variability in the demand for water for all individual irrigators of the Algerian area of SASS, while the explanatory power of the variable price the total variation of demand for water for farmers connected to a collective network is almost negligible with only 3%.

Water productivity (WP)

Specification (2) is estimated on the basis of samples of individual and collective farmers.

Table 83 gives estimates as produced by the software for both selected categories of farmers.

- The independent variables (determinants) selected explain the variability in the productivity of the water resource between 15% and 43% (dependent or explained variable) depending on the sample. The F-test is highly significant for the three selected specifications.
- The elasticity of salinity is highly significant and is characterized by the appropriate sign for the three samples selected. The sample of collective farmers is characterized by an elasticity which even exceeds 100%. The negative impact of salinity on water productivity is more detrimental to irrigators supplied by a public network than those disposing of an individual network.
- The elasticity of actual irrigated area. The elasticity of this very important variable is characterized by a significant and positive impact on the productivity of water for both categories of water users: private and collective. This finding would support the arguments already developed for the overall sample.
- The availability of farmer: where the farmer is totally dedicated to his farm, the productivity of the water resource increases by 16% in the case of an individual irrigation and 24% for a collective network.

Gross margin per hectare or profit generated by one m^3 of water used for irrigation

The estimates of the determinants of the gross margin per hectare according to individual network/collective network disaggregation confirm the results obtained in the previous section that highlight economic productivity of the water resource. The main difference to note is the importance of the highly negative impact of salinity on the gross margin per hectare irrigated. We notice that in the case of an increase of 100% in the salinity of the water, this would cause a significant decrease of 164% of the gross margin per hectare

	Algeria	Individual	Collective
Variable explained	Log of Water Productivity (LWP)		
Explanatory Variables			
Lsalin	- 0.53 (0.000) ***	- 0.34 (0.000) ***	-1.04 (0.000) ***
Laia	- 0.05(0.000) ***	-0.10 (0.000) ***	-0.49 (0.156) *
Awl	- 0.32 (0.002) ***	-0.34 (0.001) ***	0.36 (0.107) *
Lflha	0.006 (0.231)	0.006 (0.281)	0.005 (0.567)
Lhlha	0.013 (0.000) ***	0.01(0.000) ***	0.009 (0.047) **
Re	0.20 (0.004) ***	-0.007 (0.817)	0.17 (0.000) ***
Rhe	0.22 (0.000) ***	0.16 (0.001) ***	0.24 (0.002) ***
Cte	2.97 0.000) ***	3.75 (0.000) ***	2.3 (0.00) ***
N	1104	783	321
Adj R-quared	0.25	0.15	0.43
F	51.09	21.13	35.69

*The P-values are in parentheses. ***, **, *: statistically significant at the levels of 1, 5 & 10%.*

Table 83. Water Productivity (according to the water source perspective).

	Algeria	Individual network	Collective network
Variable explained	Log of the gross margin per hectare (lgmpha)		
Explanatory Variables			
Lwcmc	-0.37 (0.000) ***	-0.97 (0.000) ***	0.15 (0.094)
Lsalin	-0.97 (0.000) ***	-0.53 (0.000) ***	-1.64 (0.000) ***
Wor	-0.002 (0.678)	-	-
Lflha	0.01 (0.121) *	0.005 (0.458)	0.02 (0.097)
Laia	-0.11 (0.000) ***	-0.2 (0.000) ***	-0.05 (0.140)
Re	0.1 (0.000) ***	-0.19 (0.000) ***	0.11 (0.001) ***
Awl	-0.37 (0.004) ***	-0.42 (0.001) ***	0.04 (0.877)
Cte	13.4 (0.000) ***	14.9 (0.000) ***	12.8 (0.000) ***
N	1104	783	321
Adj R-squared	0.33	0.48	0.51
F	79.61	105.65	57.11

*The P-values are in parentheses. ***, **, *: statistically significant at the levels of 1, 5 & 10%.*

Table 84. Gross margin per hectare (according to the water source perspective).

irrigated by a collective network. We also note the importance of the price variable in the context of a private network and even its irrelevance for the collective network.

Total production per hectare

Table 85 shows the results of estimating the determinants of total production per hectare for the whole of Algeria (column 2), for the collective business farmers (column 4) and for those with a Private irrigation network (column 3).

	Algeria	Individual network	Collective network
Variable explained	Total production per hectare (TPHA)		
Explanatory Variables			
Lflha	0.012 (0.014) **	0.016 (0.000) ***	0.007(0.300)
Lhlha	0.03 (0.000) ***	0.03 (0.000) ***	0.17 (0.000)** *
Lwcha	0.54 (0.000) ***	0.38 (0.000) ***	0.51 (0.000) ***
Lintha	0.032 (0.000) ***	0.03 (0.000) ***	0.03 (0.000) ***
Feed	0.12 (0.000) ***	0.014 (0.000) ***	0.007 (0.017) **
Wor	-0.007 (0.060) *	-0.005 (0.199)	-
Re	0.13 (0.000) ***	-0.022 (0.511)	0.15 (0.000) ***
Lsalin	-0.65 (0.000) ***	-0.58 (0.000) ***	-0.94 (0.000) ***
Laia	-0.15 (0.000) ***	-0.22 (0.000) ***	-0.07 (0.006) ***
Cte	7.09 (0.000) ***	9.32 (0.000) ***	7.53 (0.000) ***
N	1104	783	321
Adj R—squared	0.48	0.43	0.66
F	111.75	66.66	77.14

*The P-values are in parentheses. ***, **, *: statistically significant at the levels of 1, 5 & 10%. et 10 %.*

Table 85. Total production per hectare (TPHA) (according to the nature of the water source).

All the results obtained are relevant:

- All the variables selected explain the variability of the total production between 43 and 66% for the three categories of farmers. The F-test is highly significant for the three categories of farmers.
- The impact of all production inputs [cost of family labor per hectare (men per year), the cost of wage labor per hectare, cost of water per hectare input per hectare (fertilizer, insecticide, herbicide, manure, etc.), and the cost of livestock feed] is positive and highly significant.
- Farm size (AIA) has the expected sign and impact. In fact, the smaller the irrigated area, the higher the production per hectare. This result is simply due to the scarcity

of the resource. Indeed, when the actual irrigated area is large, the farmer is forced to practice a rather semi-intensive farming and therefore use less water per irrigated hectare.

- The impact of salinity on output is negative and highly significant. Indeed, when the salinity of the irrigation water increases, the yield per hectare decreases significantly for the three categories of farmers. **This result is very important because it illustrates the negative consequences of the increasing salinization of the resource due to overexploitation.**

Note: When the criterion of the type of irrigation network is selected, the two most important factors in determining the total variability in irrigated agricultural production function, for both individual farms with private irrigation networks and those connected to a collective network, are also:

- The water cost:

  for farms with individual irrigation network, elasticity is about 0.38, which means that for a 100% increase in water spending per ha, the total output would increase by 38%. While for farms connected to a collective network, this elasticity reaches 0.51%.

- The salinity of the water resources:

  for farms with an individual irrigation system, the elasticity is around -0.58; this implies that for 100% increase of the salinity of the water resources, the overall output would decrease by 58%, while for farms connected to a collective network, this elasticity even reaches -0.94%.

2.3. Quantitative analysis from a spatial perspective

The preceding analysis uses the criterion of the type of irrigation system used by the farmer. This criterion focuses primarily on the cost of irrigation water borne directly by the cropper. Another criterion is as important as the first one and puts a special focus on regional specificities of the large Algerian SASS region.

The Algerian part of the SASS is divided into four homogeneous regions:

- the region of Biskra;
- the region of Oued Souf;
- the region of Oued Righ;
- the Adrar region.

These four regions produce most of irrigated agricultural production across the Algerian Sahara. Therefore, we focus in this preliminary analysis on these regions.

We hold here too the same criteria as those adopted for analysis in the previous section, namely:

- Water consumption per hectare per farmer (WHA)
- the economic productivity of water per m^3 (WP);
- the gross margin per hectare obtained per one m^3 of water used;
- the production function.

Water consumption per hectare per farmer (WHA)

Specification (1) is estimated on the basis of samples of the farmers of four selected areas, namely Biskra, Oued Souf, Oued Righ and Adrar.

Table 86 provides a synthetic summary of the essence of the results obtained by appropriate econometric estimation.

	Algeria (without free water supplied)	Biskra	Oued Souf	Oued Righ	Adrar
Variable explained	**Water consumption per hectare per farmer (LWHA)**				
Explanatory Variables					
Lwcmc	- 0.45 ***	- 58 (0.000) ***	-0.40 (0.000) ***	-0.10 (0.033)**	-0.33 (0.000) ***
LAIARhe	- 0.12***	-15 (0.000) ***	-0.06 (0.003)***	-0.06 (0.015)**	-0.20 (0.000) ***
Lsalin	0.02	0.09 (0.077) *	-0.006 (0.869)	0.03 (0.562)	0.05 (0.198)
Lflha	-0.38***	- 0.41 (0.000) ***	-0.60 (0.021) ***	-0.56 (0.000)***	-0.18 (0.000) ***
Lhlha	0.02***	0.02 (0.000) ***	0.002 (0.597)	0.014 (0.006)**	0.01 (0.650)
Wor	0.01***	0.01 (0.000) ***	0.08 (0.001)****	0.008 (0.013) **	0.012 (0.000)***
Re	0.05***	-0.32 (0.533)	0.06 (0.337)	-0.16(0.029)**	0.000 (0.998)
Cte	-0.04 ***	-	-	-	-
	10.03 ***	9.9 (0.000) ***	9.81 (0.000)***	10.1 (0.000)***	9.9 (0.000) ***
N	1104	410	239	244	193
R-squared	0.57	0.62	0.78	0.36	0.49
F	180.19	96.29	115.69	20.91	27.83

*The P-values are in parentheses. ***, **, *: statistically significant at the levels of 1, 5 & 10%.*

Table 86. Water consumption per hectare per farmer (WHA)

- Price elasticity: this elasticity is significant and negative for the four areas. Although the regional criterion is used, the price of water has a significant impact on demand. However, this impact is quite important in the regions of Biskra and Oued Souf and important in the Adrar region. Indeed, if the cost of water increases by 100%, demand shows a significant decrease of 58% in the province of Biskra, 40% in the region of Oued Souf and 33% in the wilaya of Adrar . However, in the region of Oued Righ, mainly dominated by collective irrigation networks, the impact becomes almost insignificant with a decrease of only 10%. This can be explained simply by the fact that in this area, there is no objective incentive for the conservation of the resource, given the low cost per m^3 actually paid by the farmer.

- The elasticity of the area: this elasticity is significant and negative for the four areas. When the area of the farm increases, the demand for water per hectare decreases significantly.

Water productivity (WP)

Table 87 provides a synthetic summary of the essence of the results obtained by appropriate econometric estimation.

- The elasticity of salinity: this elasticity is highly significant and is a negative sign as expected. This result confirms and amplifies even the one obtained by the estimate according to the cost perspective. When the salinity of irrigation water increases, productivity considerably decreases in the four areas. If the salinity of the water increases by 100%, productivity declines at a rate of 104% in the area of Oued Righ, 94% in the area of Oued Souf, 38% in the Biskra region and 12% in the wilaya of Adrar. This result is of paramount importance as it shows the urgent need to combat it.

Gross margin per hectare

Table 88 shows that estimates of the determinants of the gross margin per hectare according to the spatial disaggregation of the bulk sample into four zones, confirm the essential results obtained in the previous section that focused on economic productivity of the water resource. The main difference to note is the importance of the highly negative impact of salinity on the net margin per irrigated hectare. We note that for an increase of 100% in the salinity of the water, there is a significant decrease of 168% in the gross margin per hectare in the area of Oued Righ, 131% in the Oued Souf, 78% in the region of Biskra and 33% in the wilaya of Adrar.

Total production per hectare

- The elasticity of the area: the important result that was obtained through both the overall sample and the breakdown according to the type of irrigation network criterion, namely that small farms are more efficient than large ones, is confirmed by the results shown in table 89 for the spatial breakdown. Indeed, when the irrigated area doubles, overall production shows a significant decrease of about 29% in the province of Biskra, 15% in Oued Souf, 11% in Oued Righ and finally 22% in the wilaya of Adrar.

	Algeria	Biskra	O. Souf	O. Righ	Adrar
Variable explained	Water Productivity (LWP)				
Explanatory Variables					
Lsalin	-0.53 (0.000) ***	-0.38 (0.000) ***	-0.94 (0.000) ***	-1.04 (0.000) ***	-0.12 (0.002) ***
Laia	-0.053 (0.006) ***	-0.15 (0.000) ***	0.18 (0.543)	-0.05 (0.899)	-0.31 (0.000) ***
Awl	- 0.32 (0.000) ***	- 0.51 (0.000) ***	- 0.45 (0.002) ***	-0.12 (0.686)	- 0.2 (0.254)
Lflha	0.006 (0.231)	0.015 (0.026) **	0.0004 (0.965)	0.01 (0.275)	0.013 (0.705)
Lhlha	0.013 (0.000) ***	0.012 (0.004) ***	0.012 (0.019) **	-0.0002 (0.971)	0.012 (0.036) **
Re	0.20 (0.000)***	-	-	-	-
Rhe	0.22 0.000) ***	0.01 (0.896)	0.26 (0.002) ***	0.08 (0.393)	0.005 (0.937)
Cte	2.97 (0.000)***	4.27 (0.000)***	3.77 (0.000)***	2.88 (0.000) ***	3.6 (0.000) ***
N	1104	410	239	244	193
R-squared	0.24	0.15	0.39	0.24	0.35
F	51.09	13.09	26.70	14.01	18.54

*The P-values are in parentheses. ***, **, *: statistically significant at the levels of 1, 5 & 10%.*

Table 87. Water Productivity.

	Algeria	Biskra	O. Souf	O. Righ	Adrar
Variable explained	Log of the gross margin (LGMha)				
Explanatory Variables					
Lwcmc	-0.37 (0.000) ***	-0.72 (0.000) ***	-0.79 (0.000) ***	-0.09 (0.298)	-0.13 (0.278)
Lsalin	-0.97 (0.000) ***	- 0.78 (0.000) ***	-1.31 (0.000) ***	-1.68 (0.000) ***	-0.33 (0.000) ***
Wor	-0.002 (0.678)	0.37 (0.000) ***	0.92 (0.000) ***	0.57 (0.000) ***	-0.0002 (0.967)
Lflha	0.01 (0.121) *	0.02 (0.037) **	-0.03 (0.752)	0.014(0.074)*	0.01 (0.822)
Laia	-0.11 (0.000) ***	-0.28 (0.000) ***	-0.009 (0.776)	-0.14.(001) ***	-0.45 (0.000) ***
Awl	-0.37 (0.000) ***	-0.74 (0.001) ***	-0.38 (0.000)	0.06 (0.826)	-0.04 (0.854)
Re	0.1 (0.000) ***	-	-	-	-
Cte	13.4 (0.000) ***	13.71 (0.000)***	11.66(0.000)***	11.8 (0.000) ***	13.04 (0.000) ***
N	1104	410	239	244	193
R-squared	0.33	0.45	0.67	0.53	0.40
F	79.61	55.88	83.04	46.15	22.47

*The P-values are in parentheses. ***. **. *: statistically significant at the levels of 1. 5 & 10%.*

Table 88. Gross margin.

	Algeria	Biskra	O. Souf	O. Righ	Adrar
Variable explained	Total production per hectare (LTYHA)				
Explanatory Variables					
Lflha	0.012 (0.014) **	0.03 (0.000) ***	0.02 (0.848)	0.01 (0.862)	0.02 (0.552)
Lhlha	0.03 (0.000) ***	0.02 (0.000) ***	0.03 (0.000) ***	0.01 (0.003) ***	0.01 (0.022) **
Lwcha	0.54 (0.000) ***	0.55 (0.000) ***	-0.08 (0.477)	0.27 (0.000) ***	0.85 (0.000) ***
Lintha	0.32 (0.000) ***	0.05 (0.001) ***	0.01 (0.249)	0.03 (0.001) ***	0.008(0.177)
Lfeed	0.12 (0.000) ***	0.02 (0.000) ***	0.03 (0.000) ***	0.008 (0.039) **	0.02 (0.000) ***
Wor	-0.007 (0.060) *	0.13 (0.93) *	0.08 (0.615)	0.24 (0.001) ***	0.003 (0.284)
Re	0.13 (0.000) ***	-	-	-	-
Lsalin	-0.65 (0.000) ***	-0.69 (0.000) ***	-1.54(0.000) ***	-1.18 (0.000) ***	-0.17 (0.000) ***
Laia	-0.15 (0.000) ***	-0.29 (0.000) ***	-0.15 (0.000) ***	-0.11 (0.000) ***	-0.22 (0.000) ***
Cte	7.09 (0.000) ***	7.5 (0.000) ***	14.3 (0.000) ***	9.58 (0.000) ***	4.16 (0.000) ***
N	1104	410	239	244	193
Adj R-squared	0.48	0.51	0.62	0.63	0.63
F	111.75	53.65	46.54	47.40	42.59

*The P-values are in parentheses. ***. **. *: statistically significant at the levels of 1. 5 & 10%.*

Table 89. Total production per hectare (according to the water source perspective).

- The elasticity of salinity: the results obtained with the full sample and those from samples developed according to the breakdown based on the type of irrigation network are amply confirmed by the results shown in Table 89. Indeed when the salinity of the water resource increases by 100%, the overall production of irrigated farms shows a sharp decline of about 69% in the wilaya of Biskra, 154% in Oued Souf, 118 % in Oued Righ and finally 17% in the wilaya of Adrar.

Special zoom on the wilaya of Adrar

A particular focus on the country of foggaras is quite informative. Table 90 provides a detailed analysis on some aggregates deemed important.

- The irrigation system through foggaras is still important in the wilaya of Adrar. This ancient technique of irrigation is typical of the area and is currently used by 110 farmers in 247, that is a significant percentage of (45%).
- However, these foggaras suffer from a continuous drying up. According to the survey, more than half of foggaras users use supplementary irrigation by pumping (57 out of 110).
- The Wilaya of Adrar, with its extreme climate, is characterized by the highest water

Type of irrigation network	Nbr of farmers	AIA	WHA	WCMC	MBHA	WP	AWL
Foggara	53	0.69	23,875	0.38	551,229	2018	
Hybrid (foggara + private pumping)	57	1.57	11,646	2.85	365,200	28.9	
Indiv. network	124	4.6	11,556	2.7	389,730	29.2	
Tot. Without free water	194	3.7	11948	2.67	379,934	28.5	0.660
Total	247	3.1	14,518	2.18	406,066	26.7	0.64

Table 90. Wilaya d'Adrar.

consumption per hectare across all the Algerian SASS.

- Livestock is an important component of the irrigator's income in this wilaya. It is more than a third of the average income (36%), whereas the global scale of the Algerian SASS is just 15%.

3. Summary of the main results and some recommendations

Preliminary results obtained through quantitative analysis based on the sample of Algerian farmers confirm and support the results already obtained from the Tunisian sample. The effort to collect actual data at the level of the primary user of the resource has proven useful and conclusive.

The major objective of this brief review is to focus on the essential results that are expected to propose operational recommendations to decision makers in the field.

- The approach adopted in the context of this work, which emphasizes the microeconomic perspective based primarily on collecting data from the primary user of the scarce resource, helped give results of primary importance for the success of this project. In fact, the passage from aggregated data to disaggregated data according to the appropriate criteria allowed achieving original results.

- The cost of the water at the expense of the farmer: the estimate of the elasticity of water price through the overall sample (aggregated approach) provided results justifying the irrelevance of this variable. The elasticity obtained, which was of the order of 0.06, shows that when the price of water varies by 100% from one farmer to another, the corresponding application is the subject of an insignificant decrease of 6%. This result demonstrates that any tariff policy aimed at a better conservation of the resource by a substantial increase in prices is doomed to fail because it accumulates the negative impact of pricing without radically reversing the upward trend of water demand. However, adopting a microeconomic approach based on disaggregated data leads to diametrically opposite results. All estimates of the elasticity of the price resource, detailed in the previous section, deserve special attention. **Indeed, all the results, regardless of the breakdown criterion (type** of network used, method of payment of the cost of the resource used, spatial dimension) show that when the cost paid by the irrigator increases, the latter's demand for water decreases substantially.

- The elasticity of the price of water demand varies, according to the selected irrigation network (individual or collective), the relevant geographical area (Biskra, Oued Souf, Oued Righ, Adrar) and the selected specification of 0, 20 to 0.90 *(when the price of water increases by 100%, the demand falls from 20 to 90%).* This result demonstrates the major importance of "pricing" the resource in the control of the application. This control would induce the conservation of the resource and thus help ensure its durability and sustainability for future generations and especially for the survival of a strategic region for the three countries concerned. This could help overcome the skepticism of many decision makers who think that the variable cost of water is not suitable to control the application.

- The salinity of the resource: the results that demonstrate and especially quantify the highly negative impact of salinization of the resource on the production of irrigated agriculture as well as the productivity of the most limiting input, namely water, confirm and support the results already obtained by agronomists. Let's remind that according to our estimates, the production of an irrigated hectare would fall by 150% for an increase in the salinity of the water used by 100%. All the analyses demonstrate, unambiguously, that the salinization of the resource must be fought by all the possible means.

- Elasticity of the area: this elasticity is of paramount importance to this analysis. The analysis obtained through the aggregate sample is highly significant and negative. In fact, when the irrigated area of a farm doubles, production would decline by 15. Thus, when the farm size increases, the water productivity decreases. This important result justifies land reform in favor of small farms in this context of extreme scarcity of the vital resource: water. It would be wise to opt for a reform *focused on smaller farms to occupy as many people in the country and better value the scarcest resource in this context, which is water.*

- Elasticity of agriculture without livestock (AWL). The result obtained shows that when the irrigator excludes livestock from farming activities, the allocated water productivity decreases by 33%. This result illustrates perfectly the importance of the dimension of livestock breeding in these regions.

- The impact of the availability of the farmer: when the farmer has no business other than agriculture, the productivity of the water resource increases by 22%. This result justifies a policy to encourage the farmer to devote himself entirely to his property for a better valorization of his work, the work of his family and the water resource used.

- The main determinants of irrigated agricultural production in the Algerian SASS zone are:
  - the water input with an elasticity of around 0.54 (a 100% increase in water costs per ha induces increased production of 54%) is a key variable in the management of the resource in these deprived areas;
  - salinity with an elasticity of about -0.65 (an increase in the salinity of the water resources of 100% would cause a decrease in the overall output of 65%) is also a dimension to consider carefully.
- The type of irrigation network (free, collective, individual) across Algeria, this variable is significant and has the appropriate sign. Indeed, when we move from free water to a highly subsidized water (collective network) then to a source of water slightly subsidized (private sector), water productivity increases substantially. This result is quite important in the debate on the choice between centralized management by the state (public management of irrigation water) and decentralization either by the market or through a participatory management.

Conclusion : the dimensions that have a meaningful and significant impact on the economic productivity of water are:

- the price of the resource;
- salinity;
- the size of the farm;
- family labor;
- availability of the head of the farm for agricultural work;
- the importance of livestock in the farm income.

Any economic policy that aims to improve the quality of the current management of this precious resource in a context of high fragility in order to ensure its durability, should explicitly incorporate these key variables.

III. LIBYA

Two types of data analysis were carried out:

- a descriptive analysis, through simple statistics, helps reveal the most common characteristics,
- a quantitative analysis, using the most recent econometric tools, helps reveal the most important characteristics and most useful for the design of the appropriate economic policies.

1. Descriptive analysis

The main characteristics of irrigated agriculture in the Libyan Jeffara compared to other regions of the SASS zone are:

- the total absence of irrigation supplied by public and/or collective networks: out of the 493 farms included in the scope of this field investigation, none of them uses a public or collective irrigation networks. All surveyed farmers, who benefited from a public network, said they used individual wells and/or boreholes because public networks were all out of order.
- A much less intensive use: water consumption per irrigated hectare according to the spatial criterion, illustrated by line 2 of Table 91, as well as the criterion of the culture system, illustrated by line 2 of Table 92, is well below the average consumption of all other regions of the SASS area except the Tunisian Jeffara. Current consumption, which is around 9000 m^3/ha/year, is 2/3 the average of that of the other regions.
- Arboriculture, which values the least water resources, is the dominant activity: arboriculture alone occupies about half of the surveyed farms (251 farms out of 493 selected farms), although it is this activity that values the least water resources. Indeed, the water productivity of arboriculture, as shown in line 4 of Table 92, does not exceed 70% (3.77/4.33) of the overall average; while the mobilization cost of this water resource allocation is greater than the average 20% (0.043 / 0.036).
- Livestock plays an important role in the income of the farmer: the average income of each farmer from livestock is about 44% of the total revenue. In addition, over one-fifth of surveyed farmers (108 out of 493) rely primarily on farming.
- Irrigated agriculture is relatively in decline: the average area actually irrigated by farmers is currently around 6.1 ha while it was 7.2 ha at the beginning of the activity; This represents a decrease of about 18%. This regression of actual irrigated area, despite all the public investment in the mobilization of the resource, is paradoxical and requires an appropriate explanation.

2. Quantitative analysis and commentary of the results

This analysis, which has the main objective of developing and especially quantifying the proposals of operational recommendations to submit to decision makers, will be conducted in the Libyan context only on one level, namely the overall analysis. Two main reasons explain this choice:

- the survey, for obvious security reasons, could not be carried out on the field and in the region of the Jeffara;
- all the farmers who had benefited from a public irrigation network, were obliged to

	Global sample	Marguebk	Tripoli	Jeffara	Zaouia	Zouara
Number of farmers	493	84	29	178	127	75
Water consumption per hectare per farmer (m^3/ha)	9,122	10,001	10,193	9,112	8,996	7,915
Water cost (LD/m^3)	0.036	0.027	0.34	0.039	0.041	0.029
Water Productivity (LD/m^3)	0.433	0.471	0.412	0.449	0.442	0.342
WTP (LD/m^3)	0.469	0.499	0.445	0.487	0.483	0.371
Intensification rate (super. Irrigated/sup. irrigable)	0.80	0.98	0.80	0.80	0.74	0.69
AWL (Agriculture without livestock)	0.63	0.74	0.56	0.69	0.57	0.52

Table 91. Breakdown by selected survey zone

	Global sample	Arboriculture	Plein champ	Mainly livestock	Intensive (Vegetable cropping and greenhouses)
Number of farmers	493 (100)*	276 (48)	80 (17)	57 (21)	80 (15)
Water consumption per hectare per farmer (m^3/ha)	9,122	7,982	8,800	10,066	11,821
Water cost (LD/m^3)	0.036	0.043	0.032	0.30	0.025
Water Productivity (LD/m^3)	0.433	0.377	0.398	0.526	0.523
WTP (LD/m^3)	0.469	0.420	0.430	0.556	0.548
Intensification rate (super. Irrigated/sup. irrigable)	0.80	0.78	0.83	0.79	0.85
AWL (Agriculture without livestock)	0.63	0.75	0.67	0.15	0.86

** The figures in parentheses indicate the % of farmers practicing the system of cropping selected compared to the total number of farmers.*

Table 92. Breakdown by cropping systems.

	% of the global receipt	Average	Median	Standard deviation
Arboriculture	36.1	14,703	7,725	23,469
Intercropping	6.1	2,508	0	7,013
Open field cultivation	13.3	5,440	0	14,641
Livestock revenues	44.5	18,142	6,000	51,594
Total revenue	100.0	40,794	24,365	60,760

Table 93. Variability of the global receipts of the farmer according to the four important themes.

mobilize a water source on their own as the collective networks were all out of order.

This analysis will be conducted, as for both Algeria and Tunisia, according to the following four criteria:

- Water consumption per hectare per farmer (WHA)
- Economic water productivity (WP);
- The gross margin per hectare obtained per one m^3 of water used;
- Total production per hectare.

2.1. Water consumption per hectare per farmer (WHA)

The selected specification is designed to identify the determinants of the key variable expressed in log, which is the consumption of water per hectare per farmer.

The WHA variable is well expressed in terms of the set of explanatory variables used according to specifications (1).

Table 94 summarizes the results relating to all farmers of the Libyan sample, given by the computer output that concerns all the selected irrigators.

Variable explained	Water consumption per hectare per farmer (WHA)
Explanatory Variables	
Lwcmc	- 0.25 (0.000) ***
Laia	- 0.19 (0.000) ***
Lsalin	- 0.36 (0.000) ***
Lflha	-0.004 (0.917)
Lhlha	0.01 (0.000) ***
Awl	- 0.1 (0.026) **
Re	-0.04 (0.004)***
SC	0.1 (0.000) ***
Cte	8.6 (0.000) ***
N	493
Adj R-squared	0.43
F	50.49

*The P-values are in parentheses. ***. **. *: statistically significant at the levels of 1. 5 & 10%.*

Table 94. Water consumption per hectare per farmer (WHA).

- The variables selected, namely the price of water, the actual irrigated area, the salinity of the water used, wage labor, the importance of agriculture without livestock and the cropping system, explain at least 43% of the variability of water consumption per hectare per farmer. According to the model chosen for the performance of spatial data, the result is excellent.
- The price elasticity is very significant and has the appropriate sign.

  Two criteria were used to estimate the key parameter:

  - the first is to approximate the variable price by the cost paid by the farmer;
  - the second, given just an indication, shows the DAP as an approximation of the price of the resource.

  In this context, the analysis is based essentially on the first, namely the price of the water resource approximated by the cost to the farmer: When the price of water (here the cost paid by the farmer) ranges by 100% from one farmer to another in the Libyan Jeffara, consumption (water demand) per hectare decreases by 25%. This result is very important because it shows that the price of water has a significant impact on the demand for irrigation water. Appropriate pricing of agricultural water would contribute significantly to controlling demand and thus encourage irrigators to better allocate this scarce resource and especially to preserve it.
- The impact of the farm size on water demand: the result shows that when the size of the irrigated farm increases, consumption per hectare decreases. This is partly due to the decline in intensification following the extension of irrigated areas and, secondly, to improved irrigation techniques.
- The impact of the cropping system (CS), wage labor (HLHA) and region (Re): these variables are highly significant.

2.2. Water productivity (WP)

Specification (2) is selected to estimate the determinants of water productivity.

- The independent variables (determinants) selected explain 27% of the variability in the productivity of the water resource (dependent or explained variable). The F-test is highly significant for the chosen specification.
- The elasticity of salinity is highly significant. When salinity increases by 100%, water productivity decreases by 52%.
- The elasticity of size: when the farm size increases, water productivity decreases. This important result justifies land reform in favor of small farms.

Important conclusion: The dimensions that have a meaningful and significant impact on the economic productivity of water are:

Variable explained	Log of the Water Productivity (LWP)
Explanatory Variables	
Lwcmc	- 0.18 (0.000) ***
Laia	- 0.06(0.056) **
Awl	- 0.07 (0.343)
Lsalin	-0.52 (0.000) ***
Lhlha	0.01(0.000) ***
Re	-0.05 (0.009) ***
SC	0.9 (0.000) ***
Ct	-1.2 0.000) ***
N	493
Adj R-squared	0.27
F	28.76

*The P-values are in parentheses. ***. **. *: statistically significant at the levels of 1. 5 & 10%.*

Table 95. Water Productivity.

- salinity;
- the size of the farm;
- wage labor;
- the cropping system.

Any economic policy that aims to improve the quality of the current management of this precious resource in a context of high vulnerability must be carried out through measures focused on these key variables.

2.3. Gross margin per hectare or profit generated per one m³ of water used for irrigation

The selected specification for the estimation of the determinants of the net margin are:

$$lmbha1 = \alpha_0 + \alpha_1 lwcmc + \alpha_2 lsalin + \alpha_3 SC + \alpha_4 lflha + \alpha_5 laia + \alpha_6 Re + \alpha_7 Awl$$

Where :

- Lmbha: log of the gross margin per hectare ;
- Awl: agriculture without livestock.

Variable explained	Log of the gross margin per hectare (lmbha)
Explanatory Variables	
Lwcmc	-0.43 (0.000) ***
Lsalin	-0.88 (0.000) ***
Awl	-0.17 (0.093)*
Lhlha	0.02 (0.000) ***
Laia	-0.27 (0.000) ***
Re	-0.9 (0.002) ***
SC	0.18 (0.000) ***
Cte	7.44 (0.000) ***
N	493
Adj R-squared	0.40
F	50.86

*The P-values are in parentheses. ***. **. *: statistically significant at the levels of 1. 5 & 10%.*

Table 96. Gross margin per hectare.

The two most important results that emerge from this estimation are:

- the importance of the salinity variable. In fact, according to the results shown in Table 96, when the salinity increases by 100%, the gross margin per irrigated hectare drops by at least 88%. This high sensitivity of water salinity valorization should be considered very seriously by decision makers in the field. The fight against this scourge in these highly sensitive areas must be a priority.
- the importance of the price of the resource variable. This estimate shows very clearly that this variable has a direct impact on gross margin of the farm. Indeed, when the price of water increases by 100%, the gross margin of the farm drops by at least 43%, which is far from negligible.

2.4. Total production per hectare

The specification selected for the estimation of the determinants of total production per hectare is :

$$Lrtha = \beta_0 + \beta_1 Lflha + \beta_2 Lhlha + \beta_3 Lwcha + \beta_4 Lintha + \beta_5 Lfeed + \beta_6 Laia + \beta_7 Lsalin + \beta_{10} SC + \beta_{11} RE \quad (4)$$

Where:

- Intha: the cost of inputs (manure, fertilizers, insecticides, herbicides, etc.);
- feed: the cost of cattle feed;

- The rest of the variables has already been defined above.

Variable explained	Log of the total production per hectare (LRTHA)
Explanatory Variables	
Lflha	-0.008 (0.897)
Lhlha	0.02 (0.000) ***
Lwcha	0.3 (0.000) ***
Lintha	0.005 (0.398)
Lfeed	0.02 (0.000) ***
Re	-0.03 (0.237)
Lsalin	-0.62 (0.000) ***
Laia	-0.004 (0.949)
SC	0.24 (0.000) ***
Cte	6.71 (0.000) ***
N	493
Adj R-squared	0.47
F	53.17

*The P-values are in parentheses. ***. **. *: statistically significant at the levels of 1. 5 & 10%.*

Table 97. Total production per hectare (LRTHA).

Table 97 shows that all the results are relevant, meaningful and have the appropriate sign:

- All the variables selected account for nearly half of the variability of the total production. The F-test is highly significant.
- Elasticities of all inputs, except family labor per hectare (men per year), i.e. wage labor per hectare, the cost of water per hectare, the input per hectare (fertilizers, insecticides, herbicides, manure, etc.) and the cattle feed cost **are positive and highly significant.**
- The impact of the elasticity of salinity on the output is negative and highly significant. When the salinity of the irrigation water increases by 100%, output per hectare decreases significantly by 62%. **This result is very important because it illustrates the negative consequences of the increasing salinization of the resource due to overexploitation.**
- The cropping system (CS) has a significant impact on production. When the farmer moves from arboriculture as a main activity to market gardening and greenhouse cropping, the total production increases significantly increase by around 24%.
- The family labor appears to have no significant impact on production in the Libyan Jeffara.

Note: The three most important factors in determining the total variability in irrigated agricultural production in the SASS Libyan zone are:

- The water input with an elasticity of about 0.3; which means that for a 100% increase in water costs per ha, total production increase by 30%;
- Salinity, with an elasticity of about -0.62; which implies an increase in the salinity of the water resources in 100, the overall output would decrease by 62%;
- The cropping system: the passage from arboriculture as main activity to more intensive cropping (vegetables and greenhouse cropping) substantially improve the total production.

3. Synthesis of the main results and some recommendations

Preliminary results obtained through quantitative analysis based on the sample of Libyan farmers confirm and support the results already obtained from the Tunisian and Algerian samples.

The major objective of this brief review is to focus on the essential results .

- The water cost at the expense of the farmer: the estimate of the price elasticity of water using the Libyan sample provides interesting results, justifying the approach. Indeed, this result shows the major importance of the "pricing" ddimension of the resource in the control of its demand. This control would induce the conservation and thus help ensure its durability and sustainability for future generations and especially for the survival of a strategic region for the whole Libya. This could help overcome the skepticism of many decision makers who think that the water price variable is not suitable to control the application.
- The salinity of the resource: the results, that demonstrate and quantify the highly negative impact of salinization of the resource on the production of irrigated agriculture as well as the productivity of the most limiting input which is water, confirm and support the results already obtained by agronomists. **Lets' remind that according to our estimates, the production of an irrigated hectare would fall by 62% for an increase in the salinity of the water used by 100%.** The entire analysis shows unambiguously that the salinization of the resource due to over-exploitation is a pandemic that must be fought by all means. This result, which appears less severe than those of Algeria and Tunisia, is explained by the fact that the Libyan Jeffara, the most common crops are not intensive and have already been adapted to the reality of the country, characterized by insufficient quality and quantity.
- The importance of breeding in irrigated agriculture: the obtained result indicates that when the irrigator excludes livestock from his farming activities, the productivity of the water allocated decrease quite significantly. This elasticity deserves special

attention. Indeed, this result shows perfectly the dimension of livestock in these areas. **In addition, livestock is an important part in the farmer's income:** the average livestock income for each farmer is around 44.5% of total revenue. Finally, remember that in the Libyan Jeffara, over a fifth of the surveyed farmers (108 out of 528) relies primarily on farming.

- The cropping system has a significant impact on production. When the farmer moves from arboriculture as a main activity to market gardening and greenhouse cropping, total production marks a significant increase of around 24%. It is therefore important to promote intensive irrigated cropping on more reduced areas in the Libyan Jeffara for a better valuation of the scarce resource and its conservation.
- Irrigated agriculture is relatively declining: per farmer, actually the average irrigated area is currently around 6.1 ha while it was 7.2 ha at the beginning of the activity; this represents a decrease of about 18%. This regression of actual irrigated area, despite the public investments in the mobilization of the resource, is paradoxical and requires an appropriate explanation.

Conclusion: The dimensions that have a significant and substantial impact on economic productivity of water in Libya are:

- the price of water resources;
- salinity;
- the cropping system;
- the importance of livestock in the farm income.

Any economic policy that aims to improve the quality of the current management of this precious resource in a context of high fragility in order to ensure its durability, should explicitly incorporate these key variables.

IV. OVERALL ANALYSIS

The above analyses were carried out on the basis of individual samples for each of the three countries, while this one is carried out on the basis of the global sample of the three countries in an integrated manner. It is important to note that the results obtained in the overall context are more relevant as they are based on a high number of farmers and cover all the specifics of the great SASS region.

1. Overview of the collected database

The data collected during the two campaigns of socioeconomic and environmental investigations have focused on the core sample that was developed according to scientific and technical criteria required by the statistical theory of surveys and polls. This sample was designed on the basis of 3,000 representing farmers of the entire population of the SASS region irrigators. Out of the 3,000 field surveys carried out during the first campaign, 2,521 have been validated and included in the descriptive as well as quantitative analysis. The second campaign was limited to half the sample of the first campaign that is 1,229. Only 2,521 surveys validated during the first campaign were selected by the second campaign.

Table 98 provides details of the breakdown of the bulk sample by country and within each country by each area selected.

The sample of farms surveyed represents:

- more than 90% of all farmers in the SASS region;
- the bulk of irrigated production in the SASS region;
- all the irrigated production systems in the SASS region.

Regions	1st Campaign 2011	2nd Campaign 2012	Both campaigns
Algeria	**1,280**	**850**	**2,130**
El Oued	257	200	457
(O. Righ)	248	183	431
Ouargla	50	-	50
Biskra	479	467	946
Adrar	246	-	246
Libya Jeffara	**493**	**-**	**493**
Tunisia	**748**	**379**	**1,127**
Medenine	83	-	84
Tataouine	128	-	128
Gabes	143	-	143
Tozeur	144	146	290
Kebili	250	233	483
Total SASS	**2,521**	**1,229**	**3,750**

Table 98. Spatial and temporal breakdown of the collected data.

2. Descriptive analysis

Table 99 summarizes the main findings on key variables that will be the basis for quantitative analysis. The statistics of these key variables that were calculated according to the three criteria will be used throughout both the descriptive and analytical analyses:

- The first criterion is the spatial nature that consists in detailing the results by country.

,	WHA	AIA	FLHA	SALIN	WP	WCMC	N
GLOBAL	12,868	4.2	2.95	1.76	0.413	0.036	3750
Algeria	13,520	5.1	2.09	1.75	0.405	0.036	2130
Tunisia	13,266	1.8	5.6	1.71	0.458	0.04	1127
Libya	9,134	6	0.64	1.94	0.341	0.028	493
ACCORDING TO THE NATURE OF THE WATER RESOURCE							
Ghout	22,259	0.6	6.19	1.23	0.271	0.005	38
Free (Foggara)	21,215	1.1	5.76	1.4	0.277	0.004	154
Collective Network	14,746	2.6	4.52	1.79	0.35	0.028	1498
Hybrid Network	13,432	1.9	2.23	1.56	0.289	0.048	133
Private Network	10,516	6	1.5	1.78	0.484	0.045	1927
ACCORDING TO THE CONTRIBUTION OF THE FARMER TO THE WATER COST							
Subsidized Network	15,354	2.3	4.49	1.73	0.338	0.027	1823
Private Network	10,990	6	1.8	1.75	0.533	0.051	1434

Table 99. Summary of main results

- The second focuses on the nature of the water source,
- The third focuses on the participation of the farmer in the cost of mobilizing water resources.

Consumption per hectare per farmer (WHA):

- Private farmers, who bear most of the cost of water mobilization, use this resource sparingly (on average 10,512 m^3 per hectare and 10,990 m^3 without Libyan farmers);
- Farmers connected to a collective network who pay only a small part of the actual cost, use more the resource, with 15,334 m^3 (40% more than private);
- Farmers who are lucky enough to dispose of free water, use the resource freely. Indeed, with 21,215 m^3 per hectare on average, they use about twice the volume used by the private farmer.

This result by itself shows, without any ambiguity, the importance of the cost of water in any policy of rationalization and above all the conservation of this resource in this particular region.

The average water demand per hectare, which is about 13,500 m^3, is virtually the same in Algeria and Tunisia. However, it is only 9,134 m^3/ha in Libya. This significant difference is simply due to the fact that in Libya, irrigated agriculture is rather semi-intensive while it is quite intensive in the other two countries mainly because of the importance of the palm groves.

The cost of water per m^3 (WCMC):

The cost of one m^3 of water directly paid amounted to US \$ 0.028/m^3 for the farmer connected to a collective network while the private farmer spends at least US \$ 0.045/m^3, about 61% more. This difference is much higher if we exclude the Libyan part of the overall sample (88%). In fact, the Libyan sample introduced adds a significant bias because it includes only private farmers benefiting from substantially subsidized energy and thus bear a relatively low cost per m^3. It should be noted that the actual cost incurred by the private farmer is much higher than this amount if we integrate fixed costs.

The significance of the difference between the costs paid by farmers of the collective sector and private sector in the conservation of the scarce resource will be demonstrated by quantitative analysis, detailed in the next section.

Water productivity (WP):

Table 99 provides an interesting result on the valuation of water resources by the various categories of water users:

- Operators benefiting from free water (or Ghout foggaras) and those related to a collective network value the least this valuable resource with respectively only 0.271, 0.277 and 0.350 US \$ /m^3.
- However, farmers who bear the bulk of the cost of resource mobilization, i.e. private, value much better the water used than the previous two categories, with US \$ 0.484/m^3; about 78% more, which is far from negligible.

This result on the productivity of one m^3 allocated to agricultural production is diametrically opposed to that obtained for consumption. Indeed, the private farmer uses less resources and values it much more than the other two categories that do not pay the real cost of the water demanded. *In other words, the farmer who bears the real burden of mobilization cost is capable of producing more with less water allocated per irrigated hectare*.

The actual irrigated area (AIA) :

The average area irrigated by private farmers is higher than that of the farmers connected to a collective irrigation network and especially farmers who receive free water source (*6.0 ha for the private, 2.3 ha for farms supplied by a collective irrigation network and 1.1 ha for free water*). This result is explained by the fact that those who are connected to a collective or free network are obliged to irrigate only a limited area fixed in advance by the community while the private farmer does not suffer from such restriction. In addition, the Algerian and Libyan farmers enjoy a relatively bigger farm size with respectively 5.1 ha and 6 ha on average, compared to the Tunisian farms characterized by rather small sizes with an average of 1.8 ha. This significant difference between farm sizes according to the selected country will be at the origin of different impacts on the valuation of the resource as explained in the next section.

The family labor (FLHA) :

The number of family assets per hectare are respectively 2.1 ha in Algeria, 5.8 in Tunisia and only 0.64 in Libya. It is clear that farms in Tunisia, which are usually small, are overcrowded, while the Libyan farms, which are rather large suffer from a labor shortage.

3. Quantitative analysis

This quantitative analysis, whose main objective to demonstrate and quantify the above proposals in order to submit practical recommendations to decision makers, will be carried out on two levels:

- behavioral analysis of water demand per irrigated hectare according to a spatial price variation: the study was conducted as a one-time survey where the time variable is set to the year of the survey and the only available variation at this level is only in the variation of the mobilization costs among farmers;
- analysis in terms of economic productivity for every allocated m^3: this analysis aims at studying the improvement in the valuation of the resource due to an increase in prices that induces a reduction in the expressed demand.

Two survey campaigns have been carried out on the same sample of selected farmers, and it was possible to use econometric technique of « data panel « that allows carrying out a very accurate and therefore more realistic analysis. A very brief presentation of the advantages of this technique is required.

3.1. Advantages of the data panel

The panel data, combining inter-farm differences and intra-farm dynamics, are distinguished by intrinsic benefits as well on spatial and temporal data:

- a more accurate and therefore more efficient parameters estimation of the used model;
- greater capacity to grasp the complexity of human behavior (this is the behavior of farmers in terms of combined production factors) than by individual or temporal data:
    - the panel data is used to develop and test more complex behavioral assumptions. Let's consider by way of illustration, the example of the evaluation of social or economic investment programs: assessment of the effectiveness of certain investment programs using only spaced data suffers from the fact that those who receive treatment are different from those who do not receive it. In other

words, it is impossible to simultaneously observe the result when an individual receives treatment and another does not.

- Identification of dynamic relationships: in fact, any economic behavior is necessarily dynamic, that is why most relationships that are econometrically of interest should be rather of explicit or implicit dynamic nature.

- A simplification of the calculation and statistical inference.

3.2. Analysis of water consumption per hectare per farmer

The selected specification is designed to identify the determinants of the key variable expressed in log, which is the consumption of water per hectare per farmer (WHA). This variable is thus expressed in terms of the set of explanatory variables selected according to the specification already prepared and presented in previous sections.

Table 100 summarizes the results relating respectively to all farmers of the global sample, sample of farmers benefiting from the subsidized network and sample of private farmers provided by the computer output.

Variable explained	Global sample	Subsidized network	Private network
	Water consumption per hectare per farmer (LWHA)		
Explanatory Variables			
LWCMC (Water price)	- 0.12 (***)	- 0.08 (***)	- 0.27 (***)
LAIA (Area)	- 0.04 (**)	- 0.07 (**)	- 0.09 (***)
LMBHA (Revenue)	0.32 (***)	0.23 (***)	0.38 (***)
WOR (Irrigation network)	- 0.005 (***)	- 0.005 (***)	-
COUNTRY	-	-	- 0.25 (***)
SP1 (Cropping System)	0.05 (***)	0.07 (**)	0.02 (***)
Constant	6.1 (***)	7.1 (***)	5.5 (***)
N (Nbr of observations)	3750	1823	1927
Adj-R^2	0.58	0.43	0.76
F	198.4 (***)	47.42 (***)	574 (***)

Table 100. Results of water demand estimations.

Analysis of the impact of the water cost variation based on its demand (price elasticity)

The above table shows that if we use the overall sample, when the price of water (here the cost paid by the farmer) increases by 100% in the SASS area, consumption (water demand) per hectare drops by 8% to 27%. This decrease is as high as 60% when we pass to the disaggregation of the sample by SASS region zone.

What are the fundamental reasons for this result, reversing the strongly held belief that agricultural water demand is insensitive to price?

If we use the overall sample, when the price of water increases by 100% in the SASS area, consumption per hectare drops by only 12% and even 8% for the sample that includes only the farmers benefiting from substantial subsidy from the community. This low elasticity, which means that water demand is insensitive to price, justifies the consensus that exists among decision makers in the matter, that the price variable is not relevant to any demand control policy with specific characteristics. However, this seemingly negative result is simply due to a global and crude analysis. Indeed, in the overall sample, the aggregation of the collective and private data produces a bias that distorts the real results. The transition to a more detailed analysis distinguishing the two categories shows the true relevance of the price elasticity. Quantitative analysis thus shows that through appropriate econometric modeling, an accurate disaggregation of data and the introduction of the spatial dimension, the elasticity of the demand price reaches as high as 60% in some SASS areas such as the Governorate of Gabes for example. This means that when the price increases by 100%, water demand decreases by 60%, which is far from negligible. This result is very important because it shows that the price of water has a significant impact on the demand for irrigation water. Appropriate pricing of agricultural water would contribute significantly to controlling demand and thus encourage irrigators to better allocate this scarce resource and especially to preserve it.

In the next section that concerns analysis in terms of productivity, it is demonstrated *that the active contribution of the farmer to the real cost of mobilization of water resources, substantially improves productivity*.

Recommendation 1: Every economic policy aimed at the conservation of the resource and thus promoting the sustainability of the aquifer must integrate the price instrument through an appropriate pricing. This instrument should accompany and not replace the other technical instruments (fighting against waste through network maintenance, using modern irrigation techniques, using treated wastewater, etc.).

Analysis in terms of resource productivity

The above analysis showed that when the price of water increases, demand drops significantly. This result can in any way constitute the main objective of an appropriate policy for the sustainable management of the resource. ***The major objective of any decision maker is not only reducing water demand to preserve the aquifer, but rather maintaining the level of the farmers' well-being and even its improvement through the implementation of a better productivity per one allocated m³.***

Variable explained	Global sample	Subsidized network	Individual network
	Water Productivity (LWP)		
Explanatory Variables			
1. LWCMC (Water price)	0.17 (***)	0.13 (***)	0.07 (***)
2. LSALIN (Salinity)	- 0.75 (***)	- 0.80 (***)	- 0.67 (***)
3. LAIA (Area)	0.21 (***)	0.16 (***)	0.11 (***)
4. LFLHA (Family labor)	0.19 (***)	0.21 (***)	0.13 (***)
5. LAGE^2 (Age)			
6. WOR (Irrigation network)	- 0.09 (***)	- 0.07 (**)	- 0.10 (***)
7. COUNTRY	- 0.010 (***)	- 0.006 (***)	-
8. CAMP (Campaign)	0.05 (***)	0.08 (***)	0.12 (***)
9. SP1 (Cropping System)	0.15 (***)	0.010 (***)	0.33 (***)
10. LEL (Livestock)	0.10 (***)	0.08 (***)	0.09 (***)
11. Constant	0.08 (***)	0.007 (*)	0.004
	- 0.07 (***)	- 0.41	- 0.53 (**)
N (Number of observations)	3750	1823	1927
Adj-R^2	0.31	0.34	0.28
Wald chi^2	14.70 (***)	794 (***)	685 (***)

Table 101. Results of the estimation of the water productivity function.

The results shown in Table 101 show that when the price of the resource increases, besides the fact that his demand decrease significantly (previous result), its valuation is experiencing significant growth. This result which shows that the farmer faces an increasingly reduced water volume due to the increase of its price is strongly encouraged to make better use of every allocated m^3 by significantly improving its productivity. According to the results illustrated by the first line of the table, we find that when the price of the resource increases by 100%, productivity has grown significantly from 7 to 17%, which is far from negligible.

All other results shown in Table 101, which quantify the impact of a set of important determinants of economic water productivity deserve a detailed presentation:

The negative impact of salinity on the productivity of the resource is logical but alarming. According to the results shown by the second line of the table, when the salinity increases by 100% (when it increases from 2 g/l to 4g/l for example), the resource's productivity drops to 67 to 80%. *This salinity is a pandemic that actually threatens the viability of all irrigated agriculture in the SASS zone.* All estimates of the impact of this variable on the total production of irrigated agriculture, the gross margin of the farms and on the productivity of water, are significant. This negative impact of salinity is found regardless of the selected irrigation network and the country concerned.

Recommendation 2: The design and promotion of an effective anti-salinity policy are essential to ensure the survival of the whole structure already weakened by over-exploitation.

The importance of family labor in the valuation of the resource. The fourth line of Table 101 shows that when the number of family assets doubles per hectare (goes for example from one family member to two per hectare), resource productivity significantly increases from 13 to 21% depending on the type 'of sample used. Indeed, the presence of a family active member on the farm, in the form of supervision over the other active employees, significantly improves the productivity of the resource. The positive role of family labor on the profitability of any business is largely confirmed by other researchs in economic theory, namely the labor market.

Recommendation 3: Promote the appropriate policy to encourage young people to stay in the area and opt for farm work in order to strengthen the role of family workforce.

The aging farm chiefs has a significant negative effect on the valuation of the water. The results given in the fifth row of the table shows very clearly that when the farm chief ages, the productivity of the resource he manages shows a significant decline.

Recommendation 4: Implement a rejuvenation policy encouraging the involvement of young farmers.

The introduction of livestock in the cropping system of irrigated farms in the SASS area significantly improves the productivity of the water resource.

Recommendation 5: Promote a policy advocating the integration of livestock activities into irrigated farming systems.

The importance of the farm size: the results of estimates of the impact of the size of irrigated farms on the resource's productivity differ from one country to another in the SASS zone. In Algeria and Libya, where the average size of irrigated farms is relatively high, the elasticity of the size obtained is significantly negative. This result, which states that when the farm size increases resource productivity decreases, suggests a land reform in favor of smaller farms. In contrast, in Tunisia, particularly in the Jerid and Nefzaoua where fragmentation has reached alarming levels, this elasticity is positive, suggesting that an agrarian reform aimed at the consolidation of farms in order to promote profitable units with viable sizes is required.

The choice of the cropping system adopted by the farmer has a highly significant impact on the productivity of the resource. Particular emphasis will be placed on this aspect in the next section.

Analysis in terms of the cropping system

The last perspective focuses on the selected cropping system. Six cropping systems have been identified, namely:

- mainly vegetable and greenhouse cropping;
- traditional dense oasis system;
- open field (mainly cereals);
- arboriculture mainly;
- scattered traditional oasis systems;
- livestock-dominant system.

	Scattered oasis	Open field	Arbo	Dense Oasis	Veget. cropping	Livestock	Oasis system*	Global
Nbr of observations	994	237	386	1,409	459	164	2,404	3,750
Water consumption	10,628	8,371	7,727	16,869	11,920	13,872	14,289	12868
Irrigated area - ha)	3.9	11.6	7,727	16,869	11,920	13,872	14,289	12868
Seniority	28.3	28.3	26.6	32.1	20.28	26.8	30.6	28.3
Family labor	1.63	0.88	2.52	5.03	1.37	2.66	3.62	2.96
Salinity	E	E	M	F	F	M	M	M
Water productivity ($/m³)	0.199	0.344	0.456	0.558	0.574	0.769	0.351	0.413
Water cost ($/m³)	0.036	0.044	0.046	0.029	0.044	0.035	0.032	0.036
Gross margin per ha ($)	1,827	3,124	3,271	7,548	7,285	11,841	5,181	4,461
Elasticity of the demand for water and productivity								
Price elasticity	-0.35	-0.32	-0.15	-0.11	-0.16	-0.10	-0.13	-0.12
Elasticity of productivity	0.19	0.18	0.14	0.12	0.10	0.12	0.09	0.17

** The oasis system comprises both sparse and dense oases.*

Table 102. Summary of main results according to the cropping system perspective.

Table 102 reveals that the systems that best value water are:

- the essentially market gardening and greenhouse system;

- the dense classical oasis system;
- the livestock-dominated farming system.

Whereas the three other, namely the open field (mainly cereals); arboriculture mainly; and conventional scattered oasis systems, are characterized by very low water productivity per m^3.

The two rows of Table 102 water productivity and gross margin per ha, show very clearly the characteristic difference between these two sets.

In fact, the dense oases production systems, vegetable crops and breeding valorize each m^3 of water used in the order of 0,558 ; 0,574 and 0,769 $ US respectively, while the sparse oases production system, open field, and arboriculture only valorize water resource in the order of 0,199 ; 0,344 and 0,456 $ US per m^3 respectively. Analysis in terms of gross margin provides exactly the same results.

When simulating the hydro-economic model to achieve the solution that will enable optimal overall income of irrigated agriculture in the SASS region, special emphasis will be placed on the most rewarding systems of the resource.

Recommandation 6 : Design and implement an appropriate agrarian reform policy for the SASS irrigated sector which takes into account the specificities of each country.

V. PROSPECTS

This analysis which yielded very interesting results, can fortunately be still improved on several levels:

- First level: continue the analysis of available data:
  - further exploit the database;
  - resort to more sophisticated models.
- Second level: further develop the available database:
  - a better assessment of the actual water demand per farmer based on the data of table 103.

Crops	Irrigation method	Number of irrigations	Number of hours/Irrigation	Flow L/S	Volume consumed in m^3

Table 103. Water consumption per crop

To eliminate all errors inherent to this procedure, the ideal would be to install water meters in order to have accurate measurements.

- Extend further the temporal component by conducting new surveys campaigns to improve the dynamic dimension.

APPENDIX:
Very Brief Presentation Of The Basic Econometric Model

Econometrics, Simply defined, is the application of statistical methods to the analysis of economic problems. The basic tool of econometrics is Regression Analysis. Regression is a relationship between one or more variables called independent, explanatory or exogenous and the expected value of a dependent, explained or endogenous variable.

I. THE LINEAR REGRESSION MODEL

In a formal way, the linear multivariate model can be explained by the following function:

$$y = f(x_1, x_2, x_3, \ldots\ldots\ldots\ldots x_n) \qquad \textbf{(1)}$$

Where:

- y : is the variable to be explained that could be the demand for water by farms;
- $x_1, x_2, x_3, \ldots\ldots\ldots\ldots x_n$: is the set of explanatory variables that normally determine the value of the variable y. In our context , these variables could be the price of the resource, the irrigated area of the farm, the type of network used, the salinity of the resource, etc.;
- f: is the functional form, to be specified, which determines the impact of the explanatory variables selected on the dependent variable y.

This multi-varied linear additive model is specified in Econometrics in the following general form:

$$y = x_1\beta_1 + x_2\beta_2 + x_3\beta_3 + \ldots\ldots\ldots\ldots x_k\beta_k + \varepsilon$$

The coefficients are chosen so that the explanatory variables in the equation reproduce the behavior of the explained variable y.

The variable ε is a residual term that balances the equation. It is necessary because there is no weighted sum of the explanatory variables that can reproduce exactly the real observations of water demand, observations after observations. However, studying the adjusted values of $\beta_1, \beta_2, \beta_3, \ldots\ldots\ldots\ldots \beta_k$, we may be able to deduce patterns in the data.

The Ordinary Least Square (OLS) method is widely used to fit the β_k

This method consists in solving the following optimization problem:

$$\underset{\beta_1,\beta_2,..\beta_k,}{Min} \sum_{n=1}^{N} [y_n - (x_{n1}\beta_1 + x_{n2}\beta_2 + x_{n3}\beta_3 + \ldots\ldots\ldots\ldots x_{nk}\beta_k)]^2$$

Where n is the number of observations in the database. The term "OLS" refers to minimizing the sum of squared differences $y_n - (x_{n1}\beta_1 + x_{n2}\beta_2 + x_{n3}\beta_3 + \ldots\ldots\ldots\ldots x_{nk}\beta_k)$. We call these differences «residuals» and the objective function:

$$f(\beta_1,\beta_2,....\beta_k)=\sum_{n=1}^{N}[y_n-(x_{n1}\beta_1+x_{n2}\beta_2+x_{n3}\beta_3+......x_{nk}\beta_k)]^2$$

the sum of squared residuals. When residuals are measured at their corresponding values to the least squares, they are called the adjusted residuals.

We will present in a somewhat more detailed way the simplest case of this model, namely when we have $k=1$ and $xn1=1$ for all n.

II. THE SIMPLE LINEAR MODEL WITH ONE VARIABLE

Either:

$$y=mx+b \qquad \textbf{(2)}$$

Where y and x are two variables on which we have real data collected by the survey.

- m: is a coefficient which represents the slope of the line, and
- b: is a constant.

These two coefficients should be estimated by using appropriate procedures and based on data observed for the two variables x and y.

In the terminology of the econometrician, this equation writes as follows:

$$y=\beta_0+\beta_1X_1+\varepsilon \qquad \textbf{(3)}$$

Where:

ε : is an error term (or residual) which indicates that the equation (3) becomes stochastic (approximate).

This model represents the form of regression of the overall targeted population, which in our context is the entire of the irrigators of the SASS area. For the sake of estimates, it is essential to have data on X (the price of water) and y (the volume consumed) for 100,000 irrigators of the Zone. We know it is very costly to collect information of this size. To estimate the coefficients of this relationship, we have developed in our case a representative sample of the population of 3,000 farmers.

The functional form becomes in the case of our sample:

$$\widehat{y}=\widehat{\beta}_0+\widehat{\beta}_1X+\widehat{\varepsilon} \qquad \textbf{(4)}$$

Where the $\frown$ on the coefficient states that the equation is estimated from the selected sample and not the real starting formulation which is reserved only for the mother population.

III. INTERPRETATION

Using the previous example:

$$\widehat{y}\,(Volume\ used) = \widehat{\beta}_0 + \widehat{\beta}_1 X\,(Water\ price) + \widehat{\varepsilon}$$

- If the price is zero, the volume consumed will be $\widehat{\beta}_0$.
- The interpretation of $\widehat{\beta}_1$ is slightly a bit more complex. If we have to establish a causal relationship between x and y, we will have:

$$\frac{dy}{dx} = \beta_1 \rightarrow \frac{d\varepsilon}{dx} = 0 \rightarrow E(\varepsilon/x) = 0$$

This condition means that there is no element in the residual term that has an impact on *X*. This means that x and ε are independent.

- The error term or residual $\widehat{\varepsilon}$, which is introduced into the equation (4) to show that the relationship is rather of stochastic aspect (random) and non-deterministic as in classical mathematics, is of paramount importance in econometrics that is why it is crucial to elaborate on its interpretation:
- This term summarizes information contained in the explanatory variables of the variable y, which have been omitted for various reasons (lack of data, unobservable variable, etc.).
- Since the data collected on the variables x and y are usually measured with some error, the residual term would summarize these errors.
- This error term also represents the erratic nature that characterizes the behavior of all economic agents. Indeed, it must be emphasized that in the social sciences it is impossible to accurately determine the value of the variable to explain even if we have exact values of the explanatory variables.

We will see that the selected model, to estimate the coefficients of interest in quantitative analysis, closely depends on the assumptions used to specify the nature of the error term.

For some observation on the operator i Equation 4 thus writes:

$$\widehat{y}_i = \widehat{\beta}_0 + \widehat{\beta}_1 + x_i + \widehat{\varepsilon}_i \qquad \textbf{(5)}$$

The residual term is:

$$\widehat{\varepsilon}_i = y_i - \widehat{y}_i = y_i - \widehat{\beta}_0 - \widehat{\beta}_1 X_i$$

The goal now is to determine the two coefficients $\widehat{\beta}_0, \widehat{\beta}_1$. The question that immediately arises is: How to estimate these two parameters?

The best known method and especially the most used by econometricians is to:

Minimize the sum of residual squared deviations[1].

$$Min \sum_i \varepsilon_i^2$$

This criterion is called in the econometric literature the residual sum of squares (Sum of Squares or SS).

3.1. Method of Ordinary Least Squares (OLS) and the quality of the fit

The OLS method is to accurately estimate the regression $\widehat{y}_i = \widehat{\beta}_0 + \widehat{\beta}_1 x_i + \widehat{\varepsilon}_i$. This

is to find the line that defines the best relation between x and y in the most appropriate manner. We have seen that the best procedure to achieve this would be to minimize the sum of squared errors of the deviations namely:

$$SSM = \sum \widehat{\varepsilon}_i^2$$

The properties to be provided by the OLS method are:

1. $\sum \widehat{\varepsilon}_i^2 = 0$

As illustrated in Figure 1, the actual observations are distributed above and below the fit line. Residuals are both negative and positive. This hypothesis therefore required that the sum total of these residuals is zero.

2. $\sum \widehat{\varepsilon}_i^2 x_i = 0$

This property means that the explanatory variables are independent of residuals. In other words there is nothing in the residual term that explains the variables x_i.

[1] We note here that other criteria can be used, we mention the most known among them: minimizing the sums of the absolute values of deviations.

3. $\overline{Y} = \widehat{\beta}_0 + \widehat{\beta}_1 \overline{X}$

This property implies that the point having as coordinates the average of y_i and the average of the x_i is located in the line of fit.

4. The residual terms are homoscedastic (same variance) and independent (no correlation). Formally, this property could be written as:

$$E(\varepsilon_i, \varepsilon_j) = \begin{cases} 0 & pour \ \ i \neq j \ \ i;j=1,2,........n \\ \sigma_\varepsilon^2 & pour \ \ i=j; \ \ i;j=1,2,........n \end{cases}$$

5. The residual term ε follows a probability distribution centered around the value 0 and having a finite variance σ_ε^2.

3.2. Procedure for estimating the coefficients $\widehat{\beta}_0, \widehat{\beta}_1$ of the line of fit

The deviations that represent the residuals () from the estimated line are positive or negative since the points (representing the actual observations) are located above or below the line of fit. If these residuals ($\widehat{\varepsilon}$) are squared then summed, the resulting quantity must be non-negative and will vary directly according to the distribution of these points around the line. Different value pairs for ($\widehat{\beta}_0, \widehat{\beta}_1$)... will provide different lines of fit and thus different values for the residual sum of squares around the line.

Thus we have:

$$\sum \widehat{\varepsilon} i = f(\widehat{\beta}_0, \widehat{\beta}_1)$$

The principle is that the OLS values $\widehat{\beta}_0, \widehat{\beta}_1$ must be chosen so as to make $\sum \widehat{\varepsilon}_i$, as small as possible:

The OLS method consists therefore in choosing β_0 and β_1 so that:

$$Min \sum \widehat{\varepsilon}_i^2 = Min \sum_{i=1}^{n} (y_i - \widehat{\beta}_1)^2$$

A simple minimization procedure, through the necessary and sufficient conditions gives the result very known to econometricians namely:

$$\beta_1 = \frac{\sum x_i y_i}{\sum x_i^2}$$
$$\widehat{\beta}_0 = \overline{Y} - \widehat{\beta}_1 \overline{X}$$

Before defining the quality of the fit, which is measured by R^2, it is essential to define two key quantities, i.e. SSM (*Sum of Square of the Model*) and TSS (*Total Sum of Squares*).

$$SSM = \sum \widehat{\varepsilon}^2 = \sum (\widehat{y}_i - \overline{y})^2$$

This expression indicates the explanatory power of the model. This is to give through this expression from the change in the variable y, to be explained, which is determined by the chosen regression.

$$TSS = \sum \varepsilon^2 = \sum (y_i - \overline{y})^2$$

TSS gives the total variation in the y_i while the SSM simply gives the variation explained by the model. Indeed, in the SSM the $\widehat{y}_i$ are the values estimated by the model while in the TSS the y_i are the true values in the population.

We will therefore have:

$$TSS = SSR + SSM$$

(Total Sum of Squares Y)	Sum of Residual Squares "Unexplained" by the model	Sum of Squares "explained" for the model chosen

The quality of the selected fit is thus measured by R^2:

$$R^2 = \frac{SSM}{TSS} = 1 - \frac{SSR}{TSS}$$

This measurement of the quality of the estimate varies between 0 and 1. The higher the value of R^2 the better is the fit.

IV. ILLUSTRATIVE EXAMPLE OF THE APPROACH ADOPTED

Consider a highly simplified example as an illustrative example: Estimate the price elasticity of water demand in the Tunisian SASS area.

4.1. Estimation of parameter (coefficients) and Interpretation

Thanks to the first surveying campaign, we dispose of the following information about the cost of water and the corresponding demand by the various farmers. Based on this information, we develop the following two variables:

- **Lwcmc** : log of the cost of water per m^3.
- **Lwha** : log of the consumption of water per hectare.

These variables are taken in a logarithm in order to obtain elasticities directly.

The estimated equation by **ordinary least squares method** is therefore:

$$Lwha_i = \widehat{\beta}_0 + \widehat{\beta}_1 Lwcmc_i + \widehat{\varepsilon}_i$$

The output of the estimate of this relationship by the OLS method using the STATA software is as follows:

```
Source |      SS              df            MS              Number of obs =    732
-------------+----------------------------                  F(  1,   730)    =  192.88(1)
     Model |      125.824376       1       125.82           Prob > F        =  0.0000(3)
Residual |        476.212694    30             .652         R-squared  =  0.2090
-------------+----------------------------                  Adj R-squared =  0.2079
       Total |    602.037069     731      .8235             Root MSE       =  .80768
------------------------------------------------------------------------------
        lwha |      Coef.       Std. Err.      t (2)        P>|t|      [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lwcmc |  -.4765187   .0343113   -13.89   0.000    -.5438792   -.4091582
       _cons |     7.34428  .1228789     59.77     0.000     7.103042    7.585518
------------------------------------------------------------------------------
```

Where:

(1) F(1,730) is the Fisher test.

(2) is the Student Test and

(3) is the p-value.

This gross output could be synthesized in a summary table of the most important results:

Water consumption per hectare per farmer focusing on the price of water only.

Variable Explained	Estimated Coefficients	Water consumption per hectare per farmer
Explanatory Variable		
Lwcmc (water cost)	$\widehat{\beta}_1$	**- 0.48 (0.000) *****
Cte	$\widehat{\beta}_0$	7.34 (0.000)***

N (number of farmer in the selected sample)		732
Adj R-squared (R^2)		0.21
F		192.88

*The P-values are in parentheses. ***, **, *: Statistically significant respectively at levels 1, 5 and 10%.*

Therefore, the equation as estimated is written:

$$Lwha_i = \widehat{\beta}_0 + \widehat{\beta}_1 Lwcmc_i + \widehat{\varepsilon}_i = 7.344 - 0.476\, Lwcmc$$

Interpretation of these results:

$\widehat{\beta}_0$ =constant = 7.344

$\widehat{\beta}_1$ = Elasticity price = - 0;476

- The constant here means that when the price of the water resource is zero, consumption amounts to 1,547 m^3. As our results are Log, to return to the real figure, we must take the exponential of the results found, that is:

  Exp (7.344) = 1,547 m^3.

- The coefficient $\widehat{\beta}_1$, that represents the price elasticity of water demand, means that when the price of the resource increases by 100%, demand decreases by about 48%. As we deal with survey data, special care must be taken in interpreting the real meaning of this result.

- If we dispose of time data on a farmer over a long period of time, then we can state that for an increase in water prices by 100% demand would fall by 48%.

- \- In our case, we have information relating to 732 farmers for the year 2011 only. The price of water does not vary from one year to another as in the previous example. However, it varies from one farmer to another. Indeed, our survey reveals the difference in behavior among the various irrigators. It is quite natural that each farmer will adapt his behavior according to his own situation. The irrigator who enjoys a low-cost water resource, because of the availability of a public network in his own zone that is highly subsidized by the state, will be less willing to adopt more efficient irrigation techniques. However, the farmer who is in a situation where he must mobilize his own resources using his own means only, is obliged to use it in a more parsimonious way. In this case, the interpretation of the price elasticity will be as follows: *When the resource price varies by 100%, water demand would differ by 48%. This means that if the price of the resource doubles from one farmer to another, the corresponding demand decreases by 48%.*

Note: *In the case of temporal data, we will speak of dynamic or temporal price elasticity. In contrast with individual data, as in our context, we speak of spatial price elasticity.*

4.2. Quality of the fit

Econometricians developed a set of measures to give an accurate idea of the quality of the results obtained.

Among these measures, we have selected those that are most used and especially that figure in the computer output namely:

- The coefficient of determination R^2
- The Fisher Test (F)
- The Student Test (t) and
- The p-value.

**The coefficient of determination R², ** is calculated based on the information provided by the software output, it is:

$$R^2 = \frac{SS(model)}{SS(total)} = \frac{125.824376}{602.037069} = 0.2090$$

In the Tunisian SASS zone, the price of the resource supported by the farmer explains by itself about 21% of the total variation in water consumption.

The Fisher test (or F test) is a statistical test used in the comparison of selected econometric specifications, allowing the identification of the model that best fits the population considered (all croppers in the SASS area) starting from a representative sample. In our case, this test has a value of 192.88.

The question that immediately arises is: how is this value obtained and especially what does it mean?

In our example, we estimated the following simple model:

$$Lwha_i = \widehat{\beta}_0 + \widehat{\beta}_1 Lwcmc_i + \widehat{\varepsilon}_i$$

To test the quality of the selected fit, we must therefore first calculate a correlation coefficient, noted $\rho_{lwha,lwcmc}$, between the two variables included in the model, namely LWHA and LWCMC. This coefficient measures the importance of the relationship between the two variables in question.

The quality of the fit test is carried out in four phases:

1. Establish the hypotheses to test:

$H_0 : \rho_{lwha,lwcmc} = 0$ There is no relationship between the two selected variables. That is the price variable (Lwcmc) has no impact on the demand for water (LWHA). It is then said that the two variables are uncorrelated or independent.

H_1 $\rho_{lwha,lwcmc} \neq 0$ Both variables are correlated, i.e. the price of the resource has a significant impact on its demand.

2. Statistical test, called the *Test F*, is then developed as follows:

$$F = \frac{R^2(k-2)}{(1-R^2)} \cong F_{1,k-2}$$

Where R^2 is the coefficient of determination, k is the number of observations in the sample and F_c is the so-called critical value.

This critical value of F obtained from our example is therefore:

$$F = \frac{R^2(k-2)}{(1-R^2)} \cong \frac{0.2090(732-2)}{(1-0.2090)} = \frac{152.57}{0.791} = 192.88$$

This corresponds exactly to the value given by the computer output.

3. Watch the critical value given by the statistical table *F* with the chosen threshold, the degree of freedom and the number of observations in the sample. In our example this critical value is:

$$F^*_{1,k-2}(\alpha) = F^*_{1,730}(0.01)$$

α : is the tolerated error threshold. This means that in our example the error threshold that we accept is only around 1%.

Note: In every econometrics or statistics work, there is a table of the law F that gives the critical Values of this distribution.

4. Decision rule:

If $F_C > F^*$ then we reject the null hypothesis H_0 (absence of a relationship and we accept the alternative hypothesis H1 which states that lwcmc and lwha are connected).

The Student test (t): This statistical test is a special case of the F Test. In fact, the F Test is used to test the quality of the overall quality of fit of the estimated model, whereas the t-Test is most commonly used to test the quality of fit of a single coefficient in the context of a linear regression.

- The goodness-of-fit is also indicated by the *value of p-value*. This value indicates the error threshold accepted. The higher this value is low, the better the quality of the fit. In our example this value to a critical threshold of 1% is 0.00001. This means that there is a probability of 0.00001 to determine the existence of a relationship between the two variables used while in reality there is no relationship between these variables.

V. EXTENSIONS INTEGRATED INTO THE ECONOMETRIC MODELING SELECTED WITHIN THE FRAMEWORK OF THIS ANALYSIS

The example introduced is a drastic simplification of the reality with a major concern of focusing primarily on the most important aspects of the basic econometric model. This highly simplified model will be replaced by more appropriate models that integrate all possible extensions to be close to the reality of the situation analyzed in this project.

We will put particular emphasis on issues of utmost importance to clarify the analysis conducted as part of this project.

- Remind the most simplifying assumptions of the model presented and especially emphasize the extensions introduced in econometric models on which is based the analysis used in the actual estimates.
- Make a special focus on the Specificities of the Estimate of the water price Elasticity through the survey data.

5.1. Extensions of the econometric model used

- The simple model that was just introduced is based on a single explanatory variable, namely the price of water. While in reality *the explanatory variables are rather multiple. The model used in this analysis is therefore the multidimensional general model* that will incorporate the most relevant variables.
- The model of the example assumes that the explanatory variable is *independent* of the residual variable that contains, among others, the variables omitted for the time being. In reality the explanatory variables are rather *correlated*, i.e. interconnected with the residual term.
- The model of the example assumes that all variables, both explained and explanatory, are accurately measured, while in the real world all variables are rather approximations, i.e., they are characterized by manifest *errors of measurements*. The model adopted will incorporate this aspect by using the Generalized Least Square method.
- The model of the example is *linear*, while the approached phenomena are inherently *nonlinear*. Fortunately, current advances in econometric methodology allow the integration of this reality into the estimates of selected parameters.
- The model of the example retains only *quantitative* variables while most of the variables observed in reality are rather *qualitative*. In recent years the econometrics of qualitative models of variables has witnessed enormous progress.
- The OLS used within the framework of the example introduced above assumes that the residual term follows a statistical law with *finite variance*. However, the reality of several economic phenomena is rather erratic characterized by an *infinite variance.*

With the latest developments in the econometric tool that helped to integrate all of the above extensions and important advances in the computing tool, the analysis conducted as part of this project was carried out with the main concern of grasping as much as possible the complexity of the reality on the ground. Indeed, thanks to the rich database developed based on data collected within the two investigative campaigns, quantitative analysis allowed grasping the user's behavior in terms of allocations of the scarce resource among alternative uses, both in their diversity through the vast space, such as that of the SASS zone, and in their dynamic over time thanks to successive survey campaigns.

Important Note: All estimates conducted as part of the quantitative analysis, detailed in the corresponding sections, are based on the most appropriate econometric models that explicitly incorporate all the complexities of the real world that econometricians are capable of grasping today.

5.2. Characteristics of the water price elasticity estimates through survey data

Given the crucial importance of estimating water price elasticity in the design of any sustainable management policy of water resources in the countries and regions that face dramatic lack of this resource such as the vast SASS area, and especially the difficulty of achieving this, it is not surprising that the researchers involved were prepared to resort to any kind of data available.

The ideal would be to have a time series of real water prices as well as the corresponding demand, extending over a period of many years. Thus, it would have been possible to estimate the actual responses of real users in terms of volume in demand for an effective increase in prices over time. Unfortunately, in developing countries, such data are rarely available. However occasional surveys exist in many countries and regions concerned. These surveys often contain information that could help derive price elasticities that are considered indispensable.

The survey conducted throughout the SASS zone, which covers 3,000 farms, contains information about the spatial distribution of water costs per m3 and per farmer. If this valuable information is retrieved in a usable way; it would be possible to estimate the change in water demand due to a change in cost/m3. All the estimates presented in this project are therefore based on spatial data that is why the price elasticities reflect the change in farmers' water demand due to different costs of the mobilized resource.

SASS III

SOCIO-ECONOMIC ASPECTS OF IRRIGATION IN THE SASS BASIN

The North-Western Sahara Aquifer System (SASS) is a basin of over 1,000,000 km^2 shared by three countries (Algeria, Tunisia, Libya) whose water reserves are substantial with an almost fossilized aspect.

Previous studies on the SASS had focused on the characteristics and operation of the aquifer as well as the evolution of abstractions, but rarely on the valuation of the water. Phase III of the SASS project aims to restore this equilibrum by promoting the sustainable management of water resources which is the most limiting factor to any stable economic activity.

This study related to socioeconomic aspects of irrigation represents one of the two main components of the SASS III project. It aims to enrich the achievements of the hydrogeological knowledge of water resources through socio-economic and environmental data. It analyzes the operation of farms and especially the actual behavior of the irrigators with particular emphasis on ability to adapt to the challenges that threaten the sustainability of the develpment.

The analysis of surveys done on 3,000 farmers helped identify the main constraints to water productivity, but also to quantify the scope of their economic impact and to make recommendations to enhance the value of the resource.

ANRH DGRE GWA

ISBN : 978-9973-856-85-2

Sahara and Sahel Observatory
Bd du Leader Y. Arafat, BP 31, 1080 Tunis Carthage, Tunisia
Tel. : (+216).71.206.633 - Fax : (+216).71.206.636
URL : www.oss-online.org - Email : boc@oss.org.tn