EFFICIENCY ANALYSIS OF IRRIGATION WATER DEMAND INSTITUTIONS IN TUNISIA

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LIST OF MAIN ABREVIATIONS

APIA: Agence de Promotion des Investissement Agricoles

CRDA: Commissariat Régionale de Développement Agricole

CRS : Constant Return to Scale

DGRE: Direction Générale des Ressources en Eau

DGTH: Direction des Grand Travaux Hydrauliques

DEA : Data Envelopment Analysis

FJ: Fondok Jdid

FE: Farming Efficiency (Technical Efficiency)

GIH: Groupement d'Intérêt Hydraulique

IWUE: Irrigation Water Use Efficiency

LB: Lebna Barrage

MARH: Ministère de l'Agriculture et des Ressources Hydrauliques

OMVVM:

O&M: Operation and Maintenance

PR: Property Right

SE: Scale Efficiency

TND: Tunisian Dinar

VRS: Variable Return to Scale

WMP: Water Master Plan

WTP: Willingness To Pay

WUA: Water Users Association

WUE: Water Use Efficiency

Chapter 1. General Introduction and problem statement

1.1. Introduction

1.1.1. Towards world water shortage

Water scarcity, in both its quantitative and qualitative manifestations, is now emerging as a major development constraint in many countries. In countries fast approaching their physical limits for fresh water mobilization, the quantity of water available is of key concern. In other countries where water availability is less of an issue, the quality of water for urban, industrial and other economic uses is a major concern. Considering the economic, environmental and social dimensions of water, its scarcity has to be viewed in a much broader sense as a significant threat to human wellbeing. Two people in five lack proper sanitation facilities, and every day, 3 800 children die from diseases associated with the lack of safe drinking water and proper sanitation (UNESCO, 2006). In this sense, the complex interdependencies between water resources and food production have also been referred to, in recent years, as an evolving global food crisis (Hightower and Pierce, 2008; Lundqvist *et al*., 2008). In fact, the total world population is expected to grow by around 40% within the 50 next years (UNDP, 2005). During the same period, the average per capita income is also expected to rise. These two factors implicitly indicate a substantial increase in water and food demand due to more water-intense lifestyles and diets.

Whilst the nature and severity of water shortages differ from country to country, one aspect is common to most countries: water scarcity (whether quantitative, qualitative, or both), is mainly the result of inefficient use and poor management (Saleth and Dinar, 2004). From this perspective, agricultural water management is the first to be suspected due to the large amount of water consumed by this sector for irrigation purposes.

Agriculture uses around 70 percent of all freshwater withdrawals worldwide. According to the Northoff (2003), rain-fed agriculture accounts for 60% of food production in developing countries on 80% of arable land. Only 20% of arable land in developing countries is irrigated, but it produces around 40% of all crops and almost 60% of cereal production. The contribution of irrigation to world crop production is expected to increase in future decades: the irrigated area in developing countries is expected to increase by 40 million hectares (20%) by 2030. This represents less than half of the increase over the past 35 years (99 million hectares). According to the same source, the reasons for this lower level of increase are principally due to the shortage of suitable areas for developing irrigation in some countries, in addition to the required increase in investment costs for irrigation infrastructure.

Agriculture will also have to compete with other sectors, in terms of water use, if market mechanisms have free play. Most of the water savings needed to meet growing urban and industrial water demand would have to come from the agricultural sector, not only because irrigation uses the highest proportion of total water, but also because it has considerable potential for efficiency improvement. Modern irrigation schemes can achieve projected efficiencies of around 65%, whilst the currently abundant traditional schemes have an efficiency of only 35%. Assuming a typical situation, where 80% of total water use goes to agriculture, a 10% increase in irrigation efficiency would provide 50% more water for urban and industrial use (Abu-Zeid and Hamdy, 2002). This illustrates the potential for water savings in agriculture and their impact, thereby stressing the need to act in this direction.

1.1.2. Water demand management

Thus, the poor levels of water management observed in many developing countries, where water scarcity is a major constraint, raises our hopes that the crisis can be averted by improving water use and management. Nevertheless, achieving the necessary improvements is no easy task. It requires a deep consciousness and motivation by policy makers towards changing the way in which water resources are developed, allocated and managed. The design and implementation of these changes, in order to obtain an expected outcome in terms of sustainable water use, has been a major concern for research in the field of water economics during recent decades.

The scale issues involved in the exploitation of water resources justified its public ownership and state involvement in its development, distribution and management. However, with the end of the water supply era, in most countries around the world, and the increase in mobilization costs for new irrigation projects, this arrangement was shifted towards a more decentralized one. In fact, water scarcity becomes economically binding and the magnitude of water-related subsidies, including administrative overhead costs, becomes fiscally constraining (Saleth and Dinar, 2004). The social costs of public water management are beginning to exceed the corresponding social benefits. As a result, a trend towards a water demand management (WDM) approach, with more private participation in decision making for water allocation and management, is being instituted.

Water demand management (WDM) emerged as a strong complementary alternative to the water supply policies of recent decades. WDM can be understood as a collection of technical, regulatory and market tools, including, to a lesser extent, non-market mechanisms designed to promote more efficient levels or patterns of water use (Wolfe, 2006). More explicitly, the objectives of WDM could be one of the following three things (Brooks, 2003): Improve the efficiency of water used to accomplish a specific task; Adjust the nature of the task or the way it is undertaken so that it can be accomplished with less water or with lower quality water; Minimize the loss in quantity or quality of water as it flows from source, through use, to disposal. Today economic incentives, water pricing policies, decentralization and public participation, as well as education and information strategies, are powerful WDM tools, making this option a more economically effective alternative to meeting increasing demand and resource scarcity (Westerhoff and Lane, 1996; Baumann *et al.,* 1998; Mylopoulos and Mentes, 2000).

Many irrigation management transfer programmes started in recent decades through government initiatives. The introduction of these programmes was intended mainly to stimulate the efficient use of the resource through user participation (Groenfeldt, 2003; Vermillion, 1997; Svendsen, 1992; Ostrom, 1992). According to Vermillion (1997), the motivation often used to justify irrigation management transfer policies is that: (1) government bureaucracies lack the incentives and responsiveness, whilst farmers have a direct interest in increasing and sustaining the quality and cost-efficiency of irrigation management; (2) this will normally enhance the profitability of irrigated agriculture sufficiently to offset the increased cost of irrigation to farmers; (3) the government will also save money as it divests itself of the responsibility for financing the routine operational and maintenance costs of irrigation systems. The savings can be reallocated to other functions that cannot be handled or financed directly by the private sector.

The decentralization process requires most of the time some judicial, political and administrative reforms to establish formal user groups known as water users associations (WUAs). The reforms need to create formal rules and procedures for the allocation and collection of fees. (Knox and Meinzen-Dick, 2001). The WUAs constitute the heart of devolution programmes, where rights and responsibilities are transferred to a common local level, supervised and managed by a WUA. In a number of countries, WUAs are primarily concerned with the management of either entire small-scale irrigation projects, or local sub-systems within large-scale irrigation schemes. The main factors that have helped in the design of WUAs, have been drawn from research into traditional small-scale farmer-managed irrigation schemes during the 1980s (Ostrom, 1990; Wade, 1988).

However, the actual outcomes of these devolution programmes in various countries have been mixed. The objectives of achieving positive impact on resource productivity, equity, full cost recovery and environmental sustainability are not always met. In fact, these associations disappear in many cases once the donor’s financing programmes come to an end (Vermillion, 1997). In other cases, they are unable to achieve full cost recovery for the irrigation water to cover their operational costs or induce more efficient use of the resource. In some other cases, institutional reforms were established with the unique objective of collecting water fees and alleviating the charges supported by governments. For instance, Wilder and Lankao (2006) found that the outcomes of decentralization of water management in Mexico was context specific (neo-liberal reform strategy) and marked by a limited benefit. It has not resulted in efficiency or sustainability gains[1]. This failure to ensure a better performance in resource sustainability could be due to many institutional failures. The main problems relate to the transfer of property rights and to the internal organisation and functioning of the associations. These factors are, in fact, amongst the main incentive elements for farmer participation and long term sustainability.

[1] In fact, whether governments truly engage in participation or use it simply as a part of symbolic policy is a key question in the literature on participatory governance (For more details see Saleth and Dinar, 2005; Larson and Soto, 2008; Howard, 2008).

From this perspective, it would be interesting to look at the efficiency of the institutional reforms established and to provide recommendations as to their optimal functioning to maximize the social and economic value of water resources.

1.1.3. Governance and water demand management

Much of the recent literature has focused on the public response to changes in regulation and market tools (mainly pricing policies) of the WDM approach, whilst only a few studies have examined decision-makers' ability and willingness to adopt, implement and sustain WDM initiatives (Wolfe, 2006). The effect of WDM non-market tools, which attempt to improve the efficiency of water use by providing information and instilling a sense of individual responsibility for conservation, was rarely covered in the WDM literature (Gumbo *et al.*, 2003; Gumbo *et al.*, 2004; Howarth and Butler, 2004). We know more about technologies for water demand management than we apply, and we have very little knowledge on how to best promote changes in habits and behaviour at the local level (Brooks, 2004; Wolfe, 2006) or on the effect of this behaviour on the implementation and effectiveness of WDM tools.

Recent studies, call for a new approach which considers WDM tools as a larger part of the water demand approach and in which more emphasis is placed on improvements to the governance structure and decision making process, along with support for technical, economic and legal aspects. In fact, technical, economic and legal issues are determined by (not determinants of) the way in which water is governed (Brooks, 2004). Strong governance of water will then result in better monitoring of the various technical, economic and legal determinants of water management.

Irrigation governance is a key concept in this dissertation. Particular focus is given to showing its importance in enhancing the outcome of water demand management institutions in Tunisia. The governance structure is considered in the dissertation as the set of systems that control decision making with regard to water management and water service delivery (Moriarty *et al.*, 2007). It is assumed that it comprises the technical, economic, administrative, financial and social aspects of local irrigation water management (Brooks, 2004).

1.2. Looking at the water sector from an institutional perspective

In this dissertation we investigate the efficiency of some WDM tools, and more specifically the institutional ones. We analyze the importance of institutional performance as key to the success of water resource management. The overall objective is to show that water management institutions not only exist, but also influence and shape the dynamic of the irrigation water sector.

This requires a well adapted and consistent theoretical framework, able to entrench the necessary concepts, definitions and hypotheses. Consequently, we intend to use the new institutional economics (NIE) framework as the theoretical basis for this study. The advantage of NIE over neoclassical theories is its aptitude to explain what institutions are, how they arise, what purposes they serve and how they evolve and can be reformed. Literature on NIE is increasing rapidly and combines economics, law, organization theory, political science, sociology and anthropology to understand social, political and commercial institutions and to accurately reflect human behavioural attitudes to resource management.

1.2.1. Definitions and approaches

1.2.1.1. Neo-classical and New Institutional Economic theories

New institutional economics is an attempt to incorporate a theory of institutions into economics (North, 1992). Within the NIE framework, incomplete information and limited individual cognitive capacity by which the available information is processed, will determine the cost of transacting. “The costs of measuring the multiple valuable dimensions of the goods and services exchanged or of the performance of agents, and the cost of enforcing agreements determine transaction costs” (North, 1992). Transaction costs are a driving factor for the formation of institutions.

Ronald Coase (1937, 1960) was the first to establish a direct and clear link between institutions, transaction costs, and neo-classical economics. According to the neo-classical theory, efficient market equilibrium could be obtained only in a situation where transaction costs are very low. When transaction costs arise, institutions become necessary components of the national economy. Hence, institutions (and specifically property rights as argued by Coase) are crucial determinants of market efficiency. According to North (1992), NIE fits within neo-classical economics but also modifies or extends it. NIE starts from the fundamental assumption that scarcity leads to competition; it also views economics as a theory of choices subject to constraints; it employs price theory as the main approach for the analysis of institutions; and it considers changes in relative prices as a major force inducing institutional change. But, NIE modifies the rationality postulate which constitutes the basis of neo-classical economics; it adds institutions as a constraint and analyses the role of transaction costs, induced by this constraint, as the connection between institutions and production costs. Finally, NIE extends economic theory by incorporating ideas and ideologies into the analysis, modeling the political process as a critical factor for explaining inefficient markets.

As the name indicates, institutions are central to all NIE theories. In fact, there is no universal definition of institutions in the literature. From a game theory perspective, institutions could be defined, for example, as the equilibrium of players' strategies, or as the rules of the game itself. Many other definitions were based on the theory of transaction costs. We hereby seek to provide the main existing and more relevant definitions of institution.

In a very restrictive and simplistic sense, institutions could be defined as an agreement between two agents (Ménard, 2003). Most research in the field of law and economics refer to the definition provided by North (1991) who considers institutions as the humanly devised constraints that structure political, economic and social interaction. According to North, they consist of both informal constraints (sanctions, taboos, customs, traditions, and codes of conduct), and formal rules (constitutions, laws, property rights). Together with the standard constraints of neo-classical economic theory, they define the transaction costs of exchange as well as the production costs. From a game theory perspective, formal rules are the ones which cannot be changed or modified by players during the game, and need to be determined before the game starts. They give incitation to players who seek the best way to behave in order to maximize their revenue, given the formal rules. New rules will be demanded and will emerge when relative prices (payment functions) change. These rules will be negotiated and fixed on the "political market", which is structured according to the political rules in a given country.

Following this general definition of institutions, water institutions could be defined in this dissertation as "rules that together describe the action situations, delineate the action sets, provide incentives and determine outcomes, both in individual and collective decisions relating to water development, allocation, use and management" (Saleth & Dinar, 2005). The state of resource sustainability is then dependant, amongst other things, on the state and performance of these institutions.

1.2.1.2. Approach to the institutional analysis of water institutions

The basis of NIE and of this dissertation is the three-layer scheme of institutions described by Williamson (1996). The first level of institution in the three-layer scheme operates as the *institutional environment* and is also called "*the rules of the game*", the *constitutional level*, or "the *governance framework*". The second level works as the *institutions of governance* and constitutes the locus of transactions. The second level is also called "the *governance structure*". In the third level individuals make decisions as to the allocation of resources and individual or collective participation in the other levels. Decisions made by individuals on the third level of the three-layer scheme of NIE, are conditioned by their endogenous preferences and behavioural attributes and also by the environment in which these endogenous preferences are the product of social conditioning.

In water resource management, it is very important to distinguish between these three layers since the institutional environment, which is generally designed by policy makers at the constitutional level, has a strong effect on resource access, allocation and use. It provides a set of incentives which deeply determine and affect the individual behaviour of irrigators. It is also important to study the governance structure for irrigated schemes at the local level where the main policy guidelines and individual preferences interact. Finally, it is crucial to consider the individual level where the final outcomes of the water management institutions are observed.

1.2.2. Methods for analyzing the efficiency of water institutions

In addition to the distinction between the three-layer institutions scheme discussed above, the analytical approach in this dissertation is based on three main successive stages: decomposition of the water institutions into components, selection of the efficiency criteria and, finally, the application of an efficiency analysis to obtain a comparative institutional analysis.

Institutions were sometimes treated as single entities but, in reality, they are made up of analytically and functionally distinguishable components and elements (Shalet and Dinar, 2004). This interaction between institutions makes it difficult to isolate and to evaluate the effect of separated institutional components from other interlinked and nested components. The analytical approach most used to overcome this problem is to decompose institutions into major components. In this dissertation, we adopt the institutional water sector decomposition provided by Saleth and Dinar (2004) which distinguishes water law, policies, and administration as the main three institutional components of the water sector.

The concept of efficiency used in this dissertation is that of NIE, which relates efficiency to performance (Herrera, 2004). Our approach to the efficiency analysis starts with the identification of efficiency criteria against which the assessment is made. These “non-accomplished” criteria will allow us to qualify the competence of the particular institution under analysis. In the case of irrigation, Ostrom (1992) argues that the key criterion is sustainability. This can in turn open a range of criteria (e.g. efficient use of water, financial viability of irrigated systems, etc.) that may be considered for assessing the efficiency of specific institutions. In this dissertation, the focus will be on specific institutional aspects that are considered as the most important in a demand-oriented water management strategy. These are the local administration and organization of irrigation water management, the price regulation, and the irrigation property rights.

Concerning the efficiency analysis methodology, most of the studies use “comparative institutional analysis” (Coase, 1960) for the comparison of institutional environments and institutional arrangements. Comparative institutional analysis makes recommendations for the selection of the most efficient institutions and clarifies the required institutional design and change. In this dissertation, comparative water institutional analysis is used as the main foundation for the empirical validation.

1.3. Research questions, objectives and hypothesis

1.3.1. Research questions

Considering the importance of the topic, and the urgent need for solutions to manage water more efficiently in agriculture, many questions arise regarding the way in which irrigation institutions exist, function, shape and influence the performance of irrigation activity:

- What can really be considered as an irrigation institution?
- How can the performance of irrigation institutions be assessed?
- What are the main institutional components and layers of the irrigation water sector?
- How are these institutional components implemented, structured, and how do the interactions between them work?
- How we can assess the effect of irrigation institutions on individual behaviour and performance of the irrigated systems?

1.3.2. Objectives

Having delineated the approach and the context of the study, we can now state its general objective as follows:

- To show that an improvement of agricultural water use efficiency is possible if institutions for irrigation water demand management would perform better.

According to this, and given our specific case study, we can state the following specific objectives:

- To give an overview of the different notions of water institutions, their layers, components, aspects, and interactions;
- To provide an overview of the most important frameworks for the efficiency analysis of water institutions;
- To divide water institutions into their main layers and components;

- To analyze the implementation, functioning, and interactions between the main institutional components of the irrigation water sector;

- To measure individual water use efficiency, water economic values, and water demand, in different contexts, as indicators of comparative institutional performance;

1.3.3. Hypothesis

The following is a list of hypotheses that are to be tested in the development of this dissertation:

- Irrigation institutions such administrations, regulations, prices, and property rights institutions exist, matter, influence, and determine the performance of water management in agriculture;

- Performance of these irrigation institutions could be assessed through “institutional decomposition” and “comparative institutional analysis” frameworks;

- An improvement in the design, structure, and functioning of these irrigation water institutions can lead to a better valorization and sustainability of water resources;

- Individual perceptions and outcomes can be used as indicators for the assessment of irrigation institutions’ efficiency;

1.4. Research design and delimitation

1.4.1. Case study: the Tunisian context

Tunisia is a southern semi-arid Mediterranean country with limited and variable rainfall. Irrigation has been practiced in Tunisia since the Roman era. When new fruit species and substantial expertise was brought into the region by Arabs, irrigation was widely applied and led to a prosperous period (Ben mechlia, 2004). The development of large irrigation schemes increased sharply during the second half of the twentieth century. Since independence of the country in 1956, the objective in Tunisia was to develop irrigation infrastructure and to control renewable water resources to increase the stability of the water supply. Rapidly, it completed the mobilization of its renewable resources and stretched the use of irrigation water to the maximum (Ben mechlia, 2004). In 2030, the overall water demand in the country is expected to exceed its supply (Ministère d'Agriculture et des Ressources Hydrauliques (MARH), 1998).

Since the maximum water supply capacity has almost been reached, the objective of policy makers has shifted towards WDM in order to rationalize irrigation water demand and to improve the efficiency of water use at farm level. Many institutional and organizational changes have been introduced for WDM since the 70's. Decentralization, through the creation of water users' associations (WUA, also called in Tunisia: Goupement de développement agricoles 'GDA'), pricing policies and encouragement of private participation were amongst the main reforms adopted by the government in this new context. With the current growing demand for irrigation water due to the extension of irrigated lands, and competition by other sectors for water resources, better performance in terms of agricultural water use efficiency and valorization in Tunisia are both needed. Despite the fact that the implemented institutions already contributed positively to significant results in terms of resource management, many (Chebil *et al.*, 2007; Makkaoui, 2006; Ben salem *et al.*, 2005; Chraga and Chemakh, 2003) believe that further progress could be achieved by improving their structure and functioning. Our work is then situated in this context, were, as stated in the previous section, we aim to show that a large potential for improvement of the irrigation water use efficiency exists in Tunisia if institutions for irrigation water demand perform better.

In Tunisia, irrigation is the most highly developed in the governorates of Nabeul (North East of Tunisia), Kairouan (Center) and Sidi Bouzid (Central West). However, Kairouan and Sidi Bouzid are considered as agricultural-oriented governorates; whereas the tourism and manufacturing sectors are widely developed in the governorate of Nabeul, which increases pressure on water resources in this region. Also, agriculture in Cap Bon region is very diversified (tree crops, horticultural productions, cereals, etc.). For these reasons, we choose this region for the rest of our empirical applications.

1.4.2. Delimitation of the study

Water use efficiency could be enhanced in all sectors such the domestic, touristic, and industrial ones. The current work is only limited to the study of the usage of water in the irrigation sector in

Tunisia.

Irrigation management institutions are widely different and include many aspects. In this study, although most of these institutional aspects will be described in first introductive chapters, we limit our empirical investigations on three main institutional aspects which are: water users' associations functioning and governance, water pricing policies, and water property rights.

1.4.3. Research methodology

Specific methodologies were developed and used in each of the empirical chapters where we tested specific hypotheses. In each of these chapters, a methodology section describes the models used and their adaptation to our empirical validations.

1.4.4. Data

Two types of data are used in the research methodology of this thesis:

- Secondary data concerning 45 WUAs, this constitutes all the WUAs operating in the Cap Bon region. This database is collected by and centralized at the Ministry of Agriculture and Hydraulic Resources of Tunisia. It contains information about technical, administrative, and organizational characteristics and costs of each WUA.

- Primary data collected from 62 randomly selected farmers belonging to the Fondok Jdid and Lebna Barrage neighbouring areas in the Cap Bon region. Each area is managed by one WUA. The dataset includes 18.7 % (30 farmers) and 30 % (32 farmers) of the total adherent farmers to FJ and LB WUAs. This primary data was collected during the period March-May 2007. It is our main dataset and is used in most of the empirical chapters of this thesis.

- Primary data collected from 47 farmers who own 16.2 % (97.6 ha) of the total irrigated land area and hold 13.8 % (276 greenhouses) of the greenhouses located in the region of Teboulba (2060) (Central East). This data was collected in October 2005, and is used in this study only for the calculation of water use efficiency. The reason of its use is to provide a more diverse overview of irrigation water use efficiency in different Tunisian regions.

1.5. Dissertation outline

The dissertation consists of nine chapters, organized into three parts. The first part contains the second chapter outlining the conceptual and analytical approach used. In this chapter, the literature regarding institutional decomposition and performance analysis is discussed. We adopt the decomposition of water institutions into water law, policies, and administrations. We use this decomposition for the rest of the empirical applications by focusing on specific aspects from each of the latter components.

The second part of the dissertation describes the governance framework and structure for the irrigation water sector in Tunisia. It is divided into three chapters: chapter 3, 4 and 5.

Chapter 3 and 4 provides an overview of the water institutional environment in Tunisia from a formal and a macro perspective. In chapter 3, the availability of physical water resources, water uses and demands and the importance of the agricultural and irrigation activities in Tunisia are provided. In chapter 4, water laws, policies, and administrations supporting the irrigation sector in Tunisia are presented.

Chapter 5 describes the study of the governance structure and more precisely the water users' associations. The description is supported by a quantitative analysis of local WUA efficiency. In this investigation, overall, management, and engineering efficiencies of a set of 45 WUAs belonging to a homogenous agricultural region are calculated and interpreted. Determinants of these WUA efficiencies are also discussed.

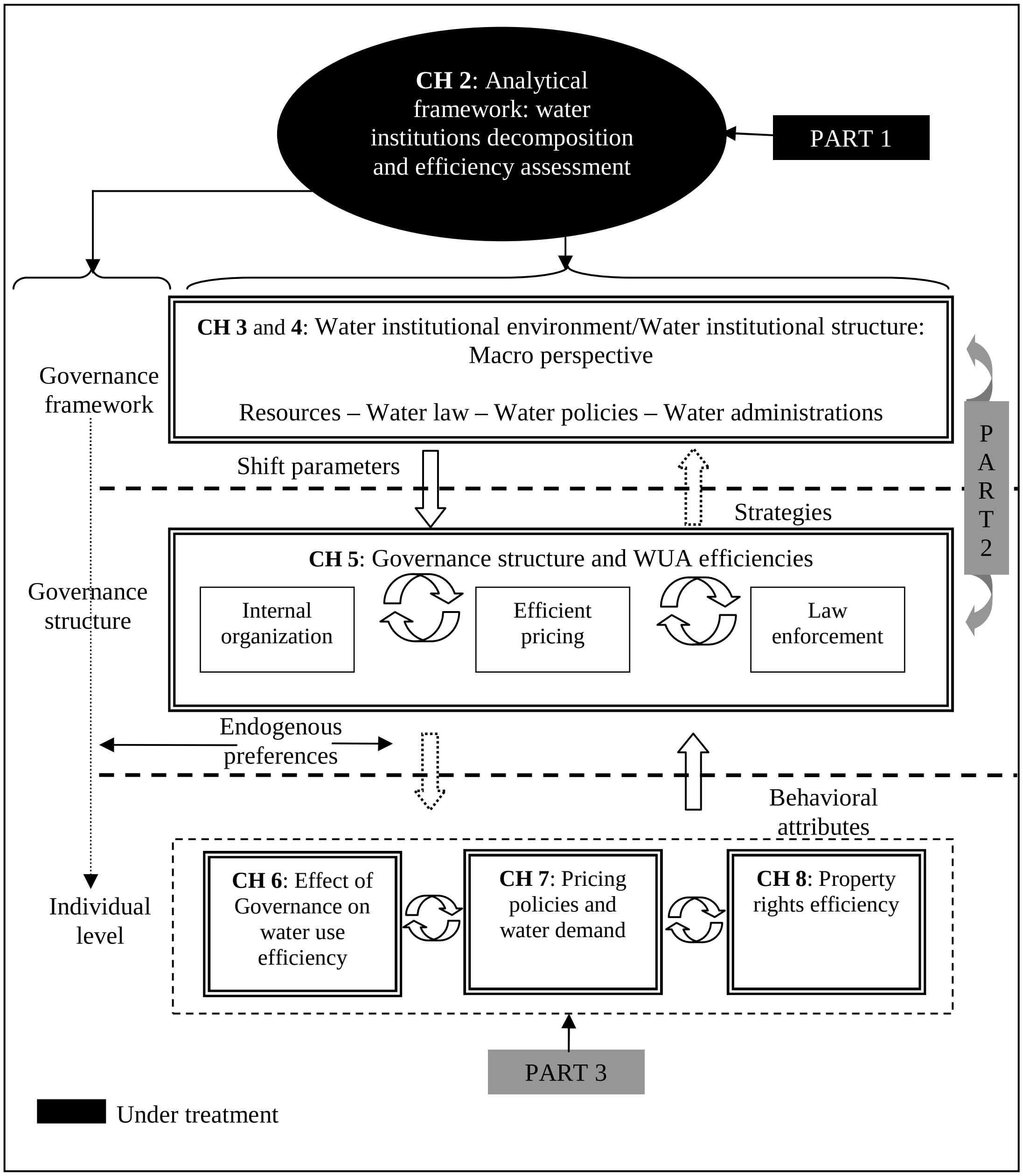
The third part of the dissertation is concerned with the implications of WUA efficiency on individual performance. Effects of WUA administration and organization, pricing policies and transfer of the "individual usage right" on farmers' irrigation water use efficiency, irrigation water demand, and economic valuation of the resource will be respectively undertaken in three chapters.

Two WUAs from this latter set identified in chapter 5 are selected. These are supposed to have the same physical and institutional governance framework, but differ in terms of their governance structure - which is assumed in this thesis to be implicitly qualified by the performance of the WUA -. In fact, one of the selected WUAs is efficient with respect to technical management whilst it is very weak in terms of its management efficiency. The second WUA has opposite performances. These efficiency qualifications are estimated from WUA relative efficiency scores calculated in chapter 5. A set of randomly selected farmers was surveyed from each WUA.

Chapter 6 of the dissertation discusses whether there is any relationship between the governance structure in each WUA, and the farmers' water use efficiency calculated at the farm level.

In chapter 7, pricing policy formulation and its effect on farmer's input demand functions will be examined. The current pricing policy in Tunisia - based on increasing volumetric prices, whilst encouraging and subsidizing the adoption of water saving technologies in order to enhance the capacity of farmers to pay higher prices - will be discussed.

Finally, chapter 8 investigates the efficiency of individual irrigation property rights. The effect of the quantification of individual "water access rights" and "water delivery rights" on farmers' economic valuation of water resources in the study area, will be assessed. Chapter 9 concludes the dissertation.


CH 2: Analytical framework: water institutions decomposition and efficiency assessment
PART 1
CH 3 and 4: Water institutional environment/Water institutional structure: Macro perspective
Resources – Water law – Water policies – Water administrations
Governance framework
Shift parameters
Strategies
P A R T 2
CH 5: Governance structure and WUA efficiencies
Internal organization
Efficient pricing
Law enforcement
Governance structure
Endogenous preferences
Behavioral attributes
CH 6: Effect of Governance on water use efficiency
CH 7: Pricing policies and water demand
CH 8: Property rights efficiency
Individual level
PART 3
Under treatment

Chapter 2: Analytical framework: Water Institutional Decomposition and Analysis (IDA)

Abstract

This chapter provides a discussion of the analytical tools that will be used for the decomposition and efficiency assessment of irrigation water institutions[2] in Tunisia. A first analytical step in the institutional evaluation process is decomposition. Institutions have to be decomposed into their components, which can be studied separately, and between which links can be established. The second step concerns the investigation and analysis of the institution-efficiency relationship. In this analytical step, first, institutional performance criteria have to be selected. Then, appropriate methodologies are required that are able to use these performance criteria in an integrated evaluation process. In the dissertation, an analytical framework was developed based on the "Institutional Analysis and Decomposition" framework of Saleth and Dinar (1999, 2001, and 2004). Water institutions are decomposed into three main components (water law, water policies, and water administration). Then, three institutional aspects (one for each component) were selected; these are: irrigation water property rights for the water law component, pricing policy and cost recovery strategy for the policy component, and functional, regulatory and accountability capacities of the local water organizations for the administration component. Also, in line with Williamson (1996), three institutional levels were considered in the framework: macro level, governance level, and individual level. The efficiency of the considered institutional aspects will be assessed at each of these levels. Special attention was given to the analysis of the individual level since we assume that the final institutional-performance outcome is "produced" at this level.

[2] In the remaining text, "irrigation water institutions" refers to the specific irrigation water demand management institutions. These will be identified and described further in this chapter.

2.1. Introduction

The mobility of water, high measurement costs, distributional disputes, and public good claims, make it difficult to manage and structure usage (Libecap, 2005). Thus, water institutions are difficult to design and differ widely between countries and regions. This complexity and diversity of institutions within the water sector raises many questions that unfortunately, are not always resolved. For instance, institutional analysis and performance assessment remain the most critical issues for research. Existing literature on the subject (both theoretical and empirical) provides little guidance to capture the various layers of institutional inter-linkages and institution-performance linkages (Saleth & Dinar, 2005). According to the latter authors, the focus is either too narrow to consider water institutions as a whole, or too descriptive or anecdotal to provide any quantitative evaluation.

Measuring institutional performance is related to the quantification of behaviour, rules, norms, and so on, and the analysis of their effects on individual and socially desired outcomes. Thus, the first question to arise here is: how rules or norms of behaviour perform? In fact, institutions do not directly make up for the efficiency of water resource management, but their presence and attributes influence its performance by drawing a general pattern of individual behaviour and collective choice. Therefore, the performance of institutions can be evaluated in an indirect way by analyzing their impact on the state of the resource, on the efficiency of the resource use and on individual/collective well being. However, institutions operate as a system characterized by intricate and multiple layers of relationships. Analyzing institutions as individual entities will provide biased information concerning their performance. In reality, institutions are made up of analytically and functionally distinguishable components and elements (Shalet and Dinar, 2004). As a result, it is necessary to isolate and to evaluate the effect of individual institutional components from those of other interlinked and nested components. This remains, however, a difficult task.

A next critical step in the evaluation process is the identification of appropriate performance criteria and methodology. Performance criteria could be considered as socially and individually desired objectives according to which the institutional efficiency assessment is done. A comparative institutional methodology is mostly used in the institutional economics literature. In fact, the identification of characteristics of successful institutional settings through comparative institutional analysis is very relevant for institutional-performance analysis. However, this approach can also be questioned, since a successful institutional setting in a specific context can fail in another context. Therefore, the institutional comparative analysis is a risky exercise that has to be undertaken very carefully.

This chapter's purpose is to provide an adapted analytical framework which can be a foundation for the evaluation methodology of irrigation demand management institutions in Tunisia. It is divided into two main parts. In the first part a literature review is presented regarding institutional decomposition and performance assessment. In the second, we discuss the analytical framework designed for efficiency analysis of some selected-irrigation institutional aspects in Tunisia.

2.2. Literature overview: water institutions decomposition and performance assessment

2.2.1. Water institutions

Following the general definition of institutions (Bromley, 1989; Ostrom, 1990; North, 1990), water institutions can be defined as "rules that together describe action situations, delineate action sets, provide incentives and determine outcomes both in individual and collective decisions relating to water development, allocation, use and management" (Saleth & Dinar, 2005). According to our knowledge, this is the most comprehensive definition of "water institutions" found in the literature. Most of the studies concerning irrigation institutions generally relate to a unique specific institutional aspect, such as irrigation property rights, water organizations, decentralization, private participation, prices, etc. Such research does not consider the complexity of the institutional scheme and the various linkages existing between the different institutional components.

Rules, mentioned in Saleth and Dinar's (2005) definition, can be both formal and macro as well as informal and micro. They constitute a structurally linked configuration (*institutional structure*) embedded within a given social, economic, and cultural context (*institutional environment*) (Saleth, 2005). Water institutions are considered as part of a larger institutional system covering other resources and sector-specific institutions. They have intricate functional linkages with land, agricultural, and environmental institutions and they could also be involved with other economic, political, and social institutions.

The interface between institutional structure and institutional environment (what Wallis and North, (1986) called “transaction sector”) is a valuable indicator for the formalization level of the water sector (Shah, 2005). This level of formalization mainly depends on the degree of integration of the water sector in the economy. Informal water economies, for instance, are marked by heavy dependence of water users on self-provision (wells, streams, etc.) and informal community-based rules. In contrast, self-provision disappears as a mode of securing water provision in developed countries, and institutional structure (arrangements) emerges as a solid interface between users and the institutional environment (Shah, 2005). Diversity of institutional arrangements and level-interdependences show the importance and the complexity of the water institution performance analysis.

2.2.2. Institutions performance assessment: some examples from the literature

Since institutions are entities that emerge, evolve, and cooperate in the intersection of economic, legal, organizational, political, social, and physical spheres, no single model or theory can suffice for their evaluation (Saleth and Dinar, 2004). What is needed is a framework for organizing various theories, to gain both diagnostic and perspective insights into the subject of inquiry (Ostrom *et al.*, 1994). This framework also has to be multidisciplinary in order to be able to integrate various theories.

Eggertsson (1996) suggests decomposing the institutional economics analysis into two main analytical levels: (i) linkages between institutions and economic performance, and (ii) influence of the institutional environment on the governance structure and contractual arrangement. Eggertsson proposes that the first analytical level needs to focus on the effect of institutions on economic performance whilst considering both the institutional environment and institutional arrangements as exogenous. He focuses on industrial organizations and relies on a transaction cost perspective. On the second level, the effect of the institutional environment remains exogenous whilst the effect of the governance structure becomes endogenous. Ostrom (1990) generalizes the relationship between institutions and performance to a non-monetary framework and incorporates some non-economic factors in the analysis (culture, ideology, etc.).

Empirical works, which attempt to evaluate institutions and their performance, generally use one or more of the following methods: case studies, comparative method examining several cases together, and econometric analysis of cross sectional data (Alesina 1994; Alson, 1996).

Remmer (1998) combines temporal and cross sectional data in order to analyze both general and specific aspects of the institutions-performance interaction and its effect on international trade cooperation for a given country. In his logistic regression, he considers democracy as a dichotomous variable. He evaluates the relationship between democracy and international cooperation in the Mercosur region between 1949 and 1985. Also, Adelman and Morris (1967) and Morris and Adelman (1988) show that capital and technology are major, but not the only, determinants of economic growth. They found that institutions are also relevant determinants and are linked to observed performance. Adelman and Lohmoller (1994) combine cross sectional and temporal data in order to simulate the impact of political structures and economic institutions on economic growth. They evaluate the effect of institutions on performance using a latent variable regression model where many latent or unobservable institutional variables are captured by their relationship with other observable variables.

A major constraint for conducting a consistent evaluation of institutional performance relates, however, to the quality of data needed. In fact, in such quantitative empirical evaluations we always need to incorporate institutional features into regression models. However, these last characteristics are mainly subjective and require a high level of expertise for them to be developed (Saleth and Dinar, 2004). Combinations of subjective information with objective data are often found in the literature of institutional economic analysis. For instance, Knack and Keefer (1986), in their cross country study concerning institutions and economic performance, combine observable quantitative variables such as investment, gross domestic product, prices, etc. with a set of institutional variables that were subjectively evaluated, such as bureaucracy, level of corruption, quality of infrastructure, etc. Each of these variables was evaluated on a particular scale. Also, Clague (1997) evaluates how measures of property rights and contract enforcement explain differences in income, growth rate, and investment. Isham and Kahkonen (1999) evaluate how institutional aspects such as rules and practices, social capital, government and non-government organizations affect the performance and the final outcome of rural water supply projects. The social capital index developed in their study was subjectively developed through the use of specific proxies. Cukierman *et al.,* (1998) not only combined temporal and cross-sectional analysis but also sought to obtain institutional information from a cross-section of policy experts through banks' custom-made questionnaire. Their aim was to obtain some perception-based institutional information to evaluate the relationship between the degree of central banks' independence and the level of inflation.

Other works evaluate institutional performance essentially from a descriptive analytical perspective. Ostrom's approach is a good representative example of this kind of study. Based on a critical review of several formal and informal irrigation water institutions around the world, Ostrom (1990) identifies some key factors underlying their success or failure. She assesses their performance in terms of eight design principles relating to the nature of rules, monitoring, sanctions, conflict resolution mechanisms, and institutional nestedness (Ostrom 1990). This framework provides some valuable insights for institutional decomposition into components and aspects.

Concerning the water sector, institutional performance was theoretically and empirically studied by many researchers (Ostrom and Ostrom, 1972, Dinar and Latey 1991; Frederiksen 1992; Le Moigne, *et al.,* 1992, 1994; Gazmuri and Rosegrant 1994; Hearne and Easter 1997, Herrera *et al*., 2004, etc.). Ostrom and Ostrom (1972) studied the way in which water institutions (law and related-organizations) evolved when water realities in the California region changed. They investigated the way in which macro water institutions are crafted within the regional economic and physical environment. They also explored the role of private incentives on collective action provision. In line with the previous study, Yang (1997) described the interactions and the co-evolution of water institutions with the resource system and economic and social interests of the population in the United States. Wade (1982) compared the performance of water control institutions between two countries using yield and employment as performance indicators. He used a descriptive approach and found that better performance can be explained by better water supply, small, decentralized, and demand-controlled systems, and good management structures. Dinar and Latey (1991) evaluated how water markets can improve irrigation water use efficiency and reduce negative economic and environmental impacts in California. Herrera *et al.,* (2004) use a Contingent Valuation method in order to assess the gap between current irrigation water value in Ecuador and its value when some institutional aspects of the farmers' irrigation property rights change. His work reveals the usefulness of contingent valuation methods in the study of institutional performance. As we can see in the literature, most of the research is focused on the performance assessment of a specific institutional aspect; it is very rare to find an overall and integrated framework. To be able to provide such a framework, an appropriate institutional decomposition is needed.

2.2.3. Institutional decomposition

Institutions operate as a system characterized by intricate and multiple layers of relationships. In fact, institutions were sometimes treated as single entities but, in reality, they are made up of analytically and functionally distinguishable components and elements (Shalet and Dinar, 2004). As a result, it is difficult to isolate and evaluate the effect of individual institutional components from those of other interlinked and nested components. The analytical approach most used to solve this problem is to decompose institutions into their major components. The decomposition of institutions was identified by North (1997) as a very important issue in the New Institutional Economics studies. By doing so, one will be able to study the efficiency of each component and to establish the linkages between them. The decomposition method also allows a distinction to be made between endogenous and exogenous features of institutions. This rationale was followed in many institutional research frameworks - amongst them the Institutional Analysis and Decomposition (IAD) framework provided by Shalet and Dinar (1999, 2001, 2004).

Decomposition attempts were often used in empirical studies of institutional economics. In the literature, much decomposition into varying levels of abstraction and/or into details of various components and subcomponents can be found. For instance, Adelman and Head (1983) decompose institutions into three categories: social mores and norms, law and regulations, and contractual arrangements. Clague (1997) also identifies three categories of institution: constitutional order, institutional arrangement, and cultural endowments. Coriat and Dosi (1998) distinguish three components of institutions: formal organizations (firms, state, economic and social organizations, etc.), shared patterns of behaviour (ethical codes, social behaviour, etc.), and norms and constraints (moral prescriptions and formal laws). Ostrom (1990) and Ostrom *et al.* (1994) decompose institutions in terms of seven sets of rules: position rules, boundary rules, scope rules, authority rules, aggregation rules, information rules, and pay-off rules. They group these rules into three main sets: constitutional choice rules, collective choice rules, and operational rules.

Also, Bromley (1989), North (1990) and Williamson (1994) distinguish, in a broader and systematic sense, between the institutional environment (or framework) and the institutional (or governance) structure. Williamson (1985) provides some advances in NIE, based on the interaction (transaction costs and organization) between these levels, stressing the importance of the decomposition exercise. The institutional environment and structure can also be divided into components and subcomponents as undertaken in other attempts at decomposition. Formal and informal rules, in addition to enforcement mechanisms could be the main components of the institutional environment (North, 1990). Social and economic organizations are, similarly, the main components of the institutional arrangements. Williamson (1985) separates organizations from the rules configuration in order to show the dynamics of these organizations and how they evolve according to these rules, i.e. how organizations interact and change the rules (environment) in which they are operating.

Despite the growth and diversity of institutional economics analysis, a comprehensive taxonomy of institutions and a framework providing a clear distinction between institutional structures is still lacking in the literature (Johnson and Nielsen, 1998). Some attempts at decomposition of natural resource institutions exist (Oakerson, 1986, 1992: Model for the analysis of common property problems; Ostrom, 1994: Institutional Analysis and Development framework; Saleth and Dinar, 1999: Institutional Decomposition and Analysis framework; Hagedorn *et al.*, 2002: Institutions of Sustainability framework) but there is hardly any framework, other than the one provided by Saleth and Dinar (1999, 2001, 2004), which provides a deep decomposition and a detailed description of the overall interaction process between institutional components and institution-performance in a broader and integrated manner for the water sector. General descriptions of the four above mentioned models (Oakerson, Ostrom, Hagedorn, and Saleth and Dinar) are provided as follows:

- *Oakerson's model*

Oakerson (1986; 1992) proposes a dynamic model of common property relationships, that can be used to decompose and compare problems and solutions across various common property situations. Oakerson's model distinguishes between four inter-related components in a common-pool resource system: (1) the technical and physical attributes of the resource; (2) the decision making arrangements and rules governing relationships between resource users; (3) patterns of interaction between users; and (4) outcomes or consequences (Fig.2.1). Oakerson decomposes each of these four components into various aspects (see Oakerson, 1986 for more details). Institutional arrangements, for instance, are those that "determine who decides what in relation to whom" (Oakerson, 1986) and could be decomposed into three categories: (1) rules and institutional arrangements which establish the ability of a group to act collectively and to make decisions together; (2) a further set of rules, called "operational rules", that regulate the way common resources are actually used; and (3) external arrangements which affect decision making. These could be constitutional and legally enabling in character or involve bureaucratic decision making in respect of operational rules. Oakerson states that outcomes could be evaluated by using the efficiency and equity of the resource use and allocation as performance criteria.

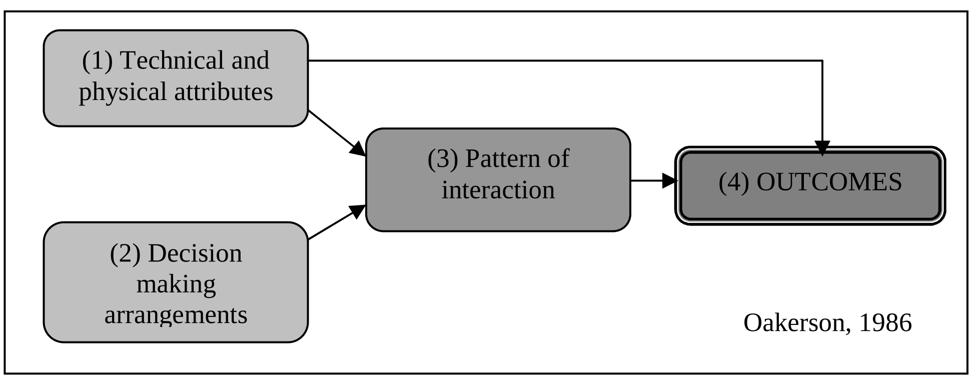


Fig 2. 1. Oakerson's model for the analysis of common property management

- *Ostrom's model*

For Ostrom (1990) and Ostrom *et al.* (1994), the policy process and outcome are assumed to be affected, to some degree, by four types of component. These are: (1) attributes of the physical world, (2) attributes of the community within which actors are embedded, (3) rules that create incentives and constraints for certain actions, and (4) interactions with other individuals (Fig.2.2).

The action arena is considered to be the unit of analysis and focus for investigation. An action situation is the "social space where individuals interact, exchange goods and services, engage in appropriation and provision activities, solve problems or fight" (Ostrom *et al.*, 1994). It includes the following elements: (1) *participants* in position who must choose between diverse (2) *actions* given the (3) *information* they possess about (4) *how actions are linked* to the (5) *potential outcomes* and (6) the *costs and benefits* assigned to each action (Ostrom *et al*., 1994).

The physical world varies from one situation to another and is affected by physical parameters and human interactions. The community also forms an important context that affects individual actions, including "the generally accepted norms of behaviour, the level of common understanding about action arenas, the extent to which preferences are homogenous, and the distribution of resources between members" (Ostrom *et al*., 1994).

Rules are statements defining what actions are required, prohibited, or permitted and the sanctions authorized if the rules are not followed. They can be changed in the hope that new outcomes emerge. Ostrom (1990, 1994) decomposes the rules into three different categories: (1) constitutional choice rules, (2) collective-choice rules, and (3) operational rules. Thus, Ostrom's IAD framework can be considered as multi-dimensional, describing three levels of actions: constitutional, collective and operational. At the constitutional level, the decision makers determine how collective choice participants will be selected and what type of relationships they should have. At the collective choice level, decision makers create rules framing the operational level activities. The operational level relates to the day-to-day activities that affect the managed system for the resource. For each level, one type of rule is used and enforced.

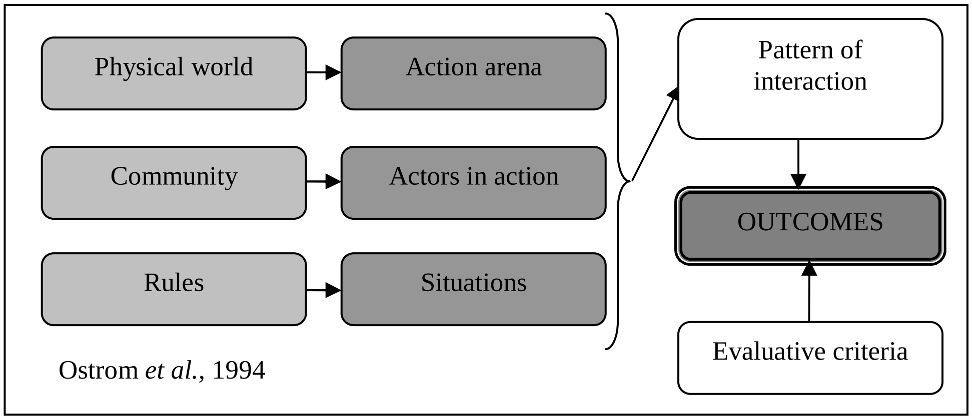


Fig 2. 2. The IAD framework

- *Hagedorn's model*

Hagedorn assumes that the *physical world* (and the related physical properties of a transaction) is as important for institutional analysis as the social *world* (and the related physical characteristics of actors) and that both may substantially affect institutional change and institutional performances (Hagedorn, 2008). Accordingly, Hagedorn proposes an analytical framework called "Institutions of sustainability" (IoS) for the study of nature-related transactions (Hagedorn *et al*., 2002; Hagedorn, 2003; 2005, 2008) in which he provides the main analytical elements that need to be taken into account to arrive at an understanding of institutions (Figure 2.3).

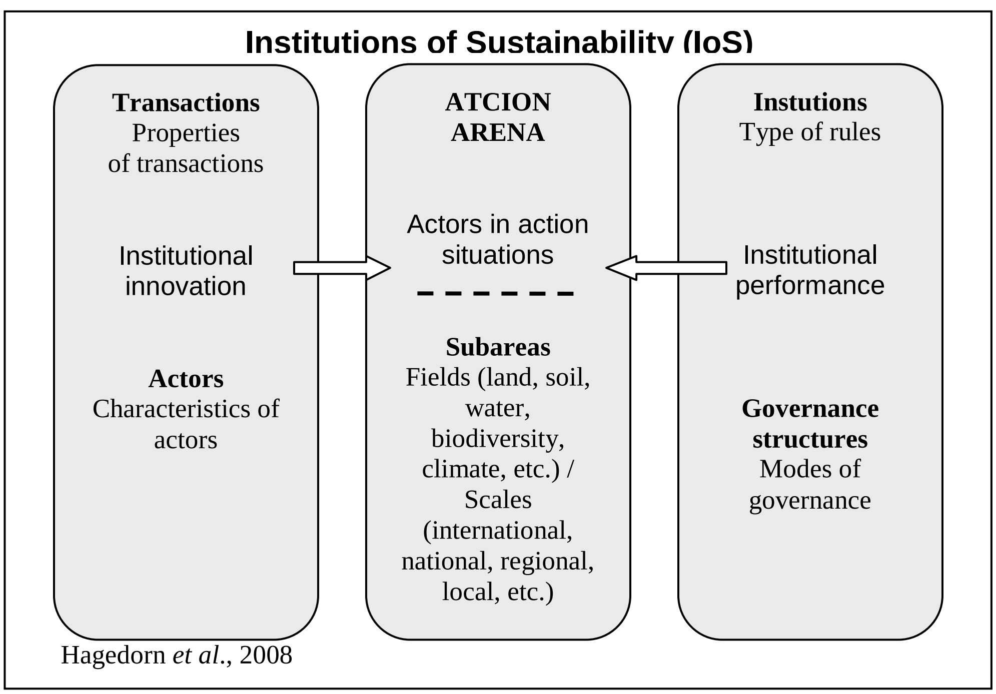


Fig 2. 3. The Institutions of Sustainability framework

This framework is built on a pool of knowledge as to which institutional configurations perform better in terms of sustainability. It focuses on how to regularize human action that leads to transactions affecting the relationship between natural and social system (Gatzweiler and Hagedorn, 2003). The approach decomposes institutions to "sets of interrelated formal and informal rules, property rights and duties". In line with Ostrom (1994), Hagedorn also distinguishes between constitutional, collective-choice, and operational rules. Institutions govern given aspects of society that are acknowledged (or sanctioned) by all or some members of society. He assumes that institutions and governance structures that make them effective emerge either spontaneously through self-organization or intentionally by human design (Hagedorn, 2008). How these institutions and governance structures are socially constructed depends on the properties of the transactions and the characteristics of the actors involved in such transactions (Hagedorn, 2008). Such processes take place in action arena where actors are confronted in an action situation. Action arenas differ by field, scale and situation. The most important action situations are: actors' constellations and orientations, forms of interaction, actors' interests, mental models and identity. Institutions and action arenas determine a set of transactions with different properties. Hagedorn considers that these transactions can be simple, complex, visible, or hidden.

Furthermore, the IoS framework considers that institution building should be described as evolution and co-evolution, a process which is dynamic, complex and a result of co-adaptation (Gatzweiler and Hagedorn, 2002). Institutional performance assessment and innovation are key elements in the dynamic and co-evolutionary nature of institutions.

- *Saleth and Dinar's Institutional Decomposition and Analysis (IDA) framework*

Based on Ostrom's Institutional Analysis and Development (IAD) framework, Saleth and Dinar (1999, 2001, 2004) developed the "Institutional Decomposition and Analysis" framework, which they applied to the water sector in order to assess the institutional structure and the institution-performance relationships from a wider and more integrated perspective. When we take a deeper look at the three hierarchically related categories of rules provided in the IAD, we can see that Saleth and Dinar decompose institutions into three main components and approximate the constitutional choice rules to "laws", the collective choice rules to "policies", and the operational rules to “administration”. These are considered as main components of water institutions.

Thus, Saleth and Dinar (2004, 2005) define institutions as “entities defined by a configuration of legal, policy, and organizational rules, conventions, and practices that are structurally linked and operationally embedded within a well-specified environment”. From this definition, they argue that decomposition of institutions is an essential step in their analysis. In line with Williamson (1975), they draw a distinction between the institutional environment for water (governance framework) and its institutional structure (governance structure). They also consider that since the institutional structure is embedded within the institutional environment, the evolution of the former is invariably conditioned by changes in the latter. Changes in the institutional structure also influence the governance framework (Williamson, 1996).

- *Institutional structure for the water sector*

Water institutional structure, as presented by Saleth and Dinar, is defined interactively by three institutional components, i.e. water law, water policy, and water administration (or water-related organizations) (Fig.2.4). These institutional components cover not only the formal and macro-level arrangements, but also the informal and micro level arrangements such as those reflected in local customs, conventions, and informal contracts (Saleth, 2004). Also, as shown in Fig 2.4, the IDA highlights some key aspects under each of these three components. In this framework, Saleth and Dinar argue that there are two types of linkage that have to be captured in an empirical study of water institutions: (1) linkages between institutional components, and (2) linkages between institution-performance.

Water law receives a central place in the functioning of water institutions since it provides the legal backing to water policy as well as the operational framework and enforcing power for water administration, including its regulatory arrangements (Saleth, 2004). In the water law component, the main institutional aspects accorded importance are: inter-governmental responsibility, water rights, conflict resolution, etc. For instance, the issue of water rights as a mechanism for allocation and accountability, gains importance in situations of water scarcity and conflict, both at the macro regional or sector level and at the micro level of communities and individual users. This aspect is interrelated with some administrative aspects, such as the structure of water administration and the regulation/accountability modes that have to be used according to the type of rights in existence.

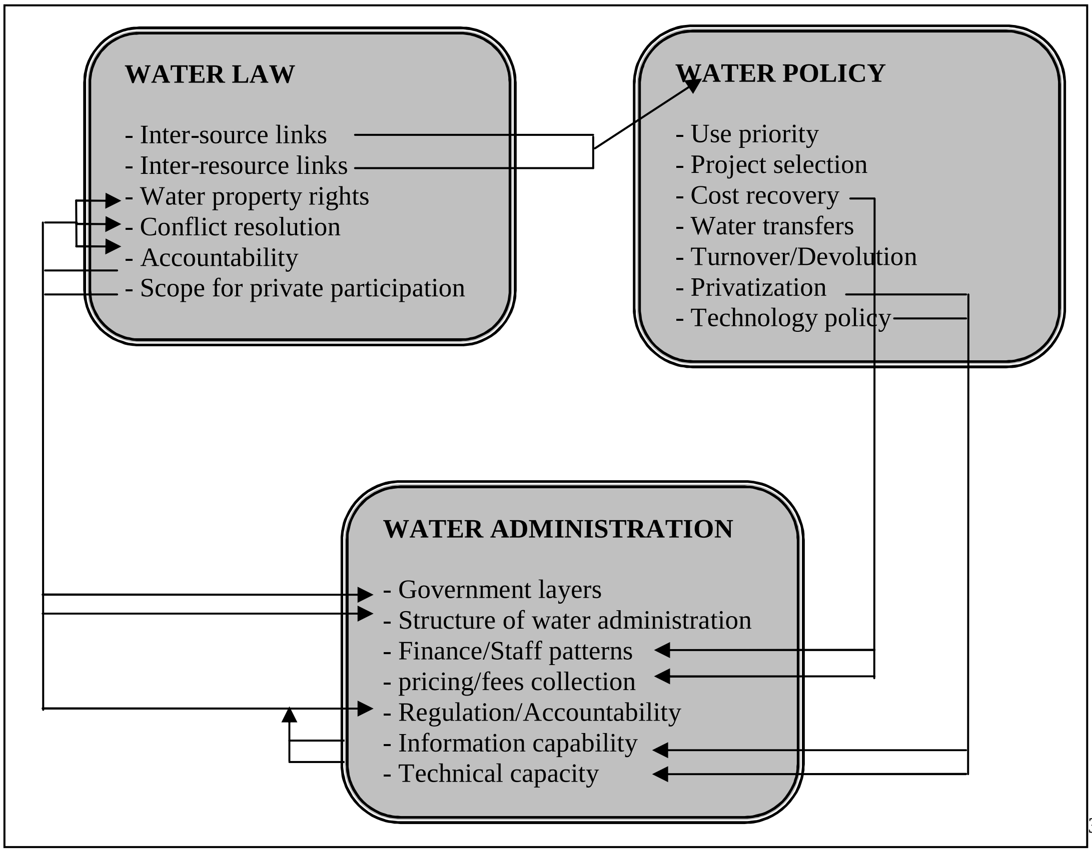


Fig 2. 4. Simplified representation of the water institutional structure (Saleth & Dinar, 1999)[3]

Water policies relate to the government's approach to water resource planning, development, allocation, and management. They do not only describe the overall policy framework but also some specific aspects such as project selection, cost recovery and pricing policies, users and private participation, etc (Fig.2.4). Finally, water administration covers the organizational, financial and managerial structures, including the regulatory apparatus and conflict resolution mechanisms, which are directly connected to the water sector (Saleth, 2004).

[3] See Saleth and Dinar, 2004) for more detailed description of each institutional aspect and their interlinkages. For instance, Saleth and Dinar argue that the legal aspects dealing with the way water sources as well as water, land, and environmental resources are treated influence such water policy aspects as priority setting for water sources and project-selection criteria. For instance, a water law that does not differentiate water by its source but recognizes the ecological linkages between water and other resources is more likely to encourage a water policy that assigns a higher priority to environmental imperatives and hydrological interconnectivity in project selection.

In this decomposition framework, Saleth and Dinar insist on two main points. Firstly, the overall performance of water institutions depends not only on the individual institutional aspects but also on the manner in which these are structurally and functionally inter-related. Some of these linkages are direct and immediate, whilst others are indirect and remote (Saleth and Dinar, 2005). Secondly, an assessment of these linkages, and the institutional channels through which their impact is transmitted, is a very important task for any reform and implementation process in the water sector.

- *Water institutional environment*

Institutional linkages and their performance implications are also subject to some exogenous and contextual influences. Water institutions exist in an environment characterized by the interactive role of many factors outside the strict boundaries of water institutions and the water sector (Fig 2.5). Saleth and Dinar consider the institutional environment as characterized by the overall physical, cultural, historic, socio-economic, and political milieu of a country or region. In Fig.2.5, two analytical segments could be distinguished; the first captures the interaction between the water institutions and water sector performance and the second captures the general environment within which such interactions occur (Saleth and Dinar, 2004). Some of the exogenous environmental factors have a direct impact on water sector performance, whilst others affect it by determining the features and functioning of water institutions.

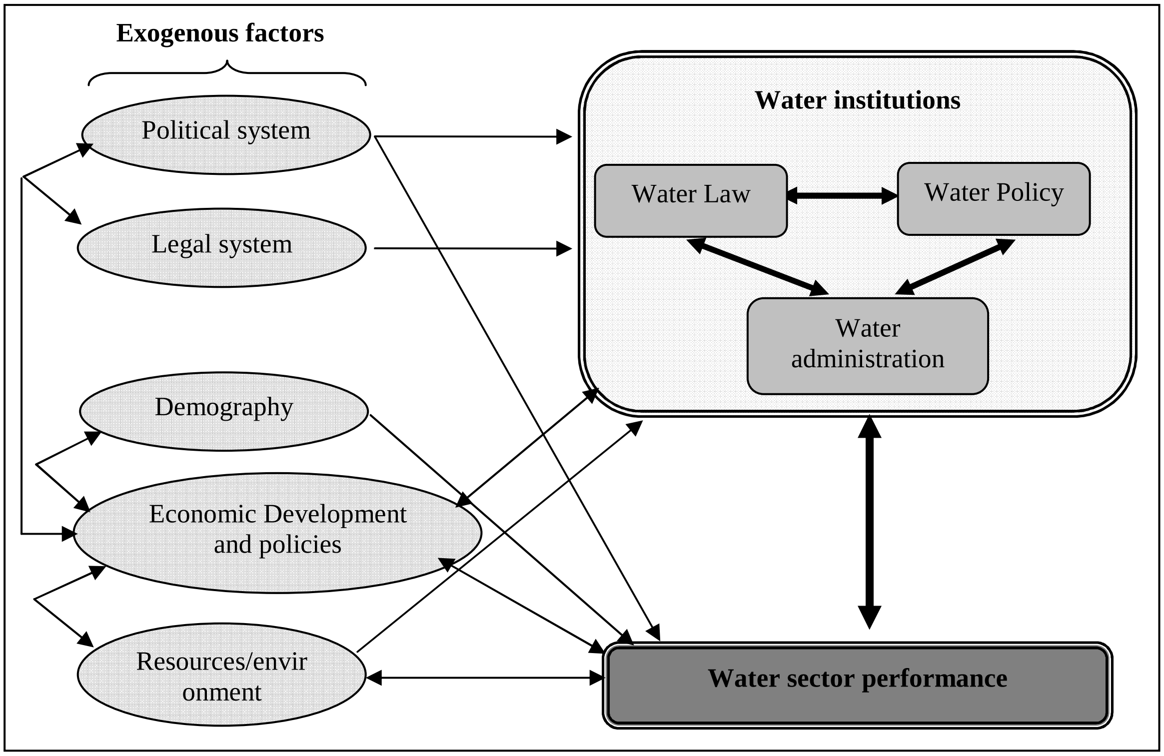


Fig 2. 5. Partial representation of the water institutional environment (Saleth & Dinar, 2004)

- *Water institution performance*

In order to evaluate the performance of the different institutional components, Saleth and Dinar developed a set of indicators dependent on the potential for expressing the institutional aspects, included in each component, in numerical terms. "Each of institutional and performance aspects is captured by one or more variables depending upon the desired level of detail… In this respect, three kinds of variables are used. They are: dummy variables taking a value of 0 or 1, scale variables taking a value between 0 and 10, and categorical variables taking an integer value in the range of -1 to N[4]. While the dummy variable indicates the presence or absence of an institutional aspect, the categorical variable captures the nature of an institutional aspect. Unlike these two variables that relate mostly to institutional aspects, the scale variable captures the judgmental perception on both institutional effectiveness as well as water sector performance" (Saleth and Dinar, 2004).

[4] While -1 indicates a lack of clarity as to the nature of the institutional aspect, N indicates the number of possible categories that varies by the institutional aspect being considered.

For instance, in one of their empirical applications, Saleth and Dinar (2004) selected the following institutional aspects under water law component: legal treatment of surface and subsurface sources (dummy variable), format of surface water rights (categorical variable taking a value within 0-6), effectiveness of conflict resolution mechanisms (scale variable), effectiveness of accountability provision (scale variable), and so on. Specifically, categorical variable related to surface water right takes 0 for no right, 1 for unclear/unauthorized/scattered rights, 2 for common/state property, 3 for riparian system, 4 for appropriative system, 5 for correlative (proportional sharing) system, and 6 for licenses/permits. Moreover, the conflict resolution mechanisms include bureaucratic systems, national water council and the like, tribunals, water court system, judicial/legislative mechanisms, river boards, basin level organization and the like, water user associations and the like, etc. Given the existence/or not of these mechanisms in a given country (region), specific score for the correspondent score-variable will be attributed.

"Water cost recovery status" is one among variables reflecting specific institutional aspect belonging to the water policy component. It is considered by the authors as categorical variable taking a value within 0-3. Specifically, it takes 0 for non-response, 1 for full subsidy, 2 for partial recovery, and 3 for full-cost recovery. Finally, a set of "*water administration variables*" can also be considered. It includes some variables reflecting administrative institutional aspects such: spatial organization of water administration (categorical variable), effectiveness of accountability arrangements (scale variable), and so on (for more details see Saleth and Dinar, 2004).

Using this decomposition in addition to the sets of variables described above, comparative assessment of water institutional performance between regions and countries in terms of their final outcome became a real possibility. As it is clear, this framework was applied by Saleth and Dinar (2004) at a macro level. Thus, only the decomposition standards provided by the IDA framework will be adopted in our dissertation where most of the empirical validations are done at an individual level.

2.3. Analytical framework for the study of irrigation institutions in Tunisia

Our theoretical position concerning the analytical decomposition of water institutions will be largely based on a simplification of the IDA framework provided by Saleth and Dinar (1999, 2001, 2004). This framework is itself based on the institutional Analysis and Development (IAD) framework furnished by Ostrom and her co-workers (Ostrom 1990; Ostrom *et al.*, 1994) which, as indicated above, characterizes institutions in terms of three hierarchically related categories of rules. Using the IDA framework, a partial institutional analysis framework, was designed for the study of irrigation water demand management institutions in Tunisia, with a focus on the micro level (Fig.2.6). The simplifications and adaptations made to the IDA framework are discussed below.

2.3.1. Adaptations to the IDA framework

Starting from the IDA, and given the complexity and the amount of information needed for the study of all institutional subcomponents (aspects) and their inter-linkages, we decided to select three main institutional aspects (one from each component), limiting our empirical analysis to the selected aspects. These are: (1) irrigation property rights, (2) pricing policies and cost recovery strategy, and (3) functional, regulatory and accountability capacities of the local water organizations.

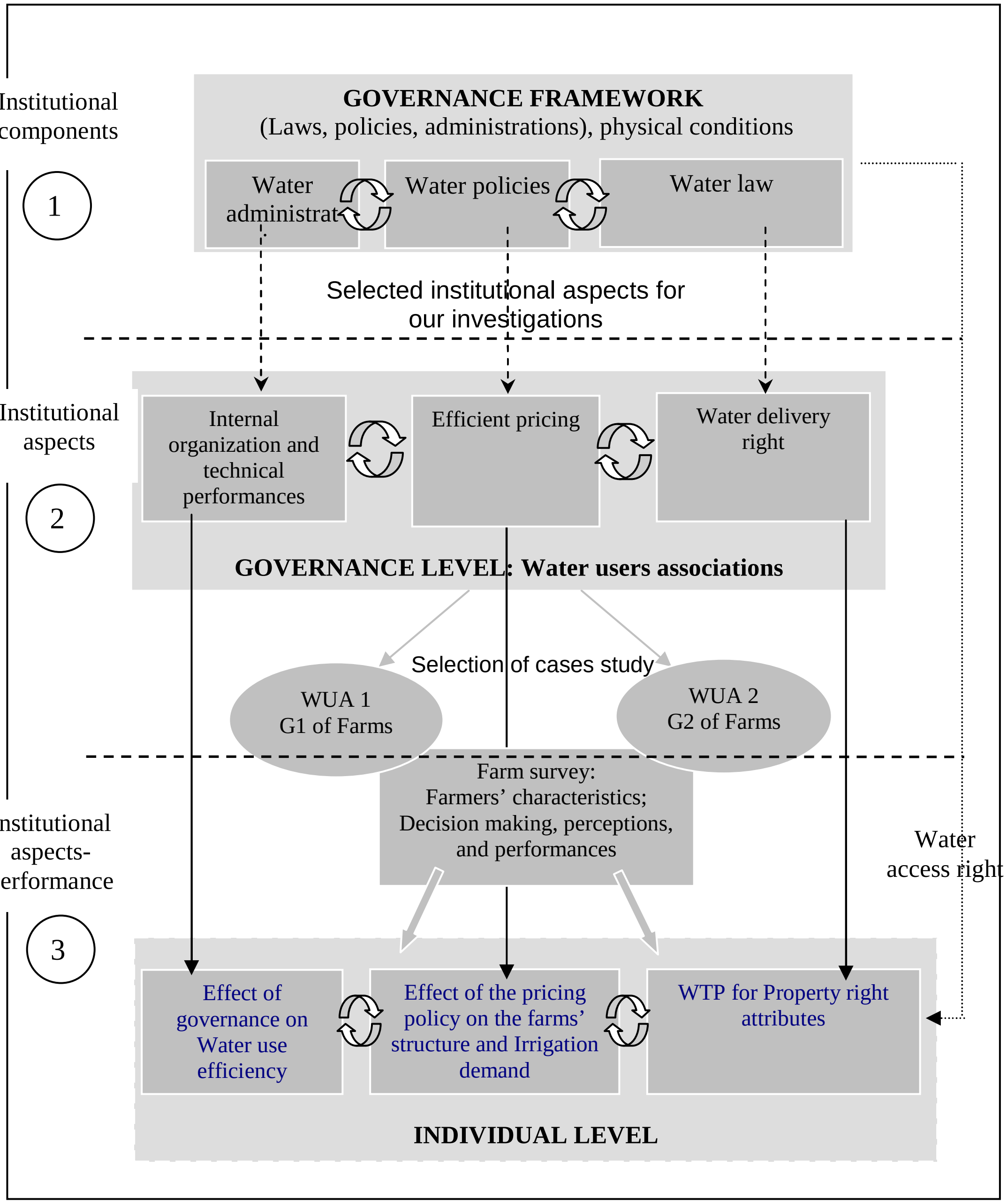


Fig 2. 6. Partial decomposition of water institutions considered in the thesis

These institutional aspects will be addressed at three levels: macro level, governance level, and individual level. At the first level, only some descriptive assessments concerning the three institutional components - including the selected aspects - will be provided. The governance level is considered in this study as lieu of direct interaction between individuals and the rules of the game (institutional components). In fact, governance is defined by Huppert *et al*. (2003) as the body of rules, enforcement mechanisms and corresponding interactive processes that coordinate and bring into line the activities of persons involved in a common outcome. Similarly, we assume that this second level of analysis corresponds to the water users' associations that are supposed to apply "the rules of the game" at a local level. However, (1) these associations could have their own specific objectives (e.g. reaching a targeted cost recovery rate, providing a positive financial account at the end of the year, etc.) that may be different from the specific objectives of the government or the farmers. Thus, their performance could be evaluated separately according to their own targets. On the other hand, (2) performance at this institutional level also has a direct effect on farmers' perceptions, which could be translated into decision making and affect the final outcome for the irrigated systems. Both effects will be considered in our analysis.

The individual level is the level upon which most of our empirical applications are based. It is of interest to observe the impact of the selected institutional aspects on individual choices and behaviour. Some individual-based perception proxies were used in order to better enlighten the direct and indirect impact of institutions on individuals. We also sought to integrate this perceptional information within our quantitative models. At this empirical level, we incorporated the combined effect of the two remaining aspects (from the three aspects previously selected) when studying the effect of a given institutional aspect. The evaluation of institutional performance at this level is based on individual outcomes such as productivity, efficiency in terms of resource use, willingness to provide collective action, etc. One can argue that it is difficult to establish a direct link between institutions as a whole and individual outcomes. However, we believe that perceptional information could be very useful in this respect. Using various quantitative and statistical methods, this latter type of information could help in the identification of significant relationships between specific institutional aspects and individual outcomes. Specific institutional aspects and performance indicators for our empirical applications will be described in more detail in each corresponding chapter.

2.3.2. Institutional efficiency

After decomposing the irrigation water institutions, our second purpose will be to evaluate their efficiency. The concept of efficiency, used in this dissertation, is that of NIE, which relates efficiency to performance (Herrera, 2004). As indicated in previous sections, our analytical question is to understand how different institutions involved in the functioning of irrigation systems would affect farmers' decision making and the observed outcomes of these systems. Given the fact that we are in a situation of conflicting interests between actors (government, water agencies, and farmers), each institutional efficiency evaluation in this dissertation will be done to a unique and well-specified target. In other words, the efficiency of the institutional aspects will be evaluated for each actor according to his own objectives.

Institutions and resource protection may be evaluated and compared in different contexts that take account of institutional performance and relationships (Wells 1998). Analyzing institutional performance can help policymakers evaluate alternative arrangements for natural resource protection and facilitate community participation in natural resource management (Agrawal and Gibson 1999). By the same token, we consider that local payments for the provision of water and water services are examples of institutional arrangements that may help to achieve water resource protection in Tunisia. The task is then how to evaluate the available institutional arrangements that are, or could be, applied in order to enhance provision and levels of protection.

Schmid (2004) proposes the use of institutional impact analysis that allows for an analytical assessment of institutional performance. It provides a framework for predicting and comparing alternative institutions in terms of substantive performance measures (e.g., economic outcomes and distribution). Performance, in this context, is a relative measure associated with a given set of social goals (efficiency, equity, etc.). Predicted performance may be based on notions of social goals (benefits) based upon theory, data collected from interested parties, or lessons learned from cases with similar situations and structures. Evaluating presumed or actual performance allows for the articulation of conclusions and/or insights concerning the likelihood of alternative structures achieving targeted social goals (Kaplowitz, 2008).

Schmid (2004) proposes two levels of institutional impact analysis. The first level attempts to explain how alternative formal and informal everyday institutions affect commodity transactions and substantive economic outcomes of wealth and their distribution. The second level, on the other hand, attempts to explain how alternative internal structures of economic organizations and contractual arrangements affect performance.

Similarly to Schmidt (2004), the "rules of the game", which are abstracted in our work by the various institutional components and aspects presented in the previous section, will be assessed at two main levels. In the first one we try to see how these alternative aspects and their qualification individually affect farmers' decision making, perceptions, and outcomes. In the second level, we focus on the combined interactive effect of these aspects. For the first level, we will need to specify for each evaluation process (1) the performance criteria according to which the efficiency assessment has to be done, in addition to (2) the evaluation method.

2.3.2.1. Performance criteria

Our approach to the efficiency analysis starts with the identification of the efficiency criteria to be used in making the assessment. These "non-accomplished" criteria allow us to qualify the competence of the particular institutional aspect under analysis. In the case of irrigation, Ostrom (1992) argues that the key criterion is sustainability. This can in turn open a range of criteria (e.g. efficient use of water, financial viability of irrigated systems, etc.) that may be considered for assessing the efficiency of each specific institutional aspect.

Given the fact that our quantitative applications are mostly done at the individual level, then, for the most part, socially and economically desirable outcomes generated by the individual irrigation activities will be considered as assessment criteria. These chiefly relate to the efficiency of irrigation water resource use at farm level, farmers' agricultural productivity, financial viability of the irrigated farms, farmers' willingness to pay and/or to participate, etc.

2.3.2.2. Evaluation method: comparative efficiency assessment

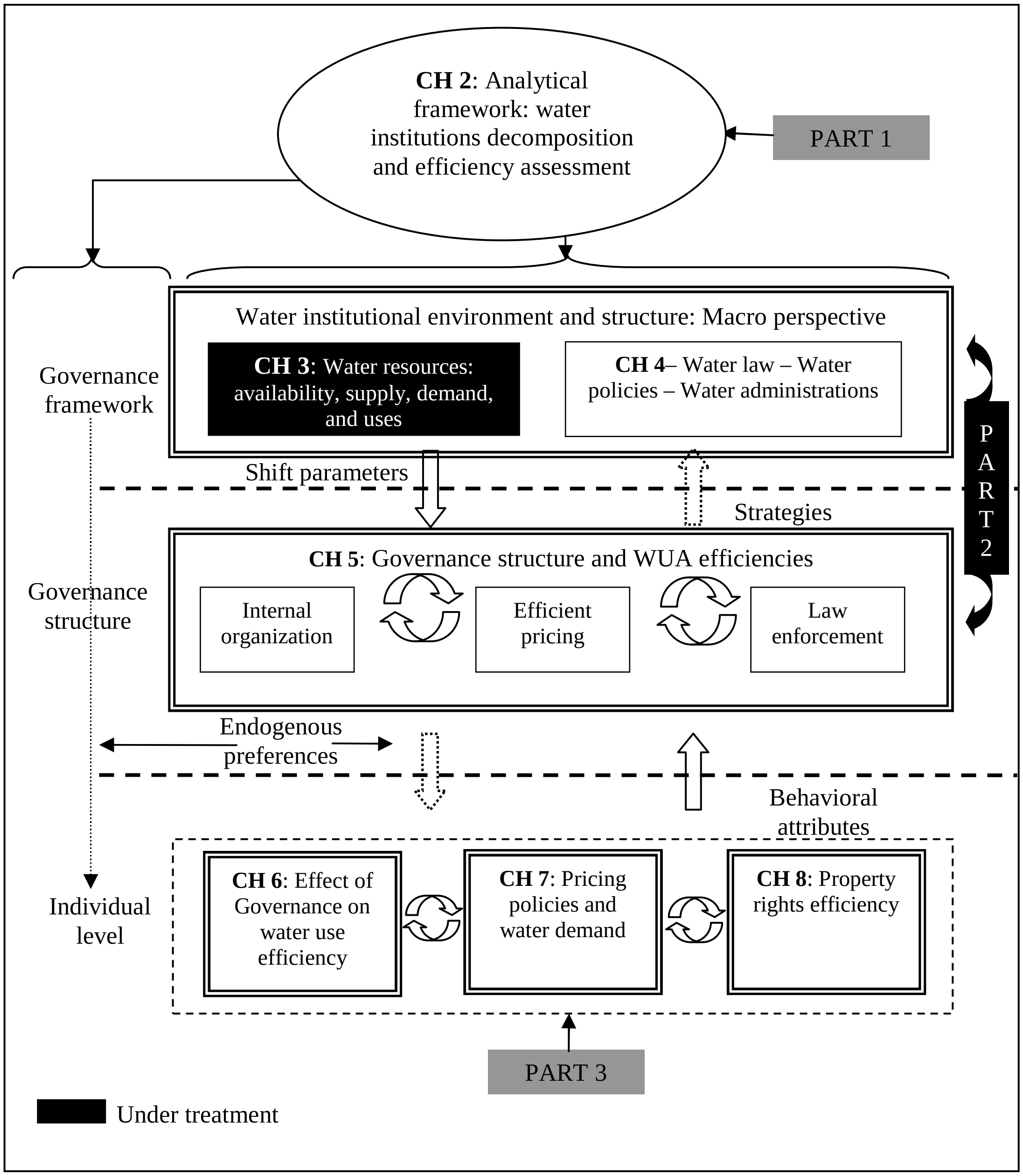
To perform the comparative efficiency of water institutions assessment, we typically identify and use an indirect evaluation approach. In each application of this approach we rely on one (or more) out of the three following gaps: (i) gap between actual options and other hypothetical ones (that have to be realistic and already applied in other contexts: regions or countries. e.g. comparison between current property right system and a hypothetical one already applied in other contexts). It is however clear that contrasting the performance of an institutional setting currently in place with another desired structure, says nothing about how to put the alternative in place, (ii) gap between the best and the worst performing: comparing the same existing institutional structures, but applied in different contexts to each other (e.g. comparison between performances of different WUA, comparison between effect of different governance structures on irrigation performances). Here, the effect of some environmental factors on the functioning of water institutions could be identified, and (iii) gap between actual and future options: comparing actual institutional options to other future options that are already planned for implementation as part of government strategy (e.g. comparison between current pricing regulation and other planned future options).

2.4. Conclusion

The basic idea in this chapter is to show how one can develop an analytical framework that allow assessing the performance of particular institution. In fact, institutions operate as a system characterized by intricate and multiple layers of relationships which makes difficult their analysis. The analytical approach most used to solve this problem is to decompose institutions in major components. Accordingly, the decomposition of water institutions into water laws, water policies, and water administrations components is considered in this dissertation. Each of these components can be decomposed further into interrelated institutional aspects. In this dissertation, only performances analysis of three particular institutional aspects (one from each component) are undertaken.

In the institutional analysis process, it is as well crucial to distinguish between different layers of institutions. In fact, not only the institutional level targeted by the analysis has to be determined but the effects of the other levels should be also considered and taken into account. In our case, we mainly focus our analysis on the individual level but we also consider the effect of governance framework as well as governance structure on individuals.

Finally, it is important for any type of performance assessment to have a set of performance criteria which should be considered as reference for the assessment process. In this dissertation, we opt for a set of socially and economically desirable outcomes generated at the individual irrigation level (e. g. efficiency of water use, financial sustainability of the irrigation activity, willingness to pay for collective action, etc). These will be used for comparative efficiency assessment of various institutional aspects considered. Explicitly, different irrigation institutional aspects are compared relatively to one or more performance criteria from the former set.


CH 2: Analytical framework: water institutions decomposition and efficiency assessment
PART 1
Water institutional environment and structure: Macro perspective
Governance framework
CH 3: Water resources: availability, supply, demand, and uses
CH 4– Water law – Water policies – Water administrations
P A R T 2
Shift parameters
Strategies
CH 5: Governance structure and WUA efficiencies
Governance structure
Internal organization
Efficient pricing
Law enforcement
Endogenous preferences
Behavioral attributes
Individual level
CH 6: Effect of Governance on water use efficiency
CH 7: Pricing policies and water demand
CH 8: Property rights efficiency
PART 3
Under treatment

Chapter 3. Water resources availability, supply, demand and uses in Tunisia

Abstract

In this chapter, we shortly review the state of water resources availability, supply, demand, and uses in Tunisia. Many remarks can be drawn from this overview. First, water demand was continuously rising during last four decades. This increasing demand is mainly due to the extension and creation of new irrigated areas and to the enhancement of the intensification rate in the already existing ones. The intensification rate for existing areas and yields of irrigated crops are still below expectations. In fact, the current intensification rate is approximately 85% whilst it could reach 130% according to government expectations. Secondly, many private irrigated areas (from wells) in Tunisia experience critical situations due to the overexploitation of groundwater and to the salinisation of lands. Thirdly, water supply will soon reach its limit; imbalance between water supply and demand will have a critical effect on irrigated agriculture. In these circumstances, the cost of water will increase and the sustainability of irrigation activity will become questionable. Finally, free trade agreements signed by Tunisia and the new trade context that is currently being implemented in the Mediterranean region raise concerns regarding efficiency and competitiveness for Tunisian farmers, which can increase pressure on natural resources.

3.1. Introduction

The North African countries in the Southern Mediterranean region are amongst those in the world facing severe water shortages. Most of these countries have a semi-arid climate with limited and variable rainfall. Moreover, the quantity of rainfall actually available for cultivation is very limited, due to very high levels of evaporation (Hamdy and Lacirignola, 1999).

Irrigation has been practiced in North Africa since the Roman era. When new fruit species and substantial expertise was brought into the region by Arabs, irrigation flourished (Ben Mechlia, 2004). During the past three decades, it has been common policy in these countries to develop irrigation infrastructure and to control renewable water resources with a view to increasing stability in terms of water supply (Ben mechlia, 2004). Renewable resources were rapidly mobilized and the use of irrigation water reached maximum levels.

3.2. Tunisian context

Tunisia is bound on the north and east by the Mediterranean Sea, on the south by Libya and on the west by Algeria. Of all the North African countries, Tunisia has the longest Mediterranean coastline, giving it sizeable fishery reserves in addition to the tourist attractions that draw millions of foreign visitors annually. Tunisia covers around 63,170 square miles, corresponding to approximately 16 million hectares. This total area comprises 30 % arable land, 27 % pasture and forests, and approximately 43 % of land that is unsuitable for agriculture (Lachaal *et al.*, 2005a). This means that only half of the country’s area contributes to agricultural production.

Table 3. 1. Total land use (1000 ha)

	1985	1990	1995	2000	2001	2002	2003	2004	2005
Agricultural area	8822	8644	9348	9551	9499	9763	9784	9830	9769
Arable land and Permanent crops	4938	4851	4878	4990	4909	4908	4930	4945	4884
Arable land	3070	2909	2842	2864	2774	2771	2790	2791	2729
Agricultural area irrigated	na	na	na	na	346	359	348	356	361

Source: FAOSTAT

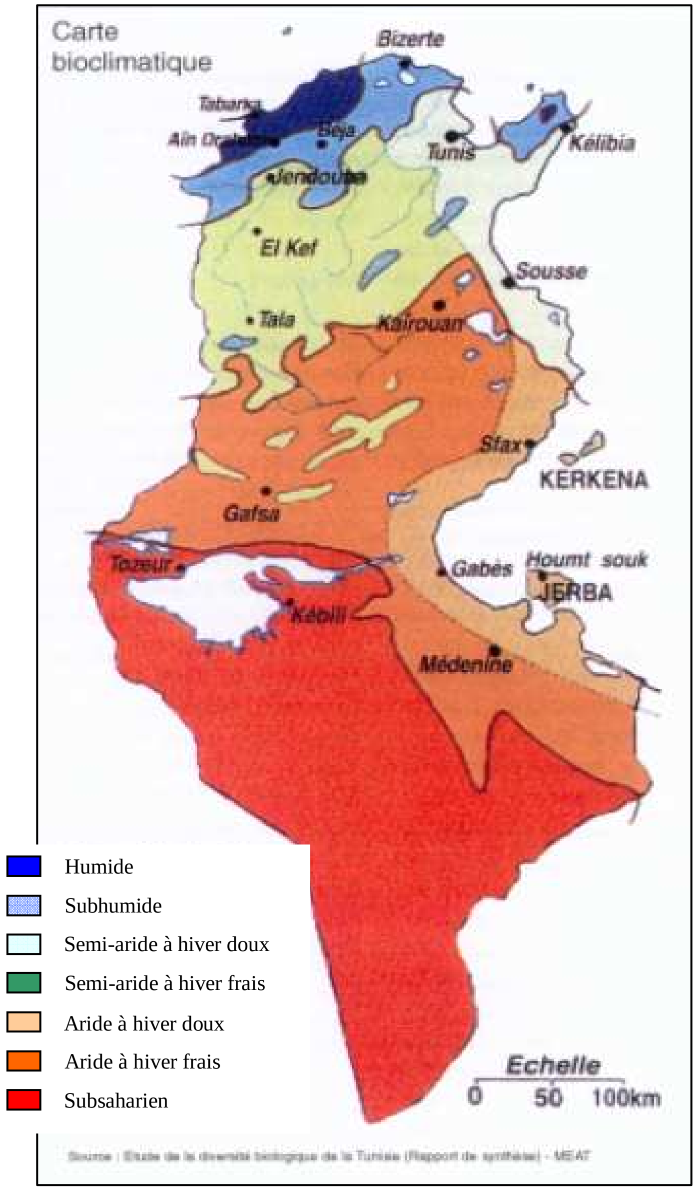


Fig 3. 1. Bioclimatic zones in Tunisia

The climate in Tunisia varies from Mediterranean to arid. The country is generally divided into the following naturally homogeneous sub-regions: humid, sub-humid, semi-arid, arid and Sahara sub-regions (Figure 3.1). Total rainfall and its distribution are highly variable from year to year and from north to south. Average annual rainfall is around 594 mm in the North, 289 mm in the Centre, and 156 mm in the South. In the extreme south of Tunisia the average rainfall is less than 100 millimetres, whereas in the extreme northern part of the country it is more than 1000 millimetres per annum (Zebidi, 1990). Average annual rainfall values can be multiplied between two and twelve times during short and intensive spells of rainfall, causing runoff and causing soil erosion. Heading towards the northern part of the country, the topography becomes increasingly hilly, leaving relatively less cultivable land in the areas of high rainfall. The opposite is observed towards the southwest, suggesting a negative correlation between the availability of arable land and that of rainfall. This implies that in most areas agricultural activity is carried out under limited and highly variable rainfall. Temperature and wind are no less variable, frequently causing serious damage to agricultural crops.

3.3. Land resource potential and constraints

Fertile lands in Tunisia cover approximately 5 million hectares. More than half (57 %) of them are located in the centre, one tenth (11 %) in the south and one third (31 %) in the north of the country. Forests and rangelands extend over a total area of 5.5 million hectares. Most of the forests and rangelands (nearly 60 %) are located in the southern region, the rest being located in the central and northern regions of the country (23% and 17% respectively). There are no more than 3.5 million hectares of highly-fertile land, of which only 500,000 hectares are suitable for irrigation (Lachaal *et al*., 2005b).

A major part (46 %) of the agricultural land, forests, and rangelands are situated on slopes which reduces their fertility and increases their sensitivity to erosion. Lands in Tunisia have been cultivated since ancient times i.e. almost three thousand years ago. The continuous cultivation of non-fertile lands, even under difficult climatic conditions, increases their risk of erosion.

Table 3. 2. Areas of major soil constraints in Tunisia

	Area (1000 km^2)	percentage
Total area	164	100
Salinity	13	8
Sodicity	5	3
Shallowness	46	28
Erosion hazard	24	14
Soils without major constraints	22	14

Source: FAO, 2000

Lands are subjected to desertification, mainly in the south of the country. 50 % of southern lands are moderately/deeply affected by this type of degradation. Moreover, salinity also affects more than 30 % of the irrigated lands in Tunisia (almost 100,000 ha) (MARH, 1996).

3.4. Agricultural land use

Lands are distributed into three large natural regions according to geo-climatic conditions and their sensitivity. The land distribution and occupation by region can be presented as follows:

- The North: The north-east specialises in intensive mixed farming, cereals and fruit farming; whereas the north west region is allocated mainly to food grains and breeding animals (intensive and extensive);

- The Centre: (i) Sahel zone is characterized by olive cultivation, market gardening and rain feed farming; (ii) the centre west and Kairouanais are allocated to mixed farming and extensive breeding;

- The South arid region: (i) The south-east specializes in olive growing, and fruit tree cultivation (littoral oasis); (ii) the south-west has mainly arboriculture and extensive breeding; (iii) continental Oasis (Nefsaoua - Jerid and Région Maâtoug).

It is clear from this distribution that the agricultural sector maintains an undeniable social and economic importance in all regions of Tunisia. It employs 28% of the active population and contributes 14 % of gross domestic product (GDP). However, these contributions face significant fluctuations due to climatic variability and changes in public agricultural policies (Lachaal *et al.*, 2005a). The main agricultural products of Tunisia are wheat, barley, citrus fruits, dates, olive oil and vegetables. Livestock production also contributes significantly to the total added value by the agricultural sector, i.e. by 1578.31 million TND (current price 2005). Horticulture and other industrial crops contribute with a value of 1249.71 million TND (current price 2005). They cover only 3 % of cultivated land and are concentrated in the northern areas. Dates, olive oil, and tomato paste are the main export products.

Tree crops are ranked highest in terms of cropped area which is around 2.137 million hectares (54 % of the cultivated lands), of which 65 % are established in the central and southern parts of the country. Southern and central regions do in fact specialize in this kind of cultivation where they represent respectively 75 % and 84% of cultivated land. The main tree crops cultivated in Tunisia are olives for olive oil, table-olives, dates, citrus fruits, grapes etc. Generally, olive oil is ranked highest in terms of its contribution to the total agricultural value addition. It constitutes 42 % of the total Tunisian agro-food sector exports and approximately 25 % of the total world exports (fourth exporter country in the world in 2005).

The food processing sector accounted for 5138 companies in the year 2002 (Lachaal *et al.*, 2005a). These are mainly related to cereals, olive oil, milk, tomatoes and fish. Fruit and vegetables are processed by 61 companies which are mainly located in the north of the country and in particular in the Cap Bon region. The food processing industry in Tunisia contributed almost 986.2 million TND in 2001 (17.6 % of the total value added for the manufacturing sector) (Lachaal *et al.*, 2005b). Investments in this sector amounted to approximately 204.3 million TND in 2001 (20 % of the total investment in the manufacturing sector).

3.5. Water resource potential

Water resources in Tunisia are estimated to be around 4700 $10^6 m^3$ (Al Atiri, 2007) (Mcm) including 650 $10^6 m^3$ of non-renewable resources (13.8 % of the total water resources) (Table 3.3). Groundwater resources account for 42.5 % of the total water potential. The per capita endowment is currently around 450 m^3 per annum. This ratio[5] will reduce to 315 m^3 per capita per annum in 2030, according to the latest government studies (Ben abdAllah, 2007).

Table 3. 3. Potential water resources in Tunisia

	North	Center	South	Total
Total available water ($10^6 m^3$)	2801	848	1020	4669
Percentage	60	18	22	100

Source: MARH, 1998[6]

[5] This ratio is higher in other Mediterranean countries such as Morocco (1083 m^3/year) or Algeria (655 m^3/year).

[6] Values in this table are also cited by Ben AbdAllah (2007)

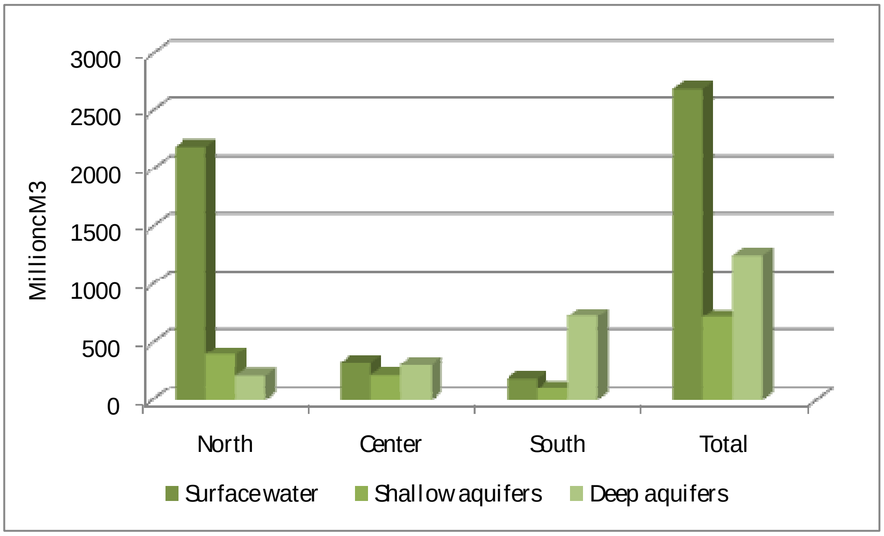


Fig 3. 2. Potential water resources in various Tunisian regions (MARH, 1998)

3.5.1. Rainfall and surface water

Surface water resources in Tunisia are characterized by problems in terms of both quantity and quality. These resources are limited because of the semi-arid to arid climate found in most of the country, with episodic droughts, and a natural deterioration in water quality owing to the salty types of rock found within the country (Ben AbdAllah, 2007). Tunisia receives on average 230 mm/year of rainfall; that equates to 36 $10^9 m^3$ of rainfall. However, this volume varies between 11 $10^9 m^3$ during a drought year and 90 $10^9 m^3$ during a very wet year. Surface water resources are estimated at 2700 $10^6 m^3$.

The north provides relatively regular contributions in terms of surface water resources and it accounts for 2190 $10^6 m^3$. It represents 82 % of the total surface water potential whilst covering only 16 % of the country. The central part covers 22 % of the area, and is characterized by irregular surface water resources. It provides 12 % of the total surface water potential. The southern part of the country which accounts for approximately 62 % of the total land area is the poorest in terms of surface water, providing very irregular resources of 190 $10^6 m^3$ which contributes only 6 % of the country's total potential for surface water.

The quality of surface water, evaluated by its degree of salinity, varies between regions. Given that a salinity of less than 1.5 g/l is acceptable, then approximately 72 % of the surface resources may be considered of good quality. Surface water quality also varies across the country with

82 % of the water resources in the north, 48 % of those in the centre and only 3 % in the south considered to be of good quality.

These inequalities in quantity and quality make water management more difficult and explain the need to transfer surface water from the northern areas to the centre and south of Tunisia in order to improve the drinking water supply and to ensure equity between consumers.

3.5.2. Groundwater

The groundwater resources are estimated to be 2000 $10^6 m^3$, confined within 212 shallow aquifers (containing 719 $10^6 m^3$) and 267 deep aquifers. It is estimated that 650 $10^6 m^3$ of this resource is mainly located in the south and is non-renewable.

Like surface water, groundwater is characterized by unequal allocation and variable quality in terms of salinity. Groundwater is distributed as follows (Ben AbdAllah, 2007):

- The north has 55 % of the shallow groundwater resources and only 18 % of the deep groundwater resources
- The centre provides 30 % of the shallow resources and 24 % of the deep resources
- The south provides 15 % of the shallow resources and has 58 % of the deep resources.

Good quality groundwater is found in only 8 % of shallow water and 20 % of deep aquifers. If it is assumed that salty water up to 3 g/l can be used in the agricultural sector and for the production of drinking water, then approximately 36 % of groundwater resources are unsuitable for these purposes.

Another phenomenon, which has a significant effect on water quality, is drought. In periods of drought, the salinity of the water stored in shallow aquifers can reach 3.5 g/l due to over-extraction, as resources are drawn down for both drinking and irrigation purposes.

3.5.3. Non-conventional water

Considerable efforts are made in Tunisia to develop non-conventional water resources, particularly desalinized and treated water, and to increase their mobilization. In fact, the production cost for these resources is generally very high. Only 5 % (190 $10^6 m^3$) of the water mobilized in Tunisia in 2005 was from non-conventional sources although its supply is increasing annually by 8 % (Fig 3.3). However, its use is limited to 24 %. Non conventional water is mainly used in agriculture (feed crops, industrial crops, forests, etc.), the urban sector (irrigation of natural parks, etc.) and the tourist sector (golf courses, hotel gardens, etc.). This limited use of non-conventional water is mainly due to (i) the existence of available conventional water next to the treatment plants (75 of which are currently operational) discourages users to use this source of water, and (ii) the limited storage capacity for non-conventional water in the irrigated areas makes its supply unstable over the agricultural seasons (Ben Hammem, 2006). However, the government plans to double the production of this water by 2030. Also, numerous incentives will be provided to encourage its use.

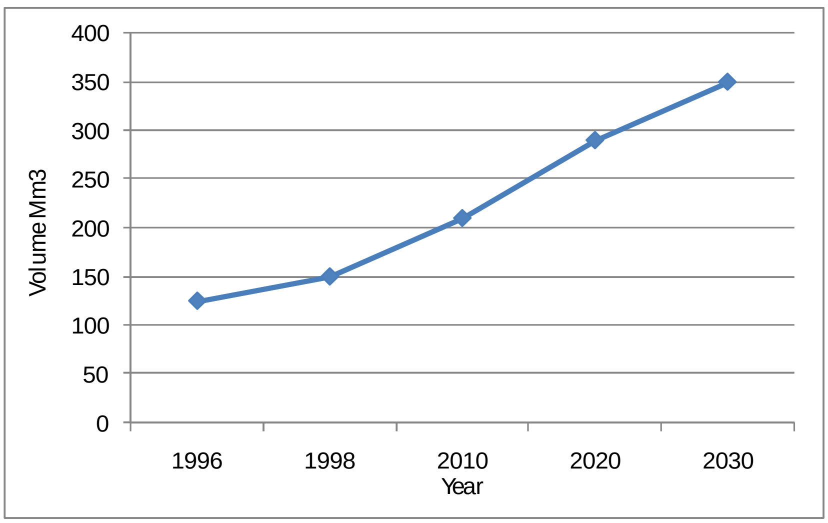


Fig 3. 3. Current and forecasted mobilization of non-conventional water (MARH, 1998)

3.6. Water demand and irrigated agriculture in Tunisia

3.6.1. Water demand by sector

From 1990 to 2010 total water demand in Tunisia is expected to increase from 1920 $10^6 m^3$ to 3165 $10^6 m^3$, representing an increase rate of 40 %. As shown in table 3.4 below, this increasing demand is mainly due to the fast growing requirements for water by the agricultural sector (more than 80 % of total water consumption) in addition to improvements in income and the development of the tourist sector. Water use for domestic and tourist purposes has doubled during the past two decades.

Table 3. 4. Evolution of water demand in Tunisia

Sectors	1990		2010	
	10^6m^3	%	10^6m^3	%
Agriculture	1575	82.1	2540	80.2
Urban	240	12.5	462	14.6
Manufacturing	85	4.4	123	3.9
Tourism	20	1	40	1.3
Total	1920	100	3165	100

Source : MARH, 1998

From another hand, the irrigated sector is crucial for the national development since it occupies 7 % of the country's useful agricultural area, but contributes significantly to the development of agriculture. It accounts for 30-35 % of agricultural production value, 95 % of horticultural crops, 30 % of dairy production, 70 % of tree crop production, 22 % of agricultural exports (mainly oranges and dates), and 26 % of total agricultural employment (Al Atiri, 2007).

3.6.2. Evolution of the irrigated areas

Irrigated areas have continued to increase in Tunisia during the past two decades (Fig 3.4). In 2003, they accounted for around 400,000 hectares, of which 32 % was in the north-east, 31 % in the centre-west, 22 % in the north-west, 9 % in the south and 6 % in the centre-east of the country (Lachaal *et al.*, 2005b; Al Atiri, 2007).

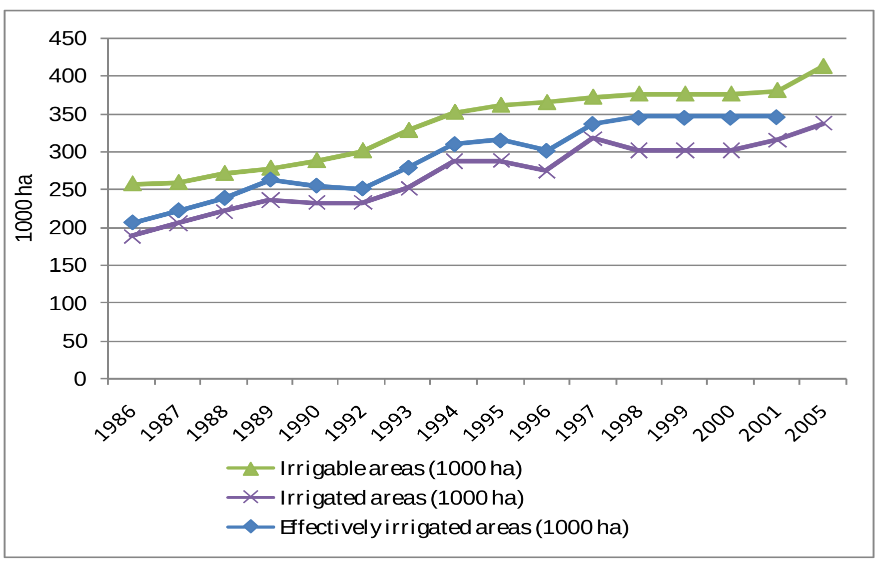


Fig 3. 4. Evolution of the irrigation areas during past decade (1986-2005) in Tunisia (MARH, 2006)

Despite this increase in irrigated land area, the intensification and occupation rates[7] are still below policy makers' expectations. The intensification rate was approximately 90% in 2005 (Fig 3.5) which is much lower than the potential rate - estimated to be around 130 % (MARH, 2006).

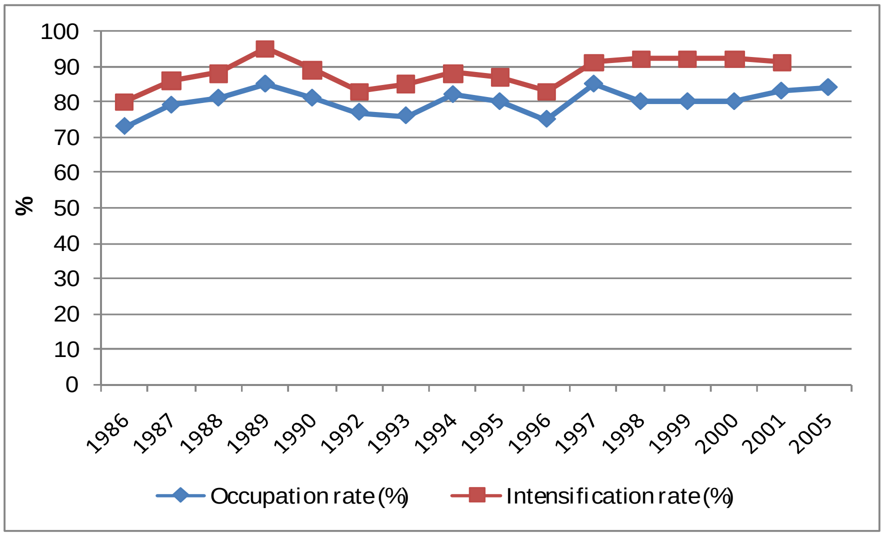


Fig 3. 5. Evolution of the occupation and intensification rates of irrigated areas In Tunisia (MARH, 2006)

In 2003, the volume of water used for irrigation was estimated at 1889 $10^6 m^3$, with average consumption per hectare of approximately 5500 m^3/year. Consumption reaches 20000 m^3/Ha/year in the oasis. In the north the average consumption is 4000 m3/hectare/year (Horchani, 2007). Water from shallow aquifers irrigates over 150,000 hectares, whilst deep groundwater irrigates around 70,000 hectares. Surface water (mainly from dams) irrigates 130,000 hectares, treated wastewater irrigates 7,000 hectares, and the rest is partly irrigated from direct pumping from natural storage (Lachaal *et al.*, 2005b).

3.6.3. Three modes for managing the irrigated areas

Three regimes of management in the irrigated areas could be identified in Tunisia (Fig 3.6). These are the private regime secured by individuals, the administrative regime secured by the CRDA (Commisariats Régionales de Développement Agricole created in the 1990's) and the collective regime secured by the WUAs (Thabet and Chebil, 2007).

[7] Occupation rate = irrigated area / irrigable area; Intensification rate = effectively irrigated areas / irrigable areas

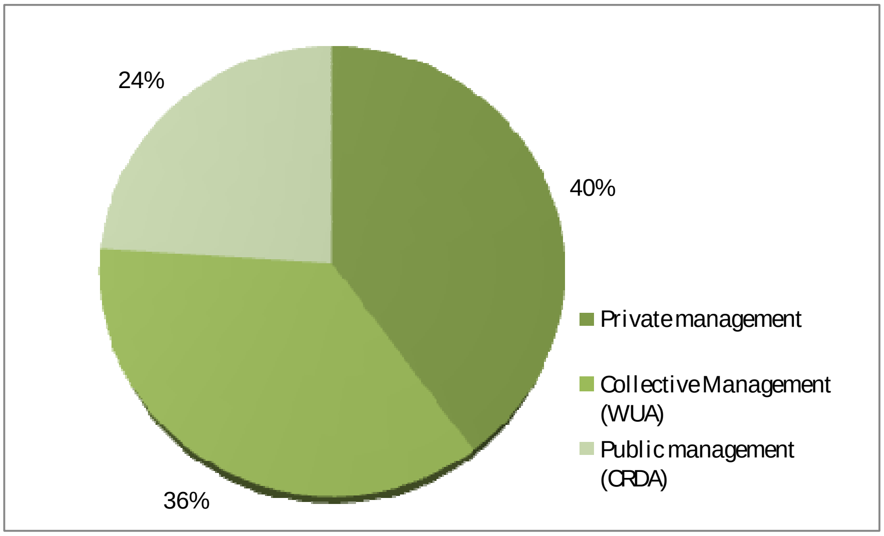


Fig 3. 6. Distribution of the irrigated areas according to the management regime (MARH, 2004)

- Private management applies to 40 % of the total irrigated area. It mainly relates to the areas irrigated from superficial aquifers, using a well or other techniques. Farmers in these areas are responsible for the investment and operational costs of their individual water systems.

- Collective management concerns areas that are managed by WUAs. These areas have expanded to cover 36 % of the total irrigated land area in Tunisia. Collective irrigation networks are set up through public funds, but their management is delegated to the WUA, which fixes the water fees and is responsible for their collection. The WUA also assumes responsibility for investment and the development of irrigation in its areas.

- Public management of large irrigated areas, which constitute around 24 % of the total irrigated lands in Tunisia. This management is still being secured by government agencies (CRDA). Under the Agricultural Reform Law, farmers participate in investment efforts in these areas and pay the total or a part of the O&M costs.

Table 3. 5. Distribution of irrigated areas according to the management regime and to the source of water (2003)

Source of water	Private irrigated perimeters (Ha)	Public Management CRDA	Collective Management GIC
Surface	-	84000	59000
Tubewells	10000	8000	74000
Shallow wells	145000	-	-
Springs and intermittent streams	10000	-	15000
Reclaimed wastewater	-	5000	2000
Total	165000	97000	150000

Source: MARH (2004)

3.6.4. Distribution of irrigated land areas between regions

The Figure 3.7 below shows the distribution of irrigated land areas in 2004 between different Tunisian governorates. It is clear that irrigation is the most highly developed in the governorates of Nabeul, Kairouan and Sidi Bouzid. However, Kairouan and Sidi Bouzid are considered as agricultural-oriented governorates; whereas the tourism and manufacturing sectors are widely developed in the governorate of Nabeul, which increases pressure on water resources in this region.

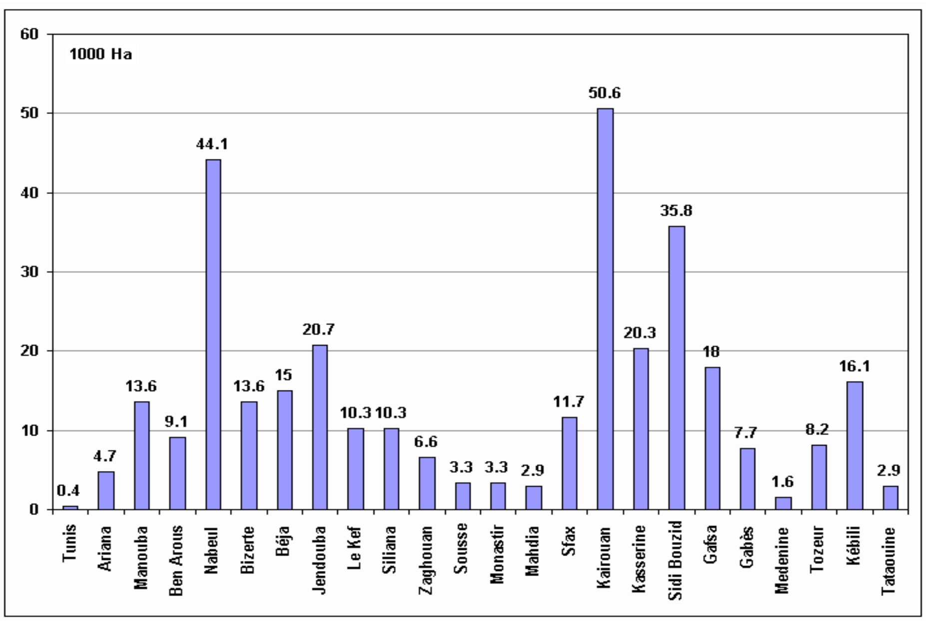


Fig 3. 7. Distribution of the irrigated areas between various governorates in Tunisia (MARH, 1995)

3.6.5. Distribution of irrigated land areas according to farm size and structure

The average proportion of irrigated land (i.e. irrigated areas / total farm size) per farm in Tunisia was around 7.8 % in 2005 (Table 3.6). Most of the irrigated farms are between 10 and 50 hectares in size. Farms in this category hold 33 % of the total irrigated land in the country. Only 5.9 % of their total size is designated for irrigation. However, farms in the small size category (less than 5 ha) irrigate an average 17.1% of the total farm size. Farmers in this category hold 24.4% of the total irrigated land in Tunisia.

Table 3. 6. Distribution of irrigated land areas in Tunisia according to farm size

Irrigated farm size	National survey 1994-1995			National survey 2004-2005		
	Total area (1000 ha)	%	Irrigated /cultivated area (%)	Total area (1000 ha)	%	Irrigated /cultivated area (%)
Less than 5 Ha	71.9	24.4	17.1	82.6	25.0	16.0
5 to 10 Ha	52.3	17.8	9.7	65.6	19.8	9.8
10 to 50 Ha	99.7	34.0	5.9	108.8	32.9	6.3
50 to 100 Ha	19.0	6.5	4.2	20.9	6.4	4.5
More than 100 Ha	50.9	17.3	5.7	52.6	15.9	6.4
Total	293.8	100	7.5	330.6	100.0	7.8

Source: MARH, 2005

3.7. Water balance

According to a previous study done by the MARH (MARH, 1998), a projection for future water demand and availability shows that a critical situation in terms of water balance is likely to occur within the next decade (year 2020-2030). In 2030, water demand is estimated to be around 2760 $10^6 m^3$, whilst available resources will only amount to approximately 2732 $10^6 m^3$ (Fig 3.8). The desalinization of brackish water is planned to reach 46 $10^6 m^3$/year whilst the treated water supply is expected to be around 350 $10^6 m^3$.

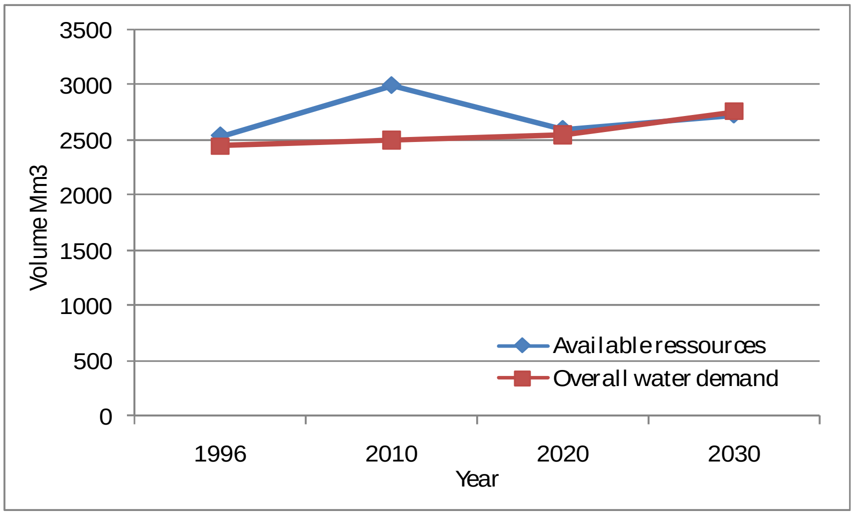


Fig 3. 8. Estimated water balance 1996-2030 (Source: MARH, 1998)

The considerable increase in water demand in Tunisia can be explained by many factors, such as rapid demographic growth, diversification of economic activities, and significant improvements in income and quality of life. The Tunisian population increased from 3.7 million inhabitants in 1956 to more than 10 million in 2001. Also, the urban population rate increased from 33 % in 1956 to 65 % currently. The number of inhabitants is forecast to reach approximately 13 million by 2025 and the per capita water availability is expected to decrease. In addition to the urban water needs, the level of agricultural production also needs to be increased to improve food security. However, in such difficult climatic conditions, irrigated agriculture remains an essential option for policy makers.

3.8. Water development: main future guidelines from the "Water Master Plan"

Unlike other North African countries, Tunisia developed and adopted numerous laws and plans regarding its water resources many decades ago. Water Master Plans (WMP) have existed since 1970. The first WMP was drafted for the northern part of Tunisia, as this is the region containing most of the resources and related activities. In 1977 and 1983 the centre and then the south followed by implementing WMPs. The MARH developed these plans and is also responsible for their implementation.

The expected future water deficit made policy makers change strategic direction from increasing water production to demand management by focusing on financial means, water pricing, new techniques, legal and institutional mechanisms.

Currently, the Tunisian national strategy centres around three major points (Ben abdAllah, 2007):

- *The management of demand*: a question of preserving the resource, ensuring economic efficiency and preserving social equity through good water distribution.
- *The integrated management of water resources*: the use of groundwater during periods of drought, the recharge of groundwater to counteract problems of over extraction and degradation, and the use of treated waste water and brackish water.
- *Resource and environmental protection*: quantitative conservation through reinforcement and improvement of water capture and storage capacities, qualitative conservation of water resources and ecosystems through reductions in pollution, monitoring, and cost evaluation.

With regard to demand management, some reduction targets were set as objectives for the current decade. These objectives are (i) reduction by 30 % in water used in agriculture, by improving and modernizing irrigation systems and distribution networks, and by replacing some of the existing hydraulic infrastructures; (ii) reduction by 20% in water used in the industry by recycling, improving production processes and the introduction of clean technologies; and (iii) reduction by 27 % in drinking water consumption, principally through modernization of current equipment.

Goals regarding integrated water management and resource protection were as follows:

- Make use of reclaimed water in the agricultural and industrial sectors
- Evaluate groundwater recharge potential
- Desalinate brackish groundwater for drinking
- Promote the use of agricultural species tolerant to salinity and hydraulic stress
- Protect water resources from pollution

3.9. Conclusion: constraints on the development of the irrigation sector

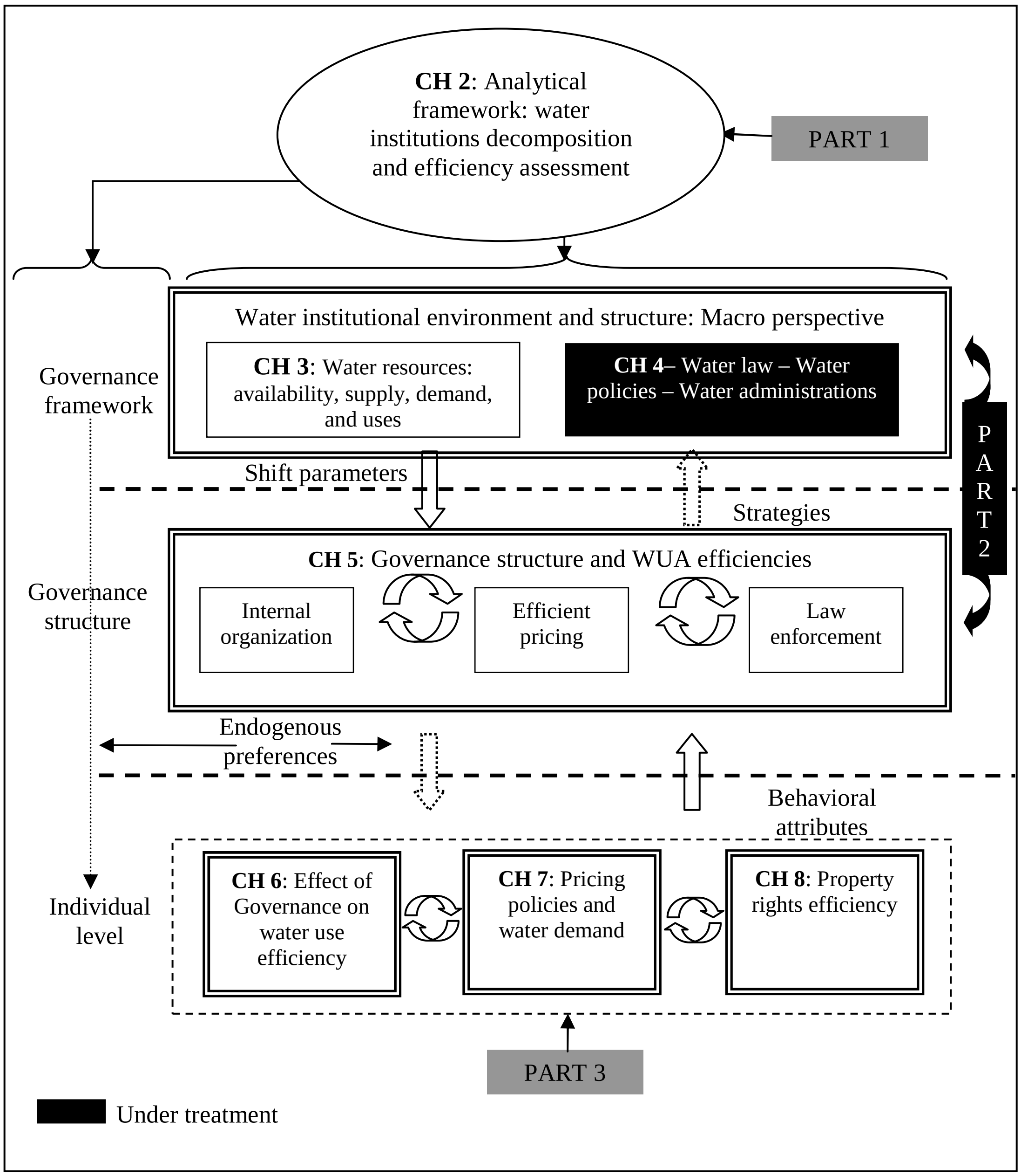
From this short discussion regarding the use and potential use of natural resources (land and water) in Tunisia, it is important to summarize the following points:

- Despite the considerable efforts made during recent years to develop new irrigated areas in Tunisia, the intensification rate for existing areas and yields of irrigated crops are still below expectations. In fact, the current intensification rate is approximately 85% whilst it could reach 130% according to government expectations. Also, yields are 50 to 60% below potential (MARH, 2006). According to Bachta *et al.* (2000) (quoted in Fouzai, 2007), the increases observed in agricultural production are mainly due to the expansion of irrigated land areas and not to the intensification of existing areas.

- Many of the private irrigated areas (from wells) experience critical situations due to the overexploitation of groundwater. The salinisation of soils in many of these areas, where groundwater is salty, is an illustration of degradation. In addition to the degradation of land and water resources, private management also provokes many conflicts between neighbouring farmers.

- Water supply will soon reach its limit; imbalance between water supply and demand will have a critical effect on irrigated agriculture. In these circumstances, the cost of water will increase and the sustainability of irrigation activity will become questionable; particularly if farmers' revenue does not improve in coming years.

- Free trade agreements signed by Tunisia and the new trade context that is currently being implemented in the Mediterranean region raise concerns regarding efficiency and competitiveness for Tunisian farmers. This is considered to be a further urgent issue which will increase pressure on natural resources.


CH 2: Analytical framework: water institutions decomposition and efficiency assessment
PART 1
Water institutional environment and structure: Macro perspective
Governance framework
CH 3: Water resources: availability, supply, demand, and uses
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Shift parameters
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PART 3
Under treatment

Chapter 4. Water laws, policies, and administration in Tunisia

Abstract

This chapter presents an overview of the main irrigation water institutional components in Tunisia. After presenting the main state of water resources availability, supply, demand and uses in the previous chapter, the current one describes water laws, policies, and administrative aspects currently implemented and operating in Tunisia. These will be discussed from a formal macro-level perspective. Results, drawn from various literatures, show that many irrigation institutions exist in the country. However, some juridical, technical, financial and social problems related to their functioning also exist and have to be reviewed and analyzed further.

4.1. Introduction

For a more precise treatment, our review of the formal macro-level water institutions in this chapter is relying on the analytical framework based on institutional decomposition. This framework distinguishes three main institutional components: water law, water policy, and water administration. It also highlights a few key institutional aspects under each principal component. The current chapter concentrates only on some of these key institutional aspects. This choice was depending on the availability of bibliographical and data resources

4.2. Water laws[8]

Water law assumes a central place in the functioning of water institutions as it gives the necessary legal basis to water policy as well as providing an operational framework and powers of enforcement for water administration and its regulatory arrangements (Saleth, 2004).

From a historical perspective, legislation relating to water resources in Tunisia can be divided into four main contexts[9]:

(1) From the first millenium BC until the arrival of Islam, particularly during the Roman period, water resources were managed by building aqueducts for domestic and agricultural use and for water transfer between regions.

(2) During the Islamic empire, water was considered to be “God’s Gift”, and consequently it was declared to be collective property, known as "waqf". In this context, some of the water resources and wells were declared as "waqf" and the public had full access rights to them. However, Islam strongly urged moderation and thriftiness in the use of water, even when performing ablution.

(3) The French colonization period (1881-1956) was characterized by the first water Decree favouring the colonists. The Decree of 24 September 1885 defined a public surface water domain, without any reference to groundwater resources. On 24 May 1920, a water committee

[8] All documents relating to specific decrees and laws which will be cited in this section could be found at: http://faolex.fao.org/faolex

[9] Based on Louati *et al*., 2005.

was appointed. The Decrees which were instituted in 1933, 1935, 1936 and 1938 provided regulations for water use and fixed the charges for this water use; the Decrees of 30 July 1936, 11 January 1945 and 17 March 1949 introduced regulations relating to the Non Governmental Organizations (NGO) involved in water use.

(4) The fourth period began with the independence of Tunisia. It was characterized by evolutionary water legislation which related specifically to resource mobilization and exploitation (urban, agricultural, industrial and tourist uses) whilst focusing on water quality and environmental protection of the resource. In order to satisfy water demands from different sectors, a national programme was established to bring into existence many types of hydraulic infrastructure. With the evolution of this plan, hydraulic planning was gradually transformed into an established legislative system. The objectives of this legislative system were to identify the rights and duties of all actors involved in the water field, to preserve water resources, and to ensure its equitable allocation. In 1975, all legislative water documents were updated and promulgated in the Water Code (Law n° 75-16, 31 March 1975).

Since 1975, the Water Code has been continually updated by modifying some legislation and adding new regulations to address socioeconomic and technical requirements. The law n°75-16, 31 March 1975, was largely modified and completed by laws n°87-35, 6 July 1987; n°88-94, 2 August 1988; The law n° 2001-116, 26 November 2001; and law n°2004-24, March 15, 2004.

In 2001, new reforms were introduced identifying water as a national resource that everyone must preserve, protect, and use in a sustainable manner, to satisfy both the needs of citizens and wider economic demand. For instance, the largest consumers (more than 5 million m^3/ year in agriculture, more than 1000 m^3/ year in the urban sector and 5000 m^3/ year in the industrial sector) came under an obligation to audit their water use periodically. Consumption quotas are imposed during periods of scarcity. The development of non-conventional water resources (desalination and treatment of wastewater) was encouraged and individuals were permitted to produce water and distribute it. Thus, the new 2001 version of the Water Code reflects an increased awareness of the need for water conservation. It makes various stakeholders aware of the importance of water and the need to prevent its overuse. Also, it reflects the urgent need to manage demand for water in line with forecasts of decreasing availability. Under this new legislation, improvements in water use efficiency in all sectors became the top priority for water management policies. Considerable measures were thus undertaken in order to promote water savings in agriculture by encouraging the adoption of water saving technologies.

The specific areas of legislation relating to the irrigation sector are summarized in the following sections.

4.2.1. Agrarian law

Irrigated areas and water use in Tunisia were affected by the agrarian laws instituted for the agricultural sector. In fact, a special law framing land reforms in the public irrigated areas was established in 1963 and modified in 2000: Law n° 63-18, 27 May 1963 (modified by the law n° 30, 6 March 2000). The reform is based on four major principles: (i) the limitation of property land size within a minimum and maximum range which could differ according to the cultural orientation of the irrigated area, (ii) the contribution of land owners to the development of their irrigated areas (e.g., investments in infrastructure), (iii) the obligatory agrarian reform which, if required, obliges a given farmer to provide part of his land ownership for the public interest (e.g. network location, other irrigation infrastructure - with the aim of achieving better valorization of irrigation water), and (iv) the obligation to valorize the lands (cultivation or other use) located in defined irrigated areas. In many cases, these rules are not well enforced.

4.2.2. Water law and decentralization

After the promulgation of the law n° 87-35, July 1987 and its related decrees, the decentralization process for water management in Tunisia could be declared officially underway. The responsibility for managing irrigated areas[10] was attributed either to the CRDA or to the WUAs. The WUA organization, mode of creation, and functioning is set out by the decrees n° 87-1261, 27 October 1987 and n°87-1262, 27 October 1987, respectively (Al Atiri, 2007). According to statute, WUAs have to be created in order to achieve one (or more) of the following objectives:

[10] Apart from those that are privately-managed

- Exploitation of public water resources at a local level;
- Fulfilment of tasks relating to public water resource management under their jurisdiction. This means for instance, that they have to organize farmers in sub-districts, to ensure the delivery of irrigation water at farm level, to collect water fees from irrigators, to undertake investment in order to accomplish these tasks, etc;
- Irrigation or sanitation of land in the perimeter through drainage or any other sanitation method; and
- Exploitation of drinking water systems[11]. In addition to irrigation, WUAs can also have greater responsibility for managing the drinking water provision in very rural areas.

These objectives were rectified by the law n°2004-24, March 15, 2004 which sets the following new objectives:

- Collective management and protection of natural resources in their territories;
- Endowment of their territories with the necessary agricultural and rural equipment and infrastructure;
- Contribution to extension services in order to enhance farm productivity in their localities;
- Cooperation and exchange of information.

It is clear that these new objectives call for increased participation and collective involvement in water resource operation and management costs. In view of these objectives, it is also evident that WUAs have become a crucial component of the institutional scheme for water in Tunisia.

According to sections 10 and 11 of the water code, each WUA has to be managed by an administrative council composed of 3 to 9 members belonging to its adherents and elected by the general assembly for a total period of three years (Hamdane, 2002). More details as to the organization and functioning of these associations will be provided in section 4.5.2 of this chapter.

[11] There are three types of GICs (called WUAs in this dissertation) (Groupement d'Intérêt collectif) which are: GICs for irrigation water management, GICs for drinking water management, and mixed GICs. GICs in Tunisia are also called GDA (Groupement de développement agricole) since 2007.

4.2.3. Property rights

The property rights for water were also changed in Tunisia by the law n° 75-16, 31 March 1975 from a full property right to a simple water usage right for a given volume that is generally relative to the area of land owned (Al Atiri, 2007). Water above this volume is then considered to be in public ownership.

4.2.4. Promoting technology

Water legislation is positive towards the development of water saving technology in the different sectors (industrial, tourism and domestic sectors). To achieve efficient water management and use, it is necessary to ensure that the technologies introduced are accessible, socially acceptable, and easy to maintain. In addition, conscious of the need to use water efficiently in agriculture, a Tunisian programme sets a direct financial subsidy for each farmer who invests in water saving technology.

4.2.5. Water law and private participation

Despite the fact that Tunisia has privatised many public services within the framework of the “privatization programme” which started in 1987, water supply and sanitation services are still wholly provided by government agencies. A previous study, carried out in 1999 by the ONAS (National Sanitation Utility of Tunisia), proposed that a number of tasks and services relating to water provision and maintenance could be contracted out under some specific forms of service-contract arrangement (Chaibi, 2006).

In order to promote the involvement of the private sector in the development of non-conventional water sources, a specific amendment to the Water Code was promulgated. The law n° 2001-116, 26 November 2001 (mainly sections 87 and 88), allows private parties to produce and distribute water, either for themselves, or for third parties, provided that the water source is non-conventional, e.g. desalination. A financial incentive programme was linked to this law, aimed at promoting the development of non-conventional water for different uses.

4.2.6. Irrigation pricing and water laws

Water provision and pricing in irrigated areas is framed by section n°106, of law n° 2001-116, 26 November 2001. According to this section, water fees used to exchange water between CRDA and WUAs, have to be fixed according to a "cahier de charge" which also has to be approved by a specific decree proposed by the minister of agriculture and hydraulic resources.

General conditions for water provision and exchange between CRDA and farmers in the public irrigated areas are specified by the decree n°91-1869, 2 December 1991. This decree describes the contract which is put in place between CRDA and the irrigator, specifying the duties and rights of each party (e.g. operation and maintenance, and installation of water meters), the pricing method (e.g. volumetric, binomial, specific-case prices), the invoicing and payment modes (e.g. deadlines, sanctions in the case of non payment), etc..

4.2.7. Quality protection

According to decree n° 91-362, 13 March 1991, an Environmental Impact Assessment (EIA) study is required for public and private projects likely to impact on the environment. Effects on hydraulic resources are also considered under this law. However the enforcement level for this law still needs to be increased (Chaibi, 2006).

Restrictions on the quality of treated water used in agriculture were also framed and specified by decree n° 89-1047, 28 July 1989, modified by decree n° 93-2447, 13 December 1993, which set the conditions for reuse of treated wastewater in the agricultural sector. Decree n° 74-1062, 28 November 1974 delegates this control and monitoring duty to the Ministry of Public Health (MPH). The quality of agricultural products produced in areas irrigated with reused treated water is also controlled by the MPH through Law n° 92-117, 7 December 1992, relating to consumer protection in Tunisia.

4.3. Water policies

Water policy relates to the declared statements as well as the intended approach of central government for water resource planning, development, allocation and management (Saleth, 2004). It includes statements that not only relate to the overall policy framework but also to specific policy issues such as investment priorities, water transfer, decentralization and private participation, field-level water conservation, and pricing and cost recovery policies.

In Tunisia, the independence of agricultural production from the highly variable climatic conditions was a main objective of policy makers during the 1950's. Accordingly, considerable public hydraulic investment was mobilized in order to control superficial water resources. Nevertheless, this water supply policy was not accompanied at that time by measures that sought to rationalize the growing demand for irrigation water. Policy makers were also facing another challenge due to the increasing competition for water resources created by other sectors (urban water use, manufacturing, tourism). These are considered to be more competitive whilst irrigation water is still being subsidized. Thus, irrigation policies have been shifted since the 1970's from supply towards an irrigation demand management perspective. New policies focus more on organizational and technical tools aiming to reach higher water use efficiencies in all areas of use. In this section, we first review the general, overall aspects of national irrigation water policy in Tunisia during the last three decades, and then provide a detailed description of pricing policies and cost recovery strategies.

From all of the relevant programmes, the following guidelines can be deduced for current national policy in Tunisia: (1) Investment in projects that aim to improve water use efficiency, (2) enhancement of participation in collective water management, (3) Pricing of water and water services and (4) subsidies and incentives for farmers and the private sector.

4.3.1. Water investment priorities

Public investment in the water sector was always considerable. In fact, 27 % of the total agricultural investment during the period 1962 to 1971, and 41 % during the period 1982 to 1991 was designated to the water sector (Mallek, 1988; Sghaier, 1995). In this sense, the major priority for the Decennial Water Resources Mobilization Strategy (1990 – 2000) was to increase water supply. The construction of more than 200 small and large dams and the drilling of more than 1000 deep groundwater wells has led to an increase in the volume of water resources mobilized from 60 % in 1990 to 87.5 % in 2004. The total budget for this strategy was around 2000 Million TND (constant price 1990[12]).

A Complementary Strategy (2001 – 2011) attempts to realize long-term objectives, in particular to ensure a sustainable balance between future demand and the availability of water resources. It partly consists of similar measures for continuing the Mobilization Strategy with the aim of reaching a mobilization rate of 95 %. Furthermore, this strategy places an emphasis on regulation measures between wet and dry years, water and soil conservation measures, and the recharge of aquifers. Thus, more attention is given to investment in technical, economic, and organizational aspects that should improve water use efficiency and cost recovery. Key strategic elements adopted in this respect are (MARH, 2006):

- Improvements in the efficiency of the collective irrigation network (through maintenance, refurbishment, and modernization projects);
- Improvements in the technology used at the plot level in order to increase water use efficiency by farmers;
- Implementation of adequate pricing methods that are well adapted to the socioeconomic conditions in each region;
- Generalization of collective management (through WUAs) across all irrigated areas[13] and enhancement of user participation;
- Overall mobilization of surface water resources

As shown in table 4.1 below, the new government strategy in terms of hydraulic investment also seeks to encourage private investment in irrigated areas. This last figure increased from 19 % in 1990 to 37 % of the total hydraulic investment in 2004.

[12] Equivalent of 1678 Million US $

[13] Except those that are privately managed.

Table 4. 1. Evolution of public and private hydraulic investment (constant price 1990)

year	Agricultural investments (10^3 DT)	Hydraulic investments (10^3 DT)	Part (%)	Inv. Hydrauliques Public (%)	Inv. Hydrauliques private (%)
1989	328237	147452	45	81	19
1990	401400	166842	42	81	19
1991	425099	124833	29	68	32
1992	459236	140810	31	75	25
1993	489199	151873	31	76	24
1994	515807	158021	31	76	24
1995	596624	232709	39	76	24
1996	782531	262734	34	75	25
1997	735990	294410	40	82	27
1998	824310	279110	34	70	30
1999	860760	295760	34	66	34
2000	890010	337770	38	67	33
2001	930010	355190	38	68	32
2002	821690	384120	47	65	35
2003	861930	373580	43	65	35
2004	939980	382140	41	63	37

Source : MARH, 2004.

4.3.2. Project funding

The hydraulic sector in Tunisia is financed through national budgets and external loans largely provided by the World Bank. The international funds have a significant influence on water projects and on the implementation of new approaches to water management in Tunisia (Table 4.2). The involvement of these agencies could help in achieving a comprehensive water management framework that integrates social, economic and environmental considerations. From another viewpoint, this involvement can also increase pressure on policy makers to implement the necessary reforms.

Table 4. 2. Financing of the Water Sector in Tunisia

Financing Source	10th Plan (2002-2006)		11th Plan (2007-2011)	
	Investments	%	Investments	%
National Budget	947	48	1300	45
External Loans	808	41	1300	45
Grants	150	8	200	7
Self-financing	70	3	28	3
Total	1975	100	2888	100

Source : MARH, 2006

4.3.3. Water transfer

The Tunisian water transfer programme started in the early 1980's by connecting large northern dams with other dams in the central part of the country (Fig 4.1). The objective of this programme was to improve the quality of water already distributed and to reinforce storage capacities in the central and southern parts of the country. Transfers from one dam to another in the same basin were also planned, depending on capacities and climatic conditions inside each basin,

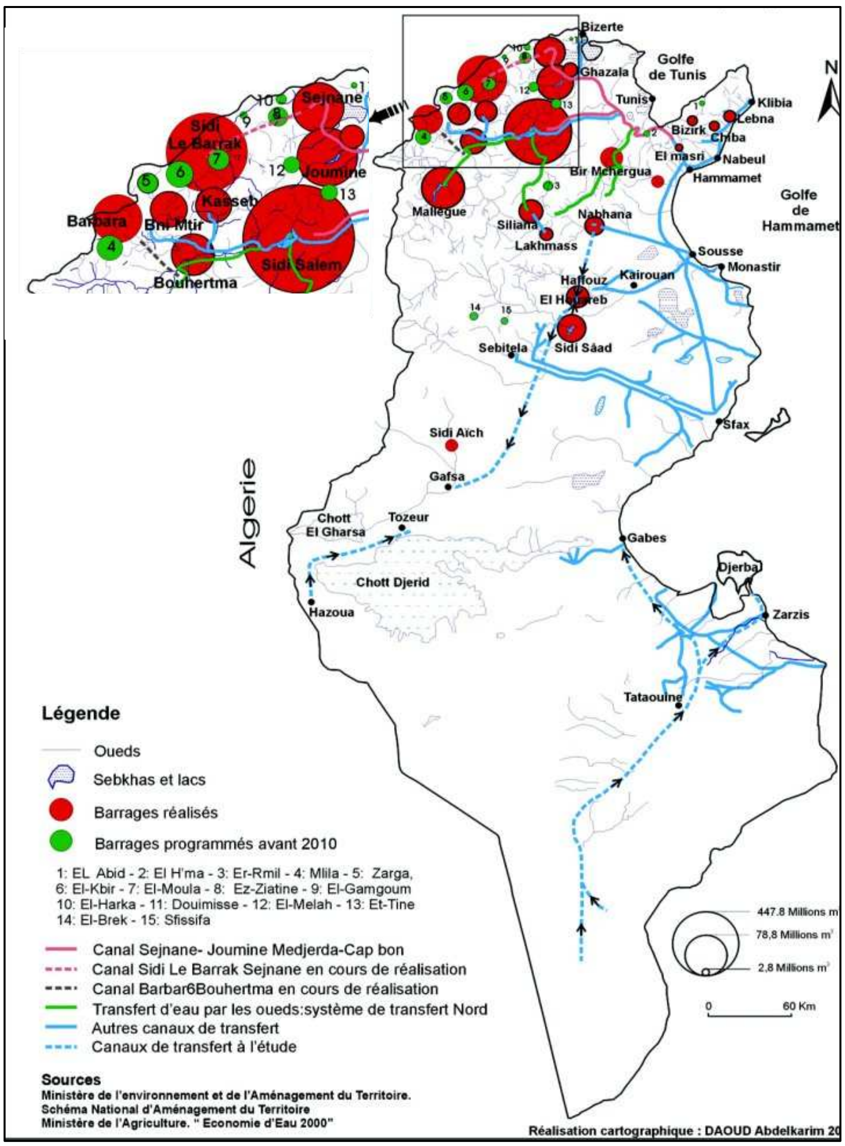


Fig 4. 1. Main dams and transfer canal in Tunisia

4.3.4. Decentralization and farmer participation

Water demand strategy in Tunisia calls for active participation by farmers and farmers' associations in managing irrigation systems. The strategy developed to enhance this participation is based on:

- Progressive disengagement of the government from tasks relating to the day-to-day operation and management of irrigation systems, and the transfer of these responsibilities to WUAs. The Government retains responsibility for maintaining and managing large infrastructures;
- Reducing direct and indirect subsidies that were provided to balance the WUA budgets. This seeks to gain higher levels of irrigation cost recovery;
- Enhancing the capacities of WUAs and allowing them to play a dynamic role in social and economic developments in agriculture.

4.3.5. Water privatization

Participation by private actors in maintenance and operational tasks in Tunisian irrigated areas commenced in 2001. In fact, at the start of the decentralization process, all operational and maintenance tasks were undertaken by the CRDA in each region. WUAs have to pay for these services via a specific invoicing procedure. A given WUA wishing to benefit from the services would submit an official demand to a specific department of their regional CRDA. Then, specialist CRDA staff would come out and complete the necessary fieldwork. Before 2001, payment for these services was not obligatory and they were perceived by WUAs, in many cases, as subsidies. However, from 2001, the CRDA began to inflate invoices for services provided to WUAs. The payment of these fees became obligatory. Those WUAs not paying ceased to benefit from the CRDA services. At the same time, the CRDA supplied a list of private companies in the region that could provide the same services at a lower price. The objectives of this strategy were twofold: firstly to raise WUA awareness as to the importance of maintenance and operational costs, and secondly to encourage the involvement of the private sector in the provision of irrigation services. Currently, more than 60 % of WUAs choose to contract with private companies for various types of service provision.

4.3.6. Field-level water conservation programme for irrigated agriculture

Significant efforts have been made since the 1970’s to promote modern field-level irrigation techniques. However, traditional gravity irrigation has persisted throughout the irrigation schemes in Tunisia. In 1993, a new coordinated programme was developed, with several simultaneous components such as; a major awareness programme for farmers, specific training for advisory technicians and irrigation engineers, support for research and development into new irrigation techniques, establishment of new national and regional organizations, and encouragement of private sector involvement, etc. The “National Irrigation Water Saving Programme” was furthered by the political decision to increase the rate of subsidy for the adoption of modern irrigation water saving equipment. The programme sets out various other actions to be undertaken in irrigated areas. Most of them seek to improve the efficiency of irrigation networks and techniques.

Actions undertaken within the framework of the “National Water Saving Programme”

- *Public and collective irrigated schemes:* For this type of irrigated area, appropriate actions are mostly determined by the specific characteristics of the common existing irrigation network. Generally, these actions can be: (i) to improve the effectiveness of the irrigation networks through the implementation of operational and management programmes and the installation of water meters; (ii) to adjust and increase water delivery capacity in order to satisfy existing water demand whilst respecting system capacity; (iii) to charge higher water rates to farmers; and (iv) to prepare a background for collective management

- *Privately irrigated schemes:* In these areas, private wells are the main source of irrigation. Some measures were undertaken to preserve the sustainability of the aquifers. Main measures are: (i) to identify the number of equipped wells in each privately irrigated scheme, in addition to the crop rotations and irrigation techniques used. This information will be used to set specific actions and rules for each scheme; (ii) in areas where aquifers are already overused, a prohibition on deepening existing wells or building new ones, in addition to the development of some awareness programmes to encourage farmers to adopt more efficient techniques, reduce their irrigated area, or grow less water-demanding crops.

- *At the parcel level:* Actions considered for the parcel level are as follows: (i) to guarantee substantial subsidies for farmers who invest in water saving technology, ranging from 40 % to 60 % of the total amount invested in the purchase of modern irrigation equipment; (ii) to enhance the capacity of local administration to improve their knowledge concerning the physical characteristics of their irrigated areas (e.g. soil, optimal doses and timings for the irrigation of different crops); (iii) to increase the intensification rate for the existing irrigated schemes; (iv) to construct storage reservoirs downstream from wells; (v) to reinforce the capacity of the local extension services.

Main results of the "National Water Saving Programme"

An evaluation of the water saving programme showed a high rate for the adoption of technology, whereby 321,000 hectares (80 % of total irrigated land) was being irrigated with modern equipment in 2005 (Fig 4.2). This area has increased by 60 % since 1995. By the end of 2000, the programme had achieved an investment of 335 Million TND (254 Million US$), of which 167 Million TND (123 Million US$) were in the form of direct subsidies to irrigators. , The following results concerning the efficiency of water use and crop yields were also recorded (MARH, 2005):

- Irrigation field-level efficiency increased from 50-60 % in 1995 to an average of 70-85 % in 2005; this was mainly due to the newly introduced techniques (e.g. sprinkler and drip irrigation). Efficiency improvements allowed savings of approximately 210 $10^6 m^3$ of water; which represents 10 % of the total water consumed for irrigation.

- Increases of 70 % in yields were recorded in market gardening and tree crops. This results in an occasional over-production of certain commodities at the national level (especially in the case of tomatoes). On average, market gardeners' profits increased by 97 % (from 2690 TND/hectare without water saving equipment to 5310 TND/hectare with equipment), whilst citrus farmers also increased their profits by 30 %.

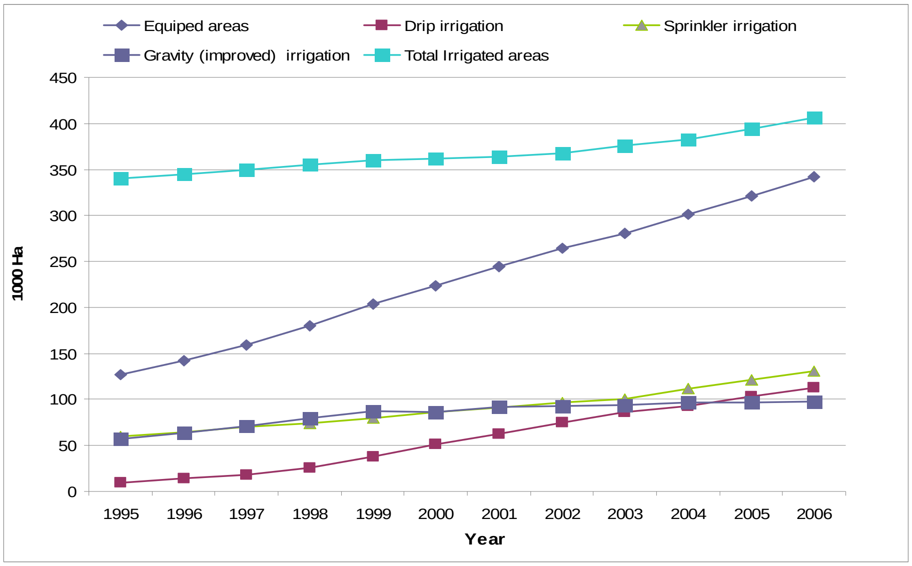


Fig 4. 2. Evolution of the areas equipped with water saving technologies

According to Al Atiri (2004), results of the programme were somewhat mixed. In fact, water saving is not very substantial in volume (because irrigators have not yet fully mastered the modern technology). However, water resources are now better valorized both at farm and national levels. Al Atiri (2004) also considers that water savings have been mainly used to intensify the existing irrigated systems. The adoption of newer water saving technology is still limited to certain high-value crops that are mainly grown by large farms well integrated into the food market chain (Fouzai, 2007).

It is also important to stress the high percentage (28.7 %) of areas equipped with "improved gravity techniques". By this technique, water is not pumped in pipes but distributed through gravity flow. Water losses with these methods are high and the level of water use efficiency obtained is generally lower when compared to the efficiencies achieved with other irrigation technologies.

4.4. Pricing and Cost recovery policies

4.4.1. Water pricing during the supply phase

Attempts to implement an adequate irrigation pricing policy in Tunisia started in the early 1970's. After the promulgation of the land reform laws in 1963, measures have been undertaken to make farmers contribute more to public hydraulic investment. At that time, a water pricing project was adopted for public areas in which large investments were made. The method applied was based on an arbitrary fixed charge per hectare and aimed to constrain users developing irrigation within their schemes by contributing to the water charge. Also, the prices set aimed to guarantee a minimum cost recovery for water production, operation, and maintenance costs (Ministry of the Economy, 1971). During the same period, the ministry of agriculture published a study on irrigation pricing in which it was clearly stated that “Pricing has to give to the water a real economic value. The water charge per cubic meter must be judiciously calculated in order to raise the conscience of users about the need for improving water use efficiency (Ben khelil, 1971)”.

Following a liberal orientation, the four-year plan (1973-76) for economic and social development in Tunisia became more explicit as to irrigation objectives. In this plan, the following main irrigation policy guidelines were mentioned:

- Producing water at a minimal cost,
- Improving water productivity,
- Intensifying the mobilization of renewable water.

At the same time, the “Office for the Development of Medjerda Valley” (Office de Mise en Valeur de la Vallée de la Medjerda: OMVVM) made several studies aiming to implement pricing methods and to provide a first attempt at a real pricing policy. This policy had to ensure three main requirements:

- Water is an important factor for wealth and those who benefit from it should pay its real price,
- Pricing of irrigation water should not be a constraint for the development of the irrigation sector,
- Pricing policy must be considered as an integral part of the global irrigation development strategy.

Some pricing systems were proposed by the OMVVM and water charges were calculated according to the time of irrigation flows. Farmers owning a total cultivated land area of less than two hectares were supplied free of charge.

Other methods for pricing irrigation water have also been applied in the public irrigated areas of Nebhana, Lakhmès and Badrouna (in the 'high valley of Medjerda'). Applied volumetric pricing methods took into consideration the soil quality, crop rotation and socio-economic conditions in each area.

The OMVVM has also adopted two-part binomial tariffs in some of these regions with the aim of promoting water conservation without hindering irrigation development. These tariffs generally include two terms: (i) fixed charge intended to cover part of the fixed production costs for water. Users have to pay this amount independently from the level of their water use; and (ii) a variable charge depending on the volume of water consumed. However this method was difficult to introduce to farmers. The designer of the method concludes (OMVVM, 1976 quoted in Thabet and Chebil, 2007): "Currently, the increase of water prices could deteriorate the financial capacity of small farmers. It would be preferable that the State undertakes the whole basic investments at least during the next transition period. Although it is difficult to implement, the increase in water prices for the future years, when economic conditions become more favorable, will be possible insofar as the user is warned about the operation".

Several other pricing systems were implemented at the beginning of the 1980's. These were implemented in the newly-created northern irrigation perimeters. A study done by the National Centre for Agricultural Studies (DEGTH, 1980) proposed a binomial pricing system for these areas, with some modifications: (i) taking into account farm characteristics and agricultural development objectives when proposing water tariffs; (ii) use of specific water prices during peak consumption periods.

Parallel to these pricing attempts, an administrative reform was implemented in Tunisia and new regional administrations were created to manage the irrigated areas in their regions. The new Regional Development Agencies had to adapt pricing systems according to their specific regional conditions (e.g. farmers' income, production systems, water availability). Recovery rates of variable costs, ranging from 19 % to 36 % of the total water cost were obtained after these considerations had been taken into account. According to the World Bank (1980), only part of the operational and maintenance (O&M) costs were reimbursed and the investment costs were not recovered.

4.4.2. Structural Adjustment Programme

In the 1990's, water pricing policy, initially applied for the most part in the Northern irrigated areas of the country, tended to spread to all the public irrigated areas managed by the regional government agencies, including oasis. The Structural Adjustment Programme (SAP) constitutes a new shift in Tunisian irrigation policy. In fact, the objective of making farmers pay for equipment renewal in addition to the O&M costs was clearly declared by the VIIIth and the IXth national economic development plans. These plans were based to a large extent on the SAP recommendations (Ministry of Agriculture, 1997).

Currently, the CRDA continues to fix and adapt pricing systems and levels within their administrative regions. After the creation of WUAs, also during the 1990's, each association was authorized to fix water prices in its locality whilst considering its financial balance and local constraints. From 1995, water tariffs were increasing on average by 15 % per annum.

4.4.3. Current pricing systems

Different pricing methods and structures are currently being applied in Tunisia. These methods differ according to the type of management (private, public, WUA, CRDA, etc.), existing equipment, and "development objectives[14]" for each region:

- Nominal pricing method: based on a fixed (variable between years) volumetric price per cubic metre of water consumed. This pricing method is applied in areas equipped with irrigation meters. It is currently being used in 285 irrigated areas[15] covering 125,338 hectares (65 % of the total public and collective irrigated areas).

[14] In areas where specific strategic crops are produced.

[15] Publicly and collectively managed areas

- Specific nominal pricing: an alternative nominal method with reduced (subsidized) rates in some areas where the government is seeking to encourage the plantation of some strategic crops.

- Per hour-charging: this pricing method is mainly applied in old irrigated districts where depreciated irrigation networks exist. These irrigated areas are currently being redeveloped to install a modern underground irrigation network with water meters. 127 irrigated areas (34,116 ha: approximately 17.6 % of the total public and collective irrigated areas) are currently using the per-hour-charging structure in Tunisia.

- Binomial pricing method: this pricing method is currently being tested and has only been introduced in 12 irrigated areas (17,550 ha: approximately 10 % of the total publicly and collectively irrigated areas). The binomial structure chiefly aims to improve the intensification rate. It is based on the assumption that water supply exceeds demand in a given scheme and that the intensification rate is low. It also aims to recover part of the fixed costs of water even if farmers do not use the whole available supply.

4.4.4 Water cost structure

In the absence of reliable and precise cost accounting in the CRDA, the total costs of irrigation water, including fixed costs, are unknown (Thabet and Chebil, 2007). The available information only covers water O&M costs. According to the MARH, Average O&M costs for irrigation water is composed of (Hamdane, 2002): 37.5 % labour costs; 17.6 % energy costs; and 10.4 % consumable products. The evolution of this cost structure for the period 1995-2003 is reported in table 4.3.

Table 4. 3. Structure of water operating and maintenance costs (1000 TND)

Year	Labor	Energy	Consumable products	Others	Total
1995	5 663	3 198	1 592	3 399	13 853
1996	5 570	2 306	2 042	2 755	12 675
1997	5 653	2 588	1 586	4 469	14 297
1998	5 758	2 581	1 820	4 827	14 988
1999	5 828	2 339	956	5 666	14 791
2000	5 934	2 983	2 411	5 361	16 690
2001	6 030	2 821	1 658	6 153	16 663
2002	5 412	3 131	1 320	8 544	18 409
2003	5 725	2 472	729	6 245	15 172
Average	5 730	2 713	1 568	5 269	15 282
Average share (%)	37.50	17.60	10.40	34.50	100

Source : DGGREE (various years)

According to Thabet and Chebil, (2007), the O&M costs provided by the MARH can only be considered as 'indicative' because they are not computed with a high level of accuracy. The workforce, for instance, can be employed in several publicly irrigated areas at the same time. This also applied to the machinery, transport vehicles, and heavy tools.

Taking into account the total volume of water invoiced by the CRDA in Tunisia, we can obtain the following average O&M cost per cubic metre as reported in table 4.4.

Table 4. 4. Trend in annual average operation and maintenance costs

Year	Total water O&M costs (TND)	Invoiced volume (Mcm)	water O&M costs (TND/Mcm)
1995	13 853 000	175 017	79
1996	12 675 000	161 578	78
1997	14 297 000	186 371	77
1998	14 988 000	169 079	89
1999	14 791 000	174 417	85
2000	16 690 000	218 793	76
2001	16 663 000	196 706	85
2002	18 409 000	238 605	77
2003	15 172 000	158 757	96
Total	137 541	1679 2 46	0.082

Source : DGGREE (various years); Thabet and Chebil, 2007.

Table 4.4 shows that, for the period 1995-2003, average O&M cost per cubic metre of water was around 0.082 TND. However, these costs do not include provision for equipment renewal nor exceptional maintenance costs. The fixed cost of water production and distribution is not considered either. The long term purpose of water pricing is to achieve total recovery of these latter costs.

4.4.5. Price levels and cost recovery

Irrigation water prices are spatially and temporally variable. In 2000, they ranged between 0.116 Tunisian Dinars per cubic metre (TND/m^3) in the Central coast and 0.035 TND/m^3 in the South (Hamdane, 2002). These prices have increased significantly during the past decade in order to take into account the inflation rate in addition to the O&M cost recovery. As mentioned above, the recommended annual increase in these prices was about 15 % in nominal terms (9 % in real terms). This rate of increase has been adopted since 1995. Consequently, average price per cubic metre, in the publicly managed irrigated areas increased from 0.060 TND/m^3 in 1995 to 0.110 TND/m^3 in 2003, with some annual variability as reported by Figure 4.3. Figure 4.3 shows that recovery of a proportion of large equipment renewal costs commenced from 1999 (see also Figure 4.4).

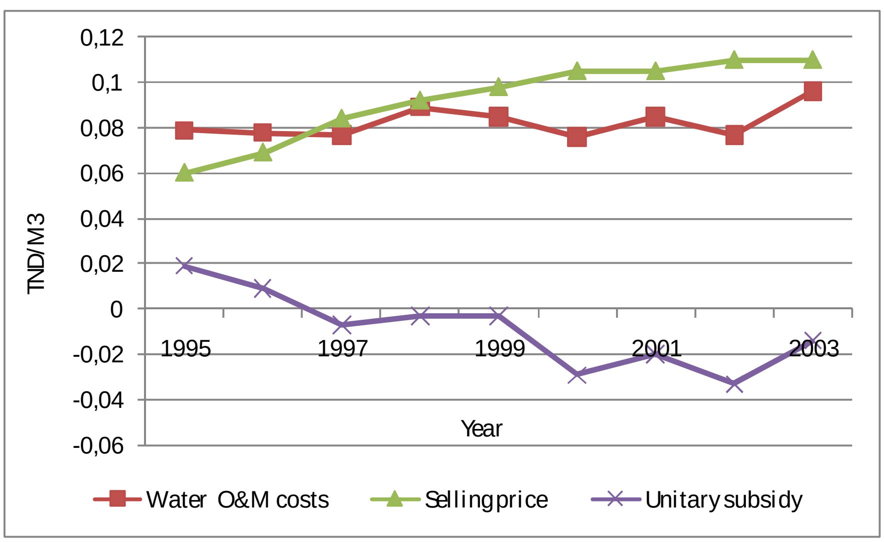


Fig 4. 3. Trend in water subsidy regarding the O&M costs[16] (TD/m3) (*MARH, various years)*

[16] The negative value of the subsidy means that the selling price covers the water O&M costs as well as a part of the renewal costs

Given that water prices and subsidies are fixed in each region according to its socioeconomic specific conditions, the recorded recovery rates consequently differ from one region to another (Fig 4.4).

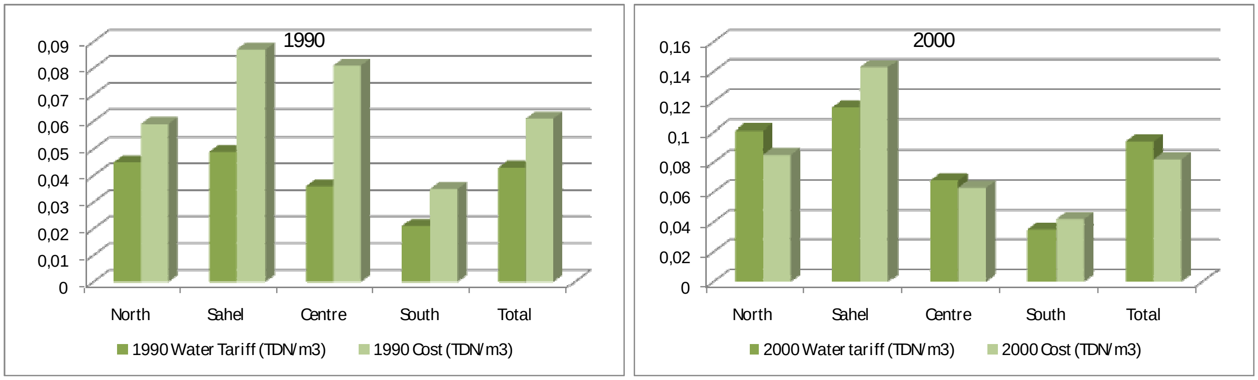


Fig 4. 4. O&M costs recovery by region (*Hamdane 2002*).

4.4.6. Future trends

The government is seeking to combine and implement various pricing methods in addition to the monomial one currently used. In areas exploiting groundwater sources, the volumetric method could have the opposite effect on water exploitation, particularly when water prices increase (Hamdane, 2002). Under these conditions, a trend to adopt a binomial pricing method is more effective in order to avoid over-exploitation of the resource from the same source.

The government also tends to take into account the socioeconomic and specific physical conditions of each irrigated area when fixing water prices. In fact, in some regions, farmers' revenue is still very low and their payment capacities should be considered before continually increasing water prices. The sustainability of irrigated activity in these areas could be threatened if accompanying development policies are not undertaken in parallel with the cost recovery objective.

4.5. National and regional water administration

4.5.1. National central administration

At the national level, the Ministry of Agriculture and Hydraulic Resources (MAHR), through its various departments, is considered as the principal manager of the water sector in Tunisia. However, other ministries, such as the ministry of public health, ministry of public finance, ministry of interior affairs, etc. could also be involved in some management aspects. Main central departments of the MAHR that are directly involved in water sector management are:

- General Department of Water Resources (Direction Générale des Ressources en Eau DGRE) which is responsible for monitoring and overall assessment of water resources at the national level;
- General Department of Dams and of Large Hydraulic Projects (Direction Générale des Barrages et des Grand Travaux hydrauliques) which is responsible for the construction of dams (and other large hydraulic projects) and their exploitation in irrigation and other uses.
- General Department of Agricultural Engineering and Water Exploitation (Direction Générale du Génie Rurale et de l'Exploitation des Eaux); This administration is responsible for: irrigation and drainage, rural equipment and development, and (irrigation) water supply for rural populations.

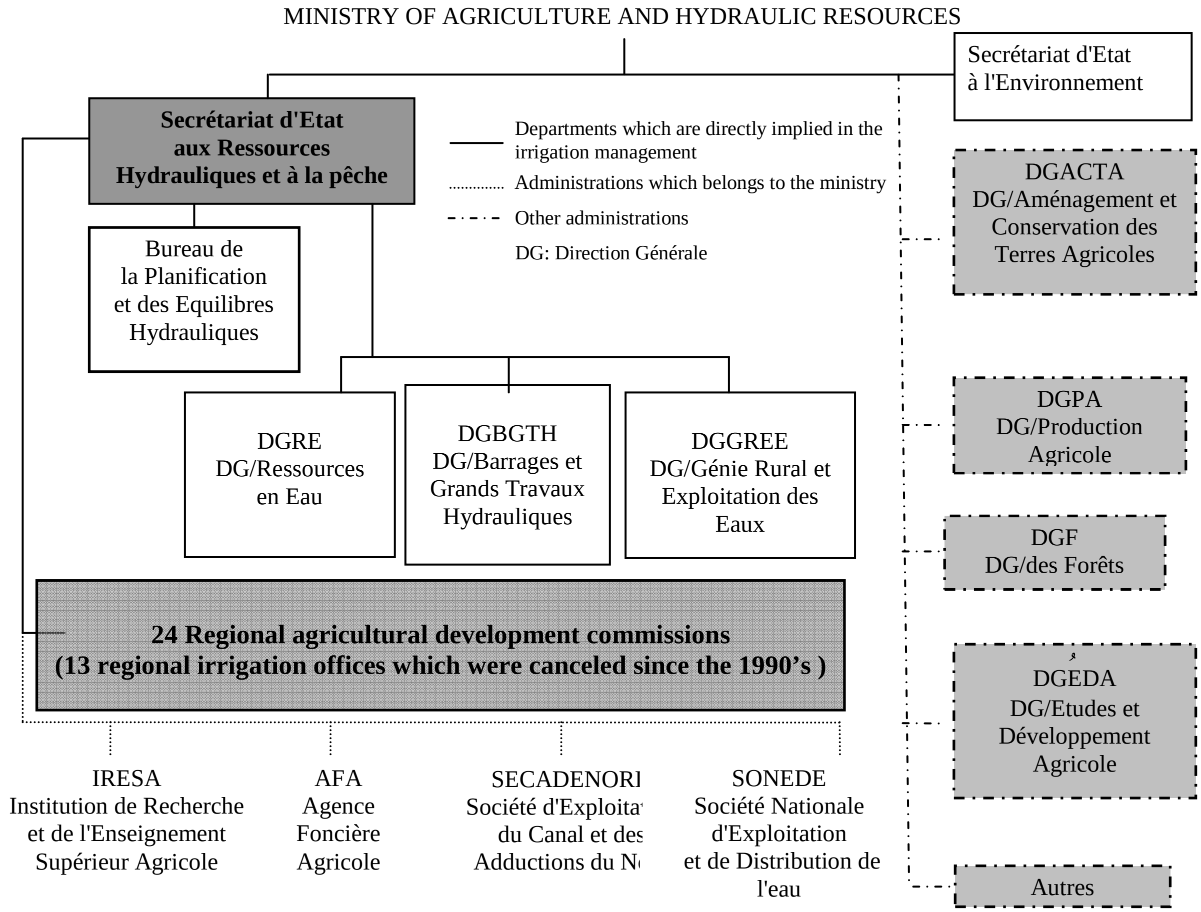


Fig 4. 5. Hierarchy of the national and regional administration involved in irrigation management in Tunisia (Al Atiri, 2003).

Some other public departments belonging to the MAHR are also involved in resource management. For instance, the SECADUNORD (Fig 4.5) is responsible for the maintenance of large water pipes and water transfer between regions. The AFA (Agence Foncière Agricole) is charged with the implementation and enforcement of agrarian law reforms (which could in some cases be related to irrigation development issues). The National agency for the protection of the environment (ANPE: Agence Nationale de Protection de l'Environnement) is a government agency that belongs to the ministry of the environment and is responsible for water quality control and monitoring.

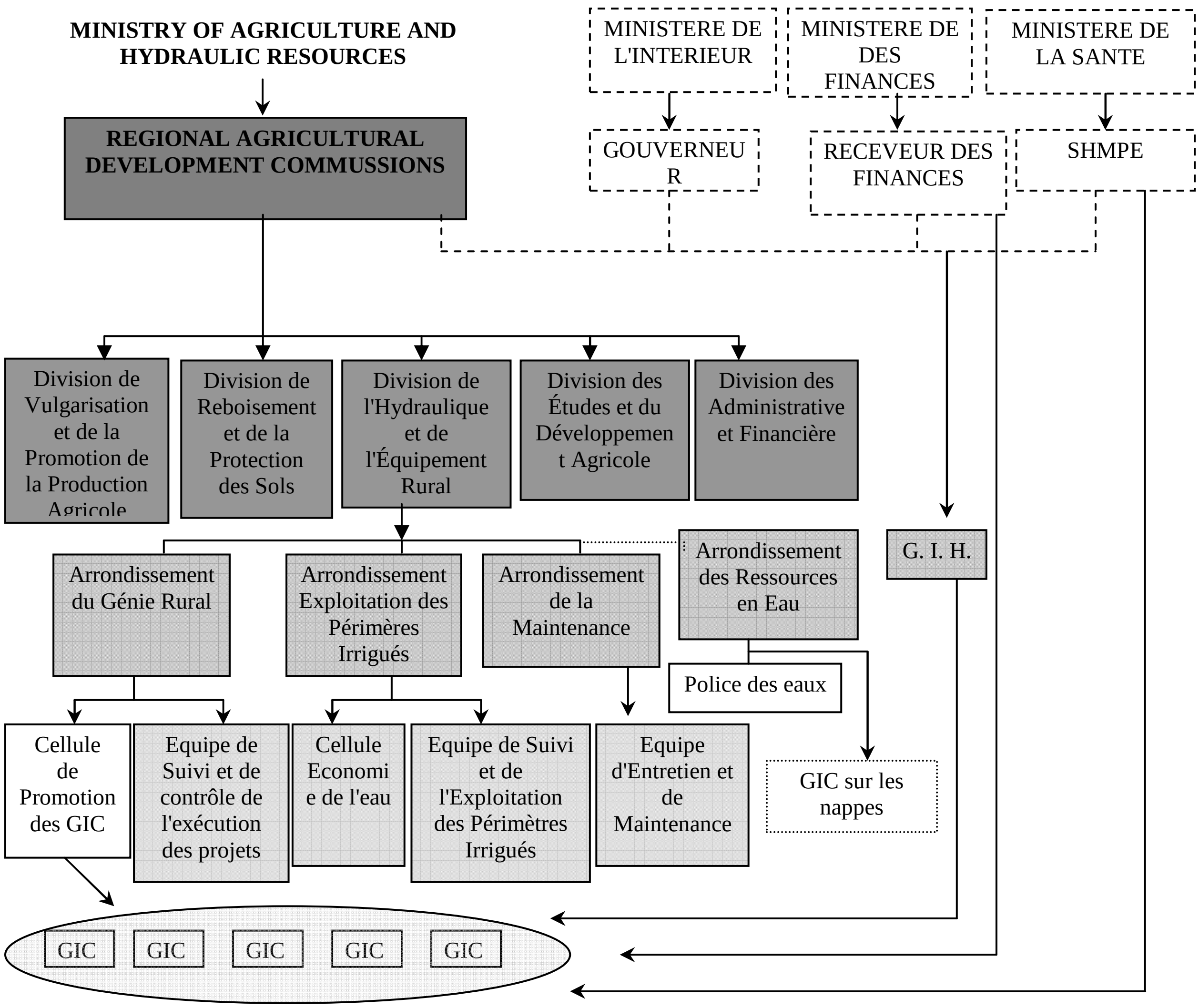


Fig 4. 6. Regional administration involved in irrigation water management (Al Atiri, 2003)
(SHMPE: Service de l'Hygiène du Milieu et de la Protection de l'Environnement, GIH: Groupement d'intéret hydraulique, GIC: Groupement d'intéret collectif)

At the regional level, there are the Regional Agricultural Development Commissions (CRDA), belonging to the MAHR (Fig 4.6). These represent the central authority of the ministry. They have legal standing and financial autonomy and are divided into many regional administrative divisions (Fig 4.6). Their principal role is the implementation of government agricultural and water policies in their regions. They are responsible for the planning and development of irrigated areas. With the help of the AVFA (Agence de vulgarization and de la formation agricole: agency for agricultural extension and training), they also promulgate agricultural and irrigation technologies across the irrigated areas under their authority.

The main CRDA administrative divisions involved in irrigation water management are: The division of rural engineering, division of public irrigated perimeters (PIP) management, division of PIP maintenance, division of water resources, division of water and soil conservation, and division of incentives and encouragement.

The CRDA undertakes all technical and financial tasks associated with the management of large irrigated areas: operation and maintenance of equipment, collection of water fees, organization of the irrigation systems, etc. However, in other areas that are managed with the participation of the WUA, the CRDA only manages large and costly tasks and continues to distribute water in bulk to WUAs for a fixed price.

The “Associations of hydraulic interests” (Groupement D’Intêrets Hydrauliques: GIH) (Fig 4.6) are important regional administrations with regard to irrigation. These are consultative entities that are chaired by the governor of the region and are composed of representatives from each WUA, from professional economic organizations, and from the relevant division of the CRDA. They have the sole decision making power with respect to creating new WUAs or the dissolution of existing ones.

Annual budgets and irrigation water tariffs are proposed by the CRDA and submitted to the MAHR for approval. The ministry decides on the level of subsidy and on the eventual financial allocation necessary to balance the CRDA irrigation management budget. Moreover, the CRDA receives specific allocations annually in order to undertake major maintenance or renovation tasks.

4.5.2. Water users’ associations

The dissolution during the 1990’s of the central “Office of Medjerda Valley Development[17]” (Office de Mise en Valeur de la Vallée de la Medjerda (OMVVM)) and the reinforcement of the CRDA role in regional irrigation development can be considered as major administrative reforms for the Tunisian water sector. Also, the revision, at the same time, of old judicial texts and the

[17] Central administration which was responsible of all irrigation management tasks at the national level.

implementation of new laws relating to collective water management are important elements in this policy shift. Within this context, various other actions were undertaken to improve regional and local management capacities - such as improvements in technical capacity, staff training, and so on. The creation of WUAs as an organizational entity, grouping together all farmers belonging to a given local irrigated area, was the main step in this decentralization process. The aim was to increase farmer participation in decision making and resource management. WUAs are established through government funding and are given responsibility for the collection of water fees as well as service related fees (infrastructure maintenance and so on). The number of WUAs for irrigation water management has risen sharply from about 100 in 1987 to 1142 in 2004 (MARH, 2006) managing more than 150,000 ha of irrigated lands (Fig 4.7).

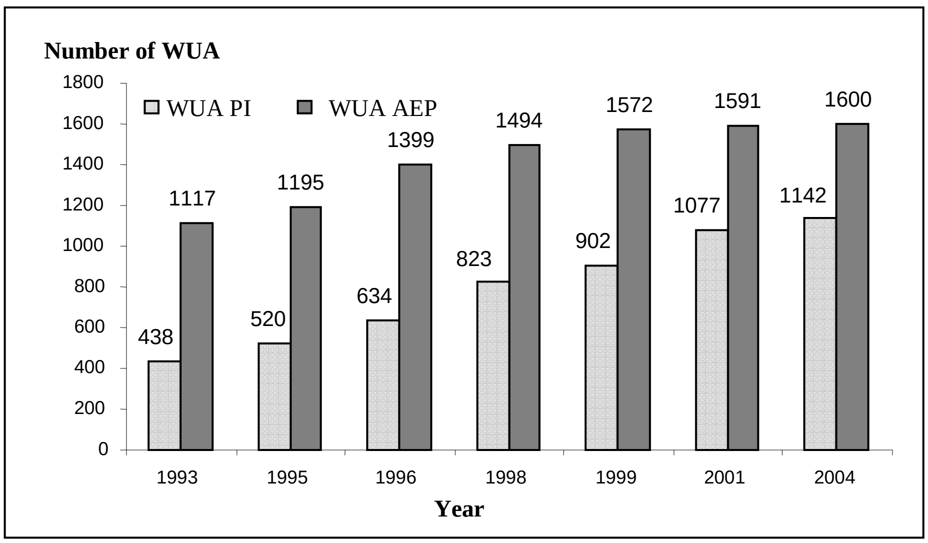


Fig 4. 7. Evolution of the number of WUAs in Tunisia (GIC PI: WUA for irrigation purposes; GIC AEP: WUA for drinking water purposes)

Many national and regional institutions are involved in the functioning of WUAs (Fig 4.8). The WUAs are monitored and framed by special regional administrative entities, belonging to the rural engineering division. This latter division provides them with important services, particularly in relation to the technical, administrative and financial training of their staff.

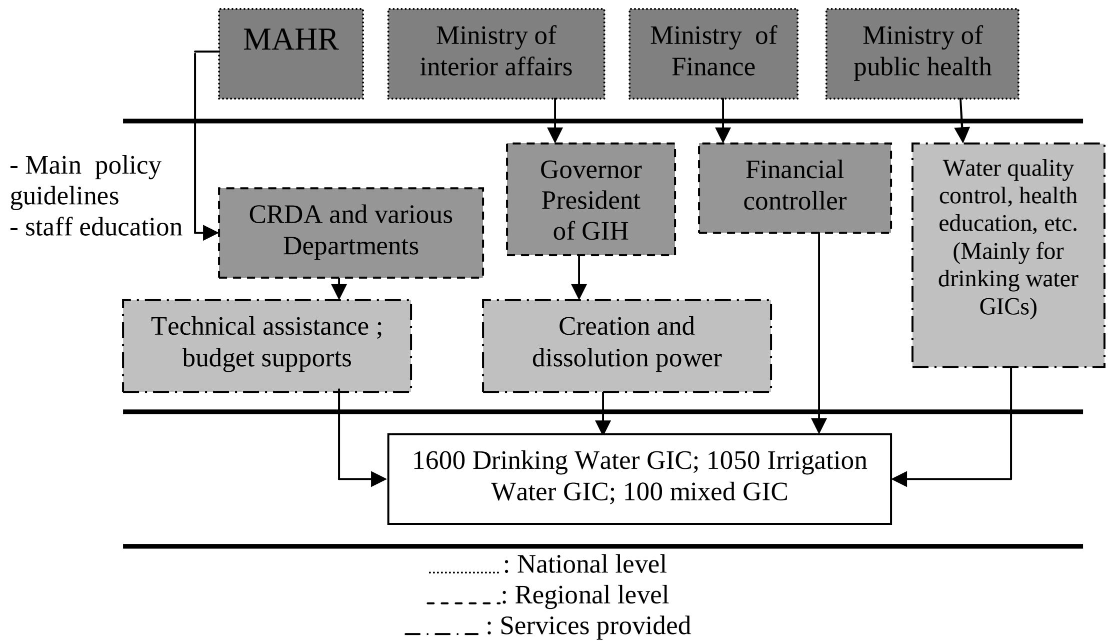


Fig 4. 8. Administrative framework of the Tunisian WUA (GIC) (Braham, 2005).

The responsibilities shared in the irrigated areas between various actors (CRDA, WUA, and farmers) are specified by three types of contract: (1) membership contract: which frames the transactions between the WUA and irrigators. It contains details of the technical and economic dimensions of the irrigation transaction; (2) management contract: which has to be put in place between the WUA and the CRDA. This contract concerns the sharing of maintenance and investment tasks between these two actors; (3) maintenance contract: which can be entered into by any WUA and a private company for doing specific maintenance tasks.

Each year, each WUA is responsible for establishing its own budget. The WUA also has the right to determine the water price and to decide whether the payment basis should be water volume in terms of production or distribution. Furthermore, they estimate the level of projected investments, and operational and maintenance charges. Financially, the WUA perform the following tasks: operation and maintenance of canals, repairs to various infrastructures, functioning of the association and investments (Table 4.5). The water charge established by the WUA comprises water buying charges, energy fees, labour charges and maintenance and management fees.

Table 4. 5. Principal financial revenue and expenditure of the WUA

Financial Revenues	Financial expenditures
1- Contribution of users for adherence to the association; 2- Water selling; 3- Revenues from other activities that the WUA are allowed to undertake; 4- Conceivable subventions; 5- Various incomes.	1- Maintenance, reparations and functioning expenditures; 2- WUA management expenditures; 3-Refunding of loans; 4- Eventual investments; 5- Unexpected expenditures.

Source: MARH, 2004

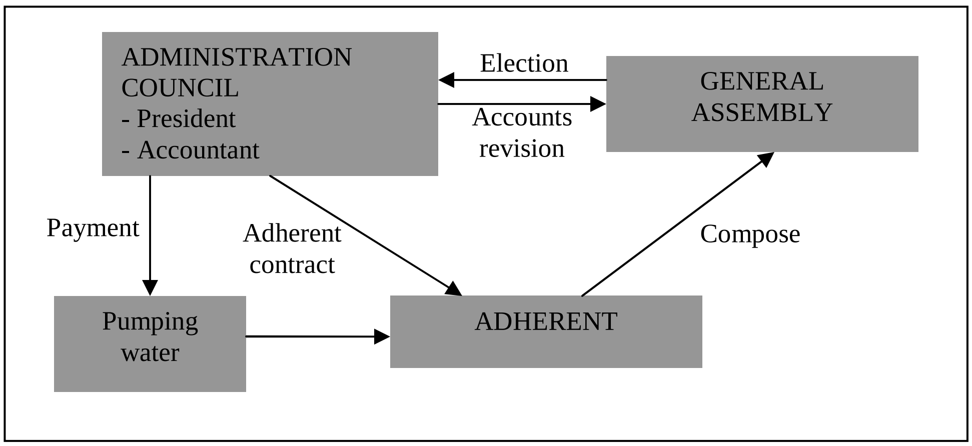


Fig 4. 9. Internal structure of WUA

WUAs are managed by an administrative council composed of between 3 and 9 members belonging to the adherents and elected by the general assembly for a total period of three years (Fig 4.9). The president of this administrative council is chosen from amongst these elected members. His main mission is to represent the interests of the WUA in its relationships with the public administration and other tiers. He can also choose a technical director (according to the needs and financial situation of the WUA) to ensure closer follow-up of various development and maintenance tasks. Financial aspects of the WUA are organised by a treasurer, appointed on the recommendation of the administrative council and approved by the governor. The accounts of the WUA are generally controlled by a regional financial agent belonging to the Ministry of Finance (Fig 4.8).

4.5.3. Some failure factors of the administration and WUAs

Some major failure factors of irrigation water administration and organizations can be drawn from empirical research and reports already made in the case of Tunisia. These can be divided into three types:

(a) Judicial factors: the management contract, that specifies the relationship between the WUA and the CRDA and describes the main responsibilities and tasks of both actors, is not well defined (Bied-Charreton, *et al*., 2004). In fact, according to the same author, specific conditions under which investment projects have to be undertaken by one or other of the actors, are not well specified. In addition, the contract duration is not specified and sanctions are not anticipated in cases where some of the contractual obligations are not met. It is broadly mentioned that large irrigation development projects have to be done by the CRDA whilst the "less important" ones are within the remit of WUA. This could be interpreted in different ways and thus lead to some confusion. Currently, the specialist departments of the MARH are working on another draft of this contract in order to clarify it.

(b) Financial and technical factors: technical problems mostly relate to the WUAs and their functioning. WUAs that were created in old irrigated districts are adversely affected by the decay of their irrigation networks and infrastructures. Renovation places high charges on the WUA. In some other cases, maintenance tasks are neglected by the managers of the WUA, and this can have a negative effect in the medium to long term. These technical factors generally affect the dependability, adequacy and efficiency of the water delivery systems. Problems and misunderstandings between irrigators and the WUA can emerge when these tasks are not well performed (Chraga and Chemakh, 2003).

Another major problem concerns the limited management capacity of the WUAs' administrative members (Ben Salem *et al*., 2005) who are for the most part, elderly, not well educated or trained (Bied-Charreton, *et al*., 2004). Indeed, the complexity of some tasks requires a higher level of competence and motivation, in addition to the full availability of managers.

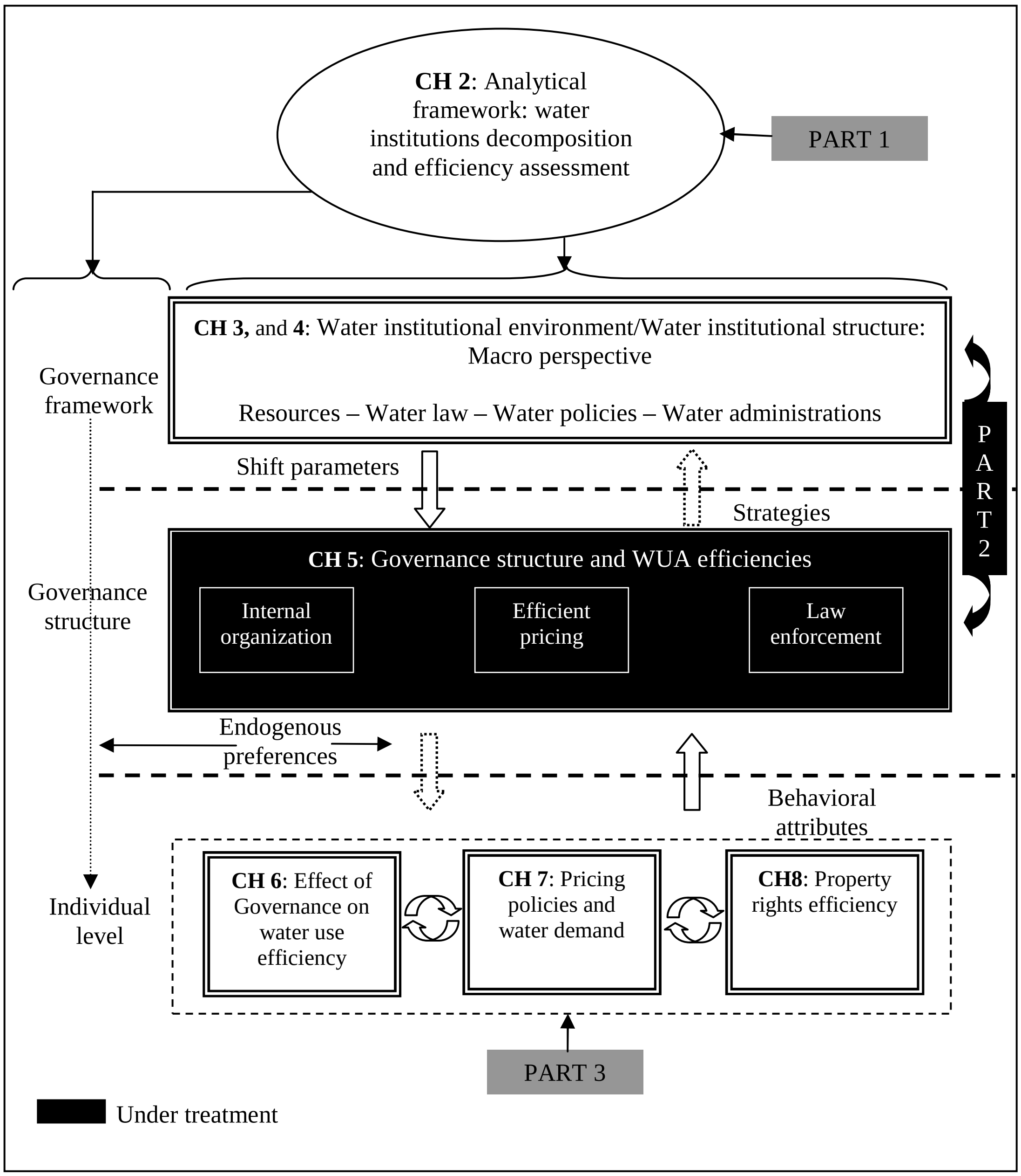
Also, the "Cellules de promotion des GDA" (CP) that support the functioning of the WUA do not have sufficient means at their disposal and are sometimes incapable of assisting all the WUAs in their regions. In fact, in each CRDA, only one CP is created and is responsible for technical and management assistance for all the existing WUAs in the region. According to Bied-Charreton, *et al*. (2004) these CPs have around 90 technicians working across all the Tunisian territory and are responsible for supporting more than 2000 WUAs around the country. This rate varies from region to region.

(c) Social factors: many social problems hinder the improvement of WUA performance in Tunisia. The lack of mobilization and motivation of farmers is a major difficulty (Chraga and Chemakh, 2003; Bied-Charreton, *et al*., 2004; Ben Salem, 2005). It is not uncommon to find a WUA without a president of the administrative council (Chraga and Chemakh, 2003; Bied-Charreton *et al*., 2004). Often, the lack of farmers' confidence in their administrative staff means that collective decisions are not respected or applied (Bied-Charreton *et al*., 2004). Furthermore, in most cases, the public authorities (CRDA) participate in the choice of WUA president, which makes its legitimacy for farmers weak, and leads to some erroneous perceptions about collective action and the principles of public participation. In some other cases, the social standing that large and rich farmers have in the association and the special treatment given to meet their demands for irrigation also negatively affect satisfaction and participation by small farmers (Chraga and Chemakh, 2003).

In this thesis, most of these factors are assumed to be exogenous to irrigation institutions. Some of them will be considered as explanatory variables when studying the efficiency of specific institutional aspects.

4.6. Conclusion

In this chapter, some failures of irrigation institutions in Tunisia are drawn from available literature. These failures are mainly due to the lack of enforcement and/or to the low technical, organizational, and social performances of existing institutions. In this respect, the rest of the dissertation will be dedicated to further investigate about efficiency of some specific irrigation institutions in Tunisia, such as WUA and local administration and organization, effect of the governance structure on irrigation performances, water property right, and pricing regulation. Potential gain that could be acquired if these various institutions would perform better in addition to main factors affecting their effectiveness will be analyzed.



CH 2: Analytical framework: water institutions decomposition and efficiency assessment
PART 1
CH 3, and 4: Water institutional environment/Water institutional structure: Macro perspective
Resources – Water law – Water policies – Water administrations
Governance framework
Shift parameters
Strategies
P A R T 2
CH 5: Governance structure and WUA efficiencies
Internal organization
Efficient pricing
Law enforcement
Governance structure
Endogenous preferences
Behavioral attributes
CH 6: Effect of Governance on water use efficiency
CH 7: Pricing policies and water demand
CH8: Property rights efficiency
Individual level
PART 3
Under treatment

Chapter 5. Efficiency of Water Users' Associations

Abstract

Relatively speaking "Public administrations" will have no further responsibility for the local management of water resources in Tunisia. In fact, this responsibility is planed to be completely devoted in the near future to WUAs in all public irrigated areas. It is for this reason that our focus in the current chapter will be on the study of WUA functional, regulatory and accountability capacities. We analyse the efficiency of local WUAs in the Cap Bon region (central Tunisia) and study its main determinants. This latter analysis is performed in two stages. Firstly, efficiency is measured via the nonparametric 'Data Envelopment Analysis' (DEA) technique. The DEA models are constructed not only to assess the overall WUA efficiency but also to evaluate the separate efficiencies of the management and engineering sub-vectors through a mathematical modification to the initial DEA model. As a second stage, critical technical and organizational determinants of efficiency are assessed using a Tobit model. Results show that, on average, 18.7% of the inputs used could be saved if the WUA were to operate on the frontier. The inefficiencies found can furthermore be attributed mainly to the number of years of experience in operating a WUA, in addition to the number of water pipes managed and the irrigation ratio. The average scale efficiency of the sample was around 71% indicating that many WUAs are not operating at an efficient scale. The scale inefficiencies result mainly from administrative and organizational variables. Sub-vector efficiencies show that, on average, the inefficiency of WUAs is linked more strongly to inefficiency in expenditure on their internal management and functioning, than to engineering inefficiencies.

Part of this chapter is accepted as:
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5.1. Introduction and problem statement

Decentralization processes in irrigation water management required judicial, institutional and administrative reforms to frame the organization of formal user groups known as water users associations (WUAs). These WUAs constitute the heart of the devolution programmes, where rights and responsibilities are transferred to a common local level, supervised and managed by WUAs. The actual outcomes of irrigation water management devolution programmes in various countries are somewhat mixed. The objectives of achieving a positive impact on resource productivity, equity, full cost recovery and environmental sustainability are not always met. In fact, WUAs often disappear after the cessation of the donor funding programme (Vermillion, 1997). In other cases, they are unable to achieve full cost recovery for irrigation water delivery or to cover their operational costs. This can occur for many reasons - such as inappropriate bundles of transferred property rights[18] and the internal organisation of the associations. These factors are incentives for farmer participation and determine long-term sustainability.

Fro example, in Tunisia, in 2003 only 27% of WUAs succeeded in covering their entire operational and maintenance costs whilst 28% of them covered even less than 50% of those costs and were still subsidized by the government (Al Atiri, 2003). It is also clear that WUAs in Tunisia still face many challenges relating to technical, financial and social factors. Problems differ however, from one WUA to another, with only some associations considered efficient. In response to this observation, and taking into account the fact that the initial judicial and administrative basis of all WUAs is the same, this study aims to undertake a comparison between WUAs' performance. Many methodologies can be used for this purpose, ranging from a simple visual comparison of performance figures to relatively sophisticated mathematical methods (Malano *et al*., 2004). In our case, the relative efficiency for a sample of Tunisian WUAs is analysed using Data Envelopment Analysis (DEA). In fact, many studies have used DEA methodology to analyse organizations' efficiency. The applications range from banks, health and educational administrations and forest organizations to airlines and railway companies (Luo,

[18] In some cases, only the responsibility for irrigation water management is transferred. However, a bundle of property rights should also be transferred to WUAs to enable the decentralization process to succeed.

2001; Kirigia *et al*., 2004; Siddharthan *et al*., 1999; Kao *et al*., 1993; Viitala, 1998; Joro and Viitala, 1999; Balaguer-Coll *et al*., 2007). However, the application undertaken in this chapter for assessing the efficiency of organizations specialising in water management is quite unique. To our knowledge, only Umetsu *et al*. (2005) have applied a similar DEA analysis of Turkish WUAs. One of the shortcomings in their paper was however, that, although they encountered significant effects for WUA size on the efficiency score, they did not consider a variable returns to scale specification. Furthermore, in the irrigation and drainage sector, DEA is often applied to estimate production efficiency for large irrigated systems and districts at regional level (Malana and Malano, 2006; Diaz Rodriguez *et al*., 2005; Malano *et al*., 2004; Diaz Rodriguez *et al*., 2004). In our study, we assume that DEA is not only suitable for analysing the efficiency of water management associations, but moreover that the methodology used allows the calculation of overall efficiency in addition to the separate sub-vector efficiencies. Using the concept of subvector efficiency, we analyze management and engineering efficiencies. In fact, by assessing management efficiency we seek to express how well a given WUA allocates its expenditure for managing its internal organization and functioning, in comparison with the rest of the WUAs in the sample. In the same sense, engineering efficiency expresses the performance of a given WUA in allocating expenditure for maintenance tasks, relative to the rest of WUAs in the studied sample. Maintenance expenditure includes expenses for maintenance and repair of the irrigation network and the pumping stations. Energy costs (for WUAs that are pumping water from a borehole) and labour costs for performing maintenance tasks are also included. As a second step, a Tobit model is estimated, to provide insight into local inefficiencies and thus to determine potential factors affecting the functioning of WUAs.

5.2. Methodology: Efficiency assessment of WUAs by DEA technique

The Tunisian authorities plan to transfer all public irrigated areas to decentralized collective management in the near future; CRDA will then cease to have responsibility for the local management of water. It is for this reason that our focus in the current chapter is on the analysis of the functional, regulatory and accountability capacities of WUAs. The relative efficiency assessment of WUAs is performed by comparing the higher to the lower performing ones. DEA methodology, which is considered to be a sophisticated mathematical tool for performance comparison, is used for this purpose. It is important to remember that, for the purposes of this empirical application, we consider the WUA as the independent decision making unit (DMU), with specific input and output vectors. WUA efficiency will then be evaluated against the set of objectives that are defined by the managers of these associations.

Measurement of technical efficiency is based upon deviations of observed output or input vectors from the best production or efficient production frontier. If a production units' actual production point lies on the frontier it is regarded as perfectly efficient. If it deviates from the frontier then it is technically inefficient, with the ratio of actual to potential production defining the level of (in)efficiency for the individual DMU. This means that our measure of technical efficiency provides an indication as to how all input use can be minimized in the production process for a given DMU, whilst continuing to produce the same level of output. Additionally, we consider the possible reduction of a subset of inputs whilst keeping other inputs, and the output, constant. This generates a "subvector efficiency" measure.

Parametric and non-parametric methods are the two main approaches used to measure technical efficiency. The results from both methods are highly correlated in most cases (Wadud and White, 2000; Thiam *et al*., 2001; Alene and Zeller, 2005), indicating that both methods are valuable and that the choice can be based on researcher preference. A major advantage of non-parametric DEA for this study is that the calculation of sub-vector efficiency for specific input use is relatively straightforward (Speelman *et al*., 2008).

5.2.1. Standard DEA model

Farrell (1957) introduces the relative efficiency concept, that permits efficiency evaluation for a DMU by comparing it to the other DMUs in a given group. This concept was extended by Charnes *et al*. (1978) who developed the first DEA model, called CCR (Charnes, Cooper and Rhodes), to incorporate many inputs and outputs simultaneously. In this way, DEA provides a straightforward approach for calculating the efficiency gap between the actions of each producer and best practice - inferred from observations of the inputs used and the outputs generated by an efficient DMU (Wadud and White, 2000; Malano *et al*., 2004; Haji, 2006). Explicitly, DEA uses piecewise linear programming to calculate the efficient or best practice frontier for a sample of

DMUs. The DMU on this technical efficiency frontier will have an efficiency score equal to 1. The DEA technique does not require the development of standards against which efficiency is measured. Derived ratings are estimated within a set of analysed units (less efficient DMUs are measured in relation to efficient ones). Moreover, different units of measurement for the various inputs and outputs can be combined within the DEA models.

The DEA model defines efficiency as the ratio of the weighted sum of outputs for a given DMU, to its weighted sum of inputs. For each DMU_k, a non-negative input vector $x^k = (x_{k1},..., x_{kN}) \in R_+^N$ is transformed to a non-negative output vector $y^k = (y_{k1},..., y_{kM}) \in R_+^M$. In an input-oriented model of technical efficiency, the production possibility set (*P*), which also describes the technology, represents the set of all feasible input-output vectors: $P = \{(x, y) / x \; can \; produce \; y\}$

One of the analysis options in DEA is a choice between Constant Returns to Scale (CRS) and Variable Returns to Scale (VRS). CRS assumes that there is no significant relationship between efficiency and the scale of operation. Thus assuming that large WUAs are just as efficient as small ones in converting inputs to outputs. Banker, Charnes and Cooper (1984) suggested an extension of the CRS DEA model to account for variable returns to scale (VRS) situations. The use of the CRS specification when not all DMUs are operating at the optimal scale will result in measures of TE which are confounded by scale efficiencies (SE). The use of the VRS specification will permit the calculation of TE without these SE effects (in Coelli. Tim., 1996). However, we anticipate that the scale of activity (size of the organization) of the WUA has an important effect on its efficiency (Umetsu *et al.*, 2005). Furthermore we assume that changes in the organization’s inputs can lead to disproportionate changes to its outputs. Therefore, the option of VRS has been chosen for this study. A second option is the choice between input-oriented and output-oriented DEA models. If the focus is to use different resources more efficiently (instead of increasing production), then the suitable model to use is an input-oriented one (Rodríguez Diaz *et al.*, 2004). In our case, it is necessary, as a national objective for the decentralization process, that the WUAs recover their expenditure to ensure their sustainability. In addition, the volume of water that a given WUA purchases from the regional water management administration is planned and fixed at the beginning of the year. This is necessary to enable the WUA to determine its water rates. Therefore, during the agricultural year, the WUAs will focus mainly on minimising their expenditure. For these reasons, it is proposed that an input-oriented model would be more suitable in our case. Recapitulating, we chose to estimate Variable Return to Scale (VRS) efficiencies through a BCC (Banker, Charnes and Cooper, 1984) input-oriented model.

Following the BCC model, if we consider *K* DMU (*k=1,…,K*), each of them uses *N* inputs variables x_{nk} (*n=1,…,N*), for producing M outputs y_{mk} (*m=1,…,M*). Each DMU_0 becomes the reference unit and then we have to resolve the following linear program (model 1) *k* times (one time for each DMU):

$$Min_{\theta,\lambda}\theta \tag{1}$$

s.t.

$$\sum_{k=1}^{K}\lambda_k y_{m,k} \geq y_{m,o} \tag{2}$$

$$\sum_{k=1}^{K}\lambda_k x_{n,k} \leq \theta.x_{n,o} \tag{3}$$

$$\sum_{k=1}^{K}\lambda_k = 1 \tag{4}$$

$$\lambda_k \geq 0 \tag{5}$$

Where θ is a variable representing the efficiency of the reference $DMU_{0,}$ and hence the percentage reduction to which each input must be subjected in order to reach the production frontier. λ_k is a vector of k elements representing the influence of each DMU in determining the efficiency of the DMU_0. The term $\sum_{k=1}^{K}\lambda_k y_{m,k}$ indicates the weighted sum of outputs of all DMU, which must be superior or equal to the output of DMU_0 (constraint 2). In constraint 3, θ is the measure of technical efficiency and represents, at the same time, the minimized objective. Thus, constraint 3 indicates that the value of θ assessed must shift the production factors toward the production frontier (for a given output level). Equation 4 consists of the convexity constraint, which specifies a variable returns to scale option. The DMU whose λ values are positive will be the reference set for DMU_0 under study. In fact, it is the linear combination of those units, which will formulate the situation objective needed to achieve efficiency.

5.2.2. Subvector DEA model

To calculate the efficiency score for the use of an individual input or subset of inputs, the 'sub-vector efficiency' concept can be introduced. This measure generates a technical efficiency for a subset of inputs whilst remaining inputs are held constant (Speelman *et al.*, 2007). The sub-vector efficiency measure looks at the potential reduction in the selected subset of inputs, holding all other inputs and outputs constant (Oude Lansink and Silva, 2004; Oude Lansink and Silva, 2003; Oude Lansink *et al.*, 2002; Färe *et al.*, 1994). Following Färe *et al.* (1994) technical sub-vector efficiency for the variable input (t) can be determined for each farm (i) by solving the following transformed model (2):

$$Min_{\theta^t,\lambda}\theta^t \tag{6}$$

s.t.

$$\sum_{k=1}^{K}\lambda_k y_{m,k} \geq y_{m,o} \tag{7}$$

$$\sum_{k=1}^{K}\lambda_k x_{n-t,k} \leq x_{n,o} \tag{8}$$

$$\sum_{k=1}^{K}\lambda_k x_{t,k} \leq \theta^t.x_{t,o} \tag{9}$$

$$\sum_{k=1}^{K}\lambda_k = 1 \tag{10}$$

$$\lambda_k \geq 0 \tag{11}$$

Where θ^t is the input t sub-vector technical efficiency score for the DMU$_0$ under study. The measure θ^t represents the maximum reduction of variable input t holding outputs and all remaining inputs (n-t) constant. All other variables are defined as in model (1). Therefore, the input t sub-vector technical efficiency model involves finding a frontier that minimises the quantity of input t (Oude Lansink *et al.*, 2002). The figure below provides a graphical distinction between both overall and subvector efficiency concepts.

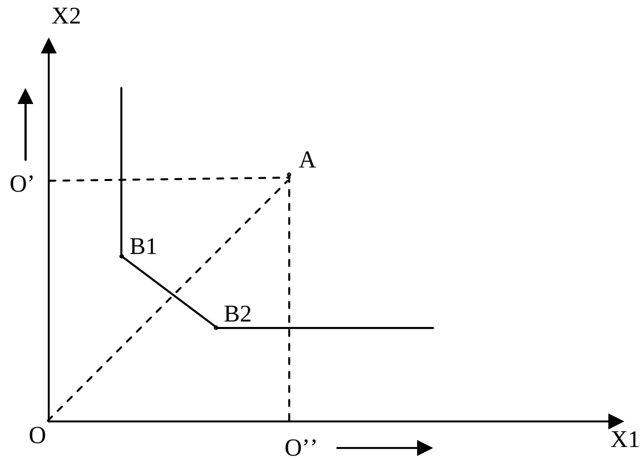


Fig 5. 1. Overall and sub-vector, Input-oriented, technical efficiency (Oude Lansink *et al*., 2002)

The overall technical efficiency for the WUA (A) is measured by the ratio OA^0/OA (Fig 5.1). The measure of overall technical efficiency assumes that both *x1* and *x2* can be reduced radially (given by 1- OA^0/OA). Subvector efficiency for a particular input *x1* assumes it is possible to reduce *x1* whilst holding *x2* and the output constant. The subvector efficiency of WUA (A) relating to a given *x1* input can then be measured by the ratio: *O'A'/OA*.

5.2.3. Tobit model

The technical structure, in addition to the administrative and organizational characteristics of WUAs, can be potential sources of inefficiency. Several variables are selected as potential determinants of their calculated efficiency levels[19]. The efficiency scores obtained in the first stage of the work are regressed on these WUA attributes.

In this second stage, ordinary least squares estimations are inconsistent, as the values of the dependent variable (efficiency scores) lie in the interval [0, 1]. A censored regression or Tobit model can be used to get a consistent estimation. The model is defined in terms of an index function:

[19] By WUA efficiency (or efficiency scores) we mean the 'technical efficiency' in its standard meaning (as presented in section 3.4.1). This kind of efficiency is distinct from 'allocative efficiency' and 'economic efficiency'. In our chapter, it is also distinct from 'engineering efficiency' and 'management efficiency' described above.

$$\theta^{t*} = \beta_r z_r + u_r \quad (12)$$

$$\theta^{t} = \begin{cases} \theta^{t*} if \ 0 \prec \theta^{t*} \prec 1; \\ 0 \ \ if \ \theta^{t*} \prec 0; \\ 1 \ \ if \ \theta^{t*} \succ 1 \end{cases} \quad (13)$$

Where θ^t are the DEA overall, scale, management, and engineering efficiencies used as a dependent variable and Z is a (*R*1*) vector of independent variables relating to attributes and characteristics of WUAs in the sample. For Tobit estimates to be consistent it is necessary that residuals (u_r) are normal distributed (Holden, 2004). The estimation is carried out by minimising a log likelihood function with a part corresponding to non-censored observations and the other for the values equal to one.

Many critics note that the use of Tobit model as a second DEA stage is invalid. In fact, it is argued that the efficiency scores are not generated by a censoring process but are fractional data (McDonald, 2009). It is also argued in other cases that complicated, unknown serial correlations exist among the estimated efficiency scores (due to the relative nature of scores generation process) (Simar and Wilson, 2007). In some other cases, the argument is that DEA scores only have a positive pile-up at one of the two corners of the interval]0,1] (Hoff, 2007). Then, according to the latter author, as several other methods for modelling limited dependent variables exist, it is straightforward to ask whether one of these may give better predictions of the DEA scores than the tobit.

Hoff 2007 has compared the within sample prediction performance of Two-limit tobit (2LT), Ordinary least squares (OLS), quasi-maximum likelihood estimation method proposed by Papke and Wooldridge (PW) (1996), and the unit-inflated beta (Beta) model using a case study from Danish fishery. In this study, the author found that OLS performed at least as well as the other methods. Tobit and the PW methods performed about as well, and the Beta model, poorly. From these results, Hoff (2007) advocates using tobit and OLS in second stage DEA. He concluded that “firstly, the tobit approach will in most cases be sufficient in representing second stage DEA models. Secondly, it is shown that OLS may actually in many cases replace tobit as sufficient second stage DEA".

Mc Donald (2009) comes to a similar conclusion about OLS, but advocate not using tobit. He argue that tobit regression can be appropriate when the dependent variable data are generated by a censoring data generating process, but is inappropriate when the data is fractional. Main suggestion of McDonald is that efficiency scores are not censored values, the censoring model does not describe how their values were generated. Consequently, tobit is inappropriate.

McDonald argues that the efficiency scores generating process can however better be described as a normalisation process. According to him, the DEA generates a production frontier using the DMU input-output data and the DEA assumptions (e.g., returns to scale and disposability of inputs). In output-oriented analyses, a DMU's efficiency score is determined as its actual output divided by the frontier output corresponding to the unit's input values. Thus, this process normalises the maximum efficiency score to be one and all efficiency scores to lie on or within the unit interval. Although there may be multiple scores of one, there is no censoring. The process generates, according to the author, a particular kind of fractional or proportional data.

The two-stage method has been criticized as well by Coelli *et al.*, (1998) and by Simar and Wilson (2000, 2007) who consider that results from this method are likely to be biased in small samples. Simar and Wilson (2007) considers that most of authors have argued that DEA efficiency estimates are somehow censored since there are typically numerous estimates equal to one, but they consider that no coherent account of how the censoring arises has been offered. They also consider that a more serious problem came from the fact that DEA efficiency estimates are serially correlated.

Arguments of the latter authors are as follows: A perturbation to an observation located on the DEA frontier will shift that frontier toward a second very similar one. As a result, some DMU who are originally on the frontier will be only close to it. Also, other DMUs will find themselves closer or further to the frontier and their efficiency scores will change accordingly. This is called serial correlation between the efficiency scores. As the sample size increase, this serial correlation disappears slowly in the DEA context (Alfonso and Aubyn, 2006).

Another source of bias comes from the fact that some environmental variable (explicative variable of DEA scores) can be correlated to the error term of equation 12. This correlation derives from the correlation between these environmental variables from one side and the inputs and outputs used for the calculation of efficiency scores, on the other side.

Simar and Wilson (2007) propose an alternative estimation and inference procedures based on bootstrap methods. The method is based on the introduction of a separability condition that implies that environmental factors (explicative variables) do not influence the frontier but can influence scores of DMUs (McDonald, 2009). Their data generating process does not allow for a two-sided noise term and the production unit efficiency terms are unit-specific truncated normal distribution. Their results show that a truncated regression estimates the correct model in their specific case. In terms of coverage of estimated confidence intervals, their double bootstrap procedure is shown to perform well.

McDonald (2009) consider that Simar and Wilson (2007) advocate a very complex estimation procedure, which may be invalid given their chosen data generating process, but is not robust to plausible departure from it (in particular, that true efficiency scores in the second stage equation are unit-specific, truncated normal random variables). Given their unusual DGP, it is unclear what interpretation can be placed on Simar and Wilson’s simulation evidence (McDonald, 2009).

Using the approach suggested by Simar and Wilson (2007) requires that all variables are included in the whole two-stage DEA process (Hansson and Öhlmér, 2008). Further, an empirical comparison between the bootstrap approaches and the DEA–Tobit approach, by Afonso and Aubyn (2006) showed that the results were very similar across methods. Moreover, du to the small size of our sample, a truncation will reduces further the size of the sample and may results in non-accurate estimates of significant variables. For this reason, in this application we followed McDonald (2009) and Hoff (2007) and we also estimated an OLS function using the same explicative variables regressed in the tobit model. Results showed that there are no significant differences between both methods. Only results from tobit regression will be then exposed.

5.3. Empirical application

5.3.1. Case study and data sample characteristics

The database used for this analysis was collected by the Agricultural and Hydraulic Resources Ministry of Tunisia. This central database concerns 45 WUAs, which constitutes all the WUAs operating in the Cap Bon region (governorate of Nabeul). The Cap Bon is located in northern Tunisia and is bounded in the East by the Mediterranean Sea (Fig 5.2). The total agricultural area for the region is 256,500 ha, of which 183,000 ha are arable land and 41,000 ha are irrigable lands. Cereals occupy the greatest land area at 53,000 ha, vegetables 35,000 ha, olives for olive oil 23,500 ha, citrus fruit 13,450 ha and others 6,300 ha (CRDA Nabeul, 2006). In 2004 around 22% of the total population in the Cap Bon region were employed in the agricultural sector. Agricultural production in Cap Bon contributes almost 15% to the total national agricultural production. The number of farms in the region is approximately 32,000 (6.6% of total Tunisian farms). Only 25,500 ha (92% of the total irrigated land) are equipped with a public irrigation network and the remaining area is irrigated from dams and other private sources. Currently, irrigated areas in Cap Bon represent about 13.3% of the total Tunisian irrigated lands and it is considered one of the most water-consuming regions in the country (Fig 5.2). 71% of the irrigated areas belong to small and average-sized farms.

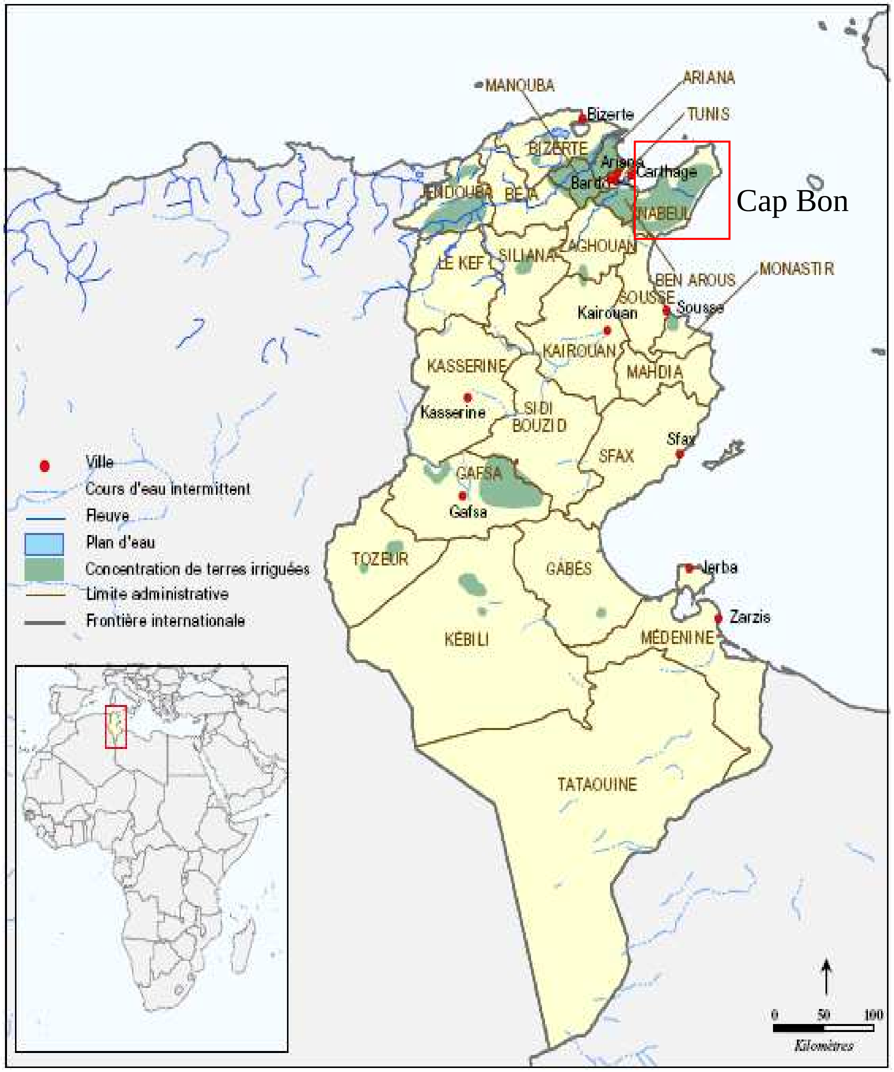


Fig 5. 2. Map of Tunisia: Cap bon region as a main irrigation water consumer[20]

5.3.2. Overall, management, and engineering efficiencies

With regard to the selection of outputs and inputs, as a general rule of thumb, there should be at least three DMUs for each input and output variable used in the model, since with less than three DMUs per input and output too many DMUs will turn out to be efficient (Alfonso and Santos, 2005). According to the database, the WUAs' expenditure can be broadly divided into management expenditure, maintenance costs, water purchasing costs, labour costs, repayment of debts and other expenditure. Given that in our empirical application, we focus on the relationship

[20] Gray-stained zones on the map show the abundance of irrigated lands in a given region.

between inputs and outputs of the WUA, we have chosen to aggregate the main financial inputs of the water users associations into management expenditure, maintenance expenditure, and purchasing water expenditure. The management expenditure vector integrates expenses relating to the internal organization and functioning of the WUA. The maintenance expenditure vector, on the other hand, integrates the cost of labour used for maintenance and the energy fees spent to pump water from drilling, in addition to the typical maintenance costs. In fact, expenditure vectors were always used as inputs for DEA models to analyse the efficiency of organizations (Kirigia *et al.*, 2004; Alfonso and Santos, 2005; Luo, 2003). However, given the multiple objectives of WUAs (equipment renewal, price minimization for socio-economic considerations, good maintenance and operational coverage rates etc.), some expenditure, such as investment, would in the short term have negative effects on the results for the WUA. In the long term, this input can have an inverse positive effect by decreasing the annual maintenance costs and increasing the total amount of the WUA return. In order to consider the investment vector as an input, more detailed panel data would be needed. Therefore, in this study, due to data limitation, it has been decided to calculate efficiency scores in a static framework and thus the investment variable is not considered. Nevertheless, this may have

The chosen outputs considered are the annual irrigated area (ha), and the total annual irrigation water delivery per unit of irrigated area (m^3 $ha^{-1}yr^{-1}$). The annual irrigated area is considered as key descriptor for irrigation and drainage scheme performance in the literature (Malano *et al.*, 2004) and the total annual irrigation water delivery per unit of irrigated area is also one of the most relevant service delivery performance indicators (Malano *et al.*, 2004). It is used as a benchmarking indicator in many International Water Management Institute (IWMI) studies. These two outputs are the only constant and stable WUA outputs in the short term. The financial revenue of the WUA, which could be a relevant output for consideration, can always change from one year to another according to the association's objectives. For example, in some cases where there is high investment in modernization, the revenue will quickly reduce during the studied year and consequently cannot be taken as an efficiency parameter to integrate it in such DEA models. Other data relating to some productive performance indicators (total gross annual agricultural production in the area managed by the WUA; total annual value of agricultural production; output per unit service area, etc.) are not relevant for our study, since we evaluate the efficiency of WUAs (as decision making units) and not the efficiency of the national policy for water demand management. According to this input-output choice, an efficient WUA will be the one that has a lower Input/Output ratio (Expenditure/m^3 and Expenditure/ha) and consequently which reflects better performance in minimizing water rates for farmers.

In the management sub-vector efficiency only the efficiency of the individual management expenditure input is considered, whilst holding the rest of the inputs and outputs constant. Generally, management expenditure is stable over time (Terraux, 2002). The engineering sub-vector efficiency considers only the inputs relating to the total expenditure on maintenance.

The 45 WUAs in Cap Bon manage around 16,000 ha of lands (9% of the total arable land in the governorate) owned by 8,206 adherent farmers. The total volume of water distributed by those associations is around 87.5 million cubic metres and the average irrigated surface area per WUA is nearly 355 ha. Basic statistics regarding the selected WUAs are shown in Table 5.1.

Table 5. 1. Basic statistics for the data used in the DEA Model

	Outputs		Inputs		
	Nbr of irrigated ha/year	Vol of water Distributed/ha (m3)	Management expenditure (TDN)	Maintenance expenditure (TDN)	Purchasing water cost (TDN)
Average	3 090.7	346.9	3 940.2	35 214.5	49 302
Standard Deviation	1 595.9	286.2	3 363.7	24 416.3	56 618.8
Minimum	491	15	103	2 873	0*
Maximum	9 427	1 342	13 539	106 185	228 252

** Water from drillings*

Several variables are hypothesized to affect the efficiency scores. Technical, administrative, and organizational characteristics of WUAs used in the Tobit Analysis came from the national survey of the structure and functioning of WUAs undertaken by the Tunisian Ministry of Agriculture and Hydraulic Resources in 2005.

Technical characteristics include the number of years of experience operating a WUA (age of the association), the number of water pipes managed by the WUA, the irrigated area under the control of the WUA and that equipped with water saving technology, the irrigation ratio[21], and the ratio of water losses in water distribution operations. Organizational and administrative characteristics are also hypothesized to have an important effect on resource management inside a given WUA. In fact, the most organized WUAs are expected to be more efficient. Variables used are: ratio of adherent farmers to the WUA, number of technical salaried staff, number of members in the administrative council, and the existence (or not) of a technical director for the WUA (Table 5.2).

Table 5. 2. Definition of variables used in Tobit regressions

Variable	Definition	Mean value
Technical characteristics of the irrigated district		
- N of years in function	Years experience operating a WUA	8.5
- N of water pipes	Number of water pipes. Each pipe is used by a group of farmers	178.4
- Areas equipped by water saving technologies	The irrigated area managed by WUA and equipped by water saving technologies (ha)	257.7
- Irrigation ratio	Area exploited, managed and irrigated /exploitable area	62.8
- Ratio of water losses	Initial quantity of water hold by the WUA/distributed quantity of water	0.06
Administrative and organizational characteristics of the WUA		
- Ratio of adherent farmers to the WUA	Number of adherents/total number of farmers belonging to the WUA geographical limits	70.9
- N of technical salaried staff	Number of technical staff working in the WUA	4.2
- N of members in the administration council	-	5.2
- Existence of a technical director	1 for WUA with technical director 0 for WUA without technical director	-

5.4. Results

5.4.1. Efficiency analysis

Using the General Algebraic Modelling System (GAMS) to solve the linear programming problems outlined above, the efficiency measures for the WUAs were estimated. Model (1) was solved 45 times to provide efficiency scores for each WUA under a VRS specification.

[21] Irrigation ratio corresponds to the ratio of the surface area grown with irrigated crops to the total surface area

Management and engineering sub-vector efficiencies were also calculated for each WUA solving model (2). Table 5.3 gives the frequency distribution for the overall efficiency estimates obtained for the WUA under study.

Table 5. 3. Frequency distribution of overall efficiency for the studied sample.

	Overall VRS Efficiency	
Efficiency level (%)	N° of WUA	%
0<Eff<=25	0	0
25<Eff<=50	4	8.89
50<Eff<=75	12	26.67
75<Eff<=100	29	64.44
Average Eff	81.34	
Scale Efficiency	0.71	

The average efficiency provides information as to the potential resource saving that could be achieved whilst maintaining the same output level. In our case, results show that overall efficiency of the WUAs in the Cap Bon region is around 81.3%. This implies that the same level of output could be achieved by using only 81.3% of the used inputs. Average scale efficiency, which can be calculated as the ratio between CRS and VRS efficiencies, is around 71%. This measure indicates that many WUAs are not operating at an efficient scale.

Results also show that management and maintenance inefficiencies are greater than the overall inefficiency. The average management efficiency is around 65.7% whilst average engineering efficiency is 74.5%. Scale efficiencies for both sub-vectors are very low, indicating that almost 40% of management and maintenance expenditure could be saved if WUAs were to operate at an efficient scale. The frequency distribution for the two efficiencies is reported in Figure 5.3.

Figure 5.3 shows that almost 6.7% of WUAs belong to the group showing weak management efficiency (between [0; 25%]) whilst 33.3% of them belong to the second group (between [25%; 50%]) for the same criterion. In both groups we note that WUAs that are inefficient in terms of management occur more frequently than WUAs that are inefficient in relation to maintenance tasks. In fact, 40% of WUAs are inefficient (between [0; 50%]) for management whilst only 22% of them are inefficient (between [0; 50%]) for maintenance. From the same perspective, 77.7% of WUAs belong to the high efficiency group [50%; 100%] for the maintenance efficiency criterion whilst only 60% of them belong to the same group if we consider management efficiency. It is clear that, on average, WUAs perform better in terms of allocating maintenance expenditure than in terms of expenditure on their internal management and functioning.

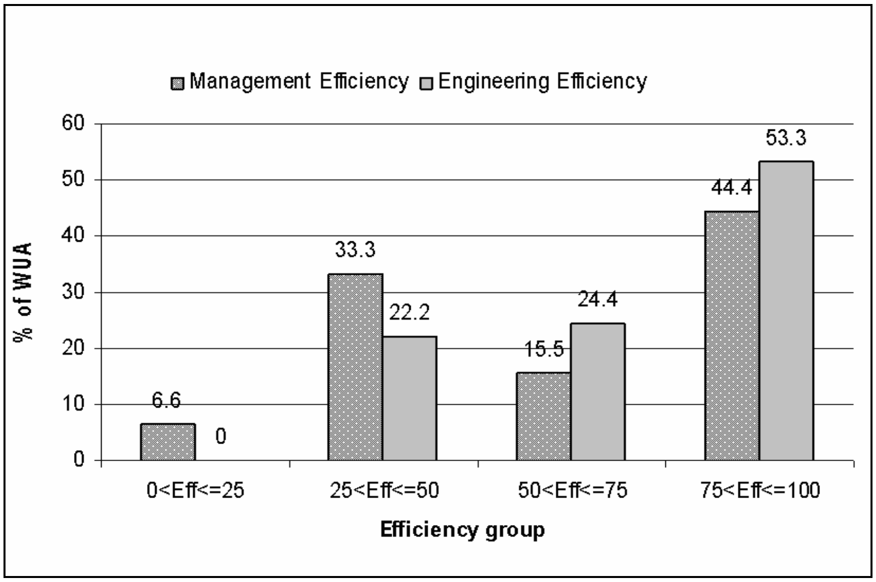


Fig 5. 3. Frequency distribution of Management and Engineering efficiencies

The pairwise correlation tests show that the weak performances of management and maintenance are highly positively correlated among them as well as to the overall technical efficiency (Table 5.4).

Table 5. 4 Results of correlation test « pairwise correlation » between overall and sub-vectors efficiencies

	OE	MSbvE	ESbvE
Overall Eff	1		
Mnagement Eff	0.848***	1	
Engineering Eff	0.951***	0.779***	1

Note: *** significant at 1%

5.4.2. Factors affecting efficiency of WUAs: follow-up Tobit analysis

The regressions in Table 5.5 represent the estimation results for factors affecting scale and overall WUA efficiency scores respectively. In Table 5.5, the regressions explain little as to the variations in the calculated efficiency scores with the pseudo R-square value ranging from 0.39 to 0.5. Most of the independent variables have no significant effect on efficiency. Of the five 'technical' characteristics used in this study, none has a significant effect on scale efficiency.

However, two organizational and administrative characteristics are of interest in explaining it. In fact, the WUA scale efficiency is positively affected by the ratio of adherent farmers, suggesting that higher ratios result in higher scale efficiencies. In addition, the number of members of the administrative council has a statistically significant negative impact on the scale efficiency (1% level). The other administrative characteristics (existence of a technical director and the number of technical salaried staff) have a negative but non-significant effect on the scale efficiencies.

Table 5. 5. Factors associated with total and scale efficiencies: results of Tobit models.

Explanatory variable	Explained variable			
	Scale Efficiency		Overall WUA efficiency	
	Estimate	P-Value	Estimate	P-Value
Technical characteristics of the irrigated district				
- N of years in operation	0.011	0.627	-0.125***	0.005
- N of water pipes	0.0003	0.303	-0.001**	0.076
- Areas equipped by water saving technologies	-0.0002	0.461	-0.0003	0.323
- Irrigation ratio	0.001	0.964	-0.008***	0.020
- Ratio of water losses	0.751	0.189	0.504	0.440
Administrative and organizational characteristics of the WUA				
- Ratio of adherents farmers to the WUA	0.004*	0.116	0.002	0.498
- N of technical salaried staff	-0.026	0.367	0.054*	0.108
- N of members in the administration council	-0.112***	0.010	-0.048	0.313
- Existence of a technical director	-0.146	0.242	-0.101	0.521
- Constant	0.955	0.014	2.695	0
σ	0.261	0.035a	0.258	0.046
Pseudo R2[22]	0.501		0.396	
Log-Likelihood	-13.077		-14.906	
LR(χ^2)	26.22		19.57	
P> χ^2	0.0019***		0.020**	
Number of observations	44		44	

*, **, *** = significant at 10%, 5%, and 1% level respectively.

[a] For σ the standard error is reported instead of the *P*-value.

[22] This is McFadden's pseudo R-squared. Tobit regression does not have an equivalent to the R-squared that is found in OLS regression; however, many people have tried to come up with one. There are a wide variety of pseudo-R-square statistics. Because this statistic does not mean what R-square means in OLS regression (the proportion of variance of the response variable explained by the predictors), interpreting this statistic should be done with great caution. For instance, a pseudo R^2 of 0.3 corresponds to R^2 linear of approx 0.6. (for more details see Hensher, *et al*., 2005; see also: http://www.ats.ucla.edu/stat/stata/output/Stata_tobit.htm)

With regard to the overall WUA efficiency scores, it is mainly the technical variables that are statistically significant. In fact, we found that the number of years in operation, the number of managed water pipes, as well as the irrigation ratio, have a significant negative effect on the efficiency of the Cap Bon WUAs. Only the number of technical salaried staff has a positive effect (10% level) on this efficiency.

Table 5.6 presents the results for the two Tobit estimates when the dependent variables are management and engineering efficiency scores respectively. For both regressions, the age of the WUA has a significant (1% level) negative effect on the regressed scores. In addition, management efficiency was also found to be negatively affected by the number of members on the administrative council. Remaining independent variables had no significant effect on either of the dependent vectors.

Table 5. 6. Factors affecting management and engineering efficiencies

Explanatory variable	Explained variable			
	Management Efficiency		Engineering efficiency	
	Estimate	P-Value	Estimate	P-Value
Technical characteristics of the irrigated district				
- N of years in operation	-0.102***	0.024	-0.113***	0.003
- N of water pipes	-0.0002	0.620	-0.0003	0.304
- Areas equipped by water saving technologies	0.0004	0.354	0.0002	0.555
- Irrigation ratio	0.0004	0.912	-0.003	0.257
- Ratio of water losses	0.454	0.607	0.338	0.608
Administrative and organizational characteristics of the WUA				
- Ratio of adherents farmers to the WUA	0.001	0.817	0.002	0.534
- N of technical salaried staff	0.002	0.952	0.007	0.813
- N of members in the administration council	-0.1*	0.100	-0.063	0.172
- Existence of a technical director	-0.162	0.409	-0.040	0.785
- Constant	2.072	0.002	2.176	0
σ	0.385	0.057 a	0.289	0.042
Pseudo R2	0.202		0.343	
Log-Likelihood	-26.065		-17.329	
LR(χ^2)	13.27		18.11	
P> χ^2	0.150		0.033**	
Number of observations	44		44	

*, **, *** = significant at 10%, 5%, and 1% level respectively.

[a] For σ the standard error is reported instead of the *P*-value.

5.5. Discussion

Results of the DEA analysis show that overall efficiency amongst water users' associations in the Cap Bon region is around 81%, in average. However, efficiency could reach a minimum of 45% for some WUAs, indicating that almost 55% of financial inputs for these associations could be saved, whilst still maintaining the same output level. About 9% of the studied WUAs have an efficiency level below 50%. Additional resources allocated from the government to support these less efficient WUAs can then be saved or reallocated for other more productive activities in the irrigated districts.

The average scale efficiency obtained shows that WUAs are not operating at an optimal scale. This finding confirms inefficiencies due to the WUA size reported by Umetsu *et al.* (2005). The latter authors have grouped 18 WUAs into 6 artificially created WUAs in order to observe the effect of a merger. Their results show that the average efficiency score improved slightly. However, Fujiie *et al.* (2005) found that collective action in local water management is difficult to organize when the size of the association (measured by its service area) is large. In our case, we can conclude that a scale adjustment could improve global efficiency and the use of financial resources in Tunisian WUAs.

Thirdly, the results for some specific tasks undertaken by WUAs indicate that the studied sample of Cap Bon WUAs not only has a poor performance in terms of allocating resources for internal management and functioning activities but also in terms of allocating resources for maintenance tasks. Operation and maintenance are included within the main WUA expenditure. Deficits in these financial tasks could have negative implications, not only for the associations' financial balance but also for the performance of the irrigated areas managed by these inefficient WUAs. Given that water rates charged to farmers are fixed according to the WUA's financial balance, it will the farmers themselves who have to support and pay for the losses resulting from the inefficient functioning of their WUA. A better accountability and structuring of WUA management could help to reduce the recorded inefficiencies. However, we should not forget the fact that these inefficiencies could also be due to old irrigation network upon which a given WUA was initially installed. In this case, it would be legitimate for these associations to benefit from government subsidies.

On the other hand, the number of members in the administrative council of the WUA had a negative and statistically significant impact on its scale efficiency. This suggests that a reduction in this number would improve the scale efficiency. This finding contradicts the logical expectation that a higher number of administrative staff would improve the accountability and governance of the WUA. We note also that this variable has a negative impact even on the global, management, and maintenance efficiencies, although only its effect on management efficiency was statistically significant. A positive factor on WUA overall efficiency is the number of technical staff employed. This may indicate that WUAs who have invested in technical staff do benefit from this expertise. In the same sense, Fujiie *et al.* (2005) proves that the staff quality in water users' associations significantly affects collective action for local water management. These two latter results stress the importance of training and structuring services provided by regional administrations to the benefit of WUAs. This crucial role of public authorities is extremely important and has to be enhanced and generalized.

The ratio of adherent farmers in a given WUA had a positive impact on its scale efficiency. This suggests that an improvement to this rate could lead to a more efficient scale of operation. However, farmers' decisions' on membership in a given WUA depends on many social, technical and economic factors (Meinzen-Dick *et al.,* 2002). Conflicts within the association and the possibility of access to groundwater are amongst the negative social factors affecting this decision. However, it is also possible that WUAs manage a small district where the number of farmers is limited[23]. Considering this latter case, more detailed studies have to be undertaken to elucidate the potential benefits of merging WUAs that operate in neighbouring areas. In addition to its benefit on the scale efficiency of WUAs, the number of adherents of a given WUA can also be a factor in decreasing water rates.

The number of years in operation for a given WUA has a negative and highly significant effect on overall and subvector efficiencies. In contrast, older associations are expected to be more

[23] Area under the authority of each WUA is determined by the public administration.

stable (Meinzen-Dick *et al*., 1994). Nevertheless, this result can be interpreted in two ways. Over time, the irrigation networks managed by the association will be older and thus need higher levels of funding for maintenance or replacement. For this reason older WUAs spend more money on maintenance and management tasks. This can influence their global efficiency and lead to resource deficits. Good network management and replacement strategies could be a solution for this kind of problem. However, in most cases the WUA administrative members or even the technical director are not well qualified. For them, developing an optimal global management plan is a difficult task. Help and guidance from government agencies will be needed in such cases (Legoupil *et al.,* 2000). The second explanation for the negative impact of WUA 'age' can be attributed to a non-social sustainability between the members of the association. According to Meinzen-Dick *et al.* (1994), older organizations are more likely to be stable because their patterns of action and trust have had more time to become established. It is then clear that a lack of trust and the presence of social conflicts between members of the association can lead the WUA to become unstable over time. In the case of Tunisia, some specific studies (Makkaoui, 2006; Ben Salem *et al.,* 2005; Chraga *and* Chemakh, 2003) report the existence of such conflicts and weak social relationships between farmers and members of the Tunisian WUA.

Finally, the negative relationship found between the main technical explanatory variables (number of water pipes managed, areas equipped by water saving technologies, ratio of irrigation) and the calculated scores for overall efficiency, confirms the theoretical expectation as to the effect of the complexity of the irrigation system on the administration of collective action (see Benjamin *and* Bagadion, 2000). In fact, these technical attributes are important determinants of the stability and reliability of the water delivery performance of WUAs. Low performance in terms of water delivery could have a negative impact on farmers' productivity and water use efficiency, particularly during peak irrigation periods. In fact, Chraga and Chemkh, (2003) and Chebil *et al.,* (2007) showed that low water delivery performance for irrigation water, due to water scarcity and technical problems in some WUAs, does affect the perceptions and the willingness of farmers to pay for water.

5.6. Conclusion

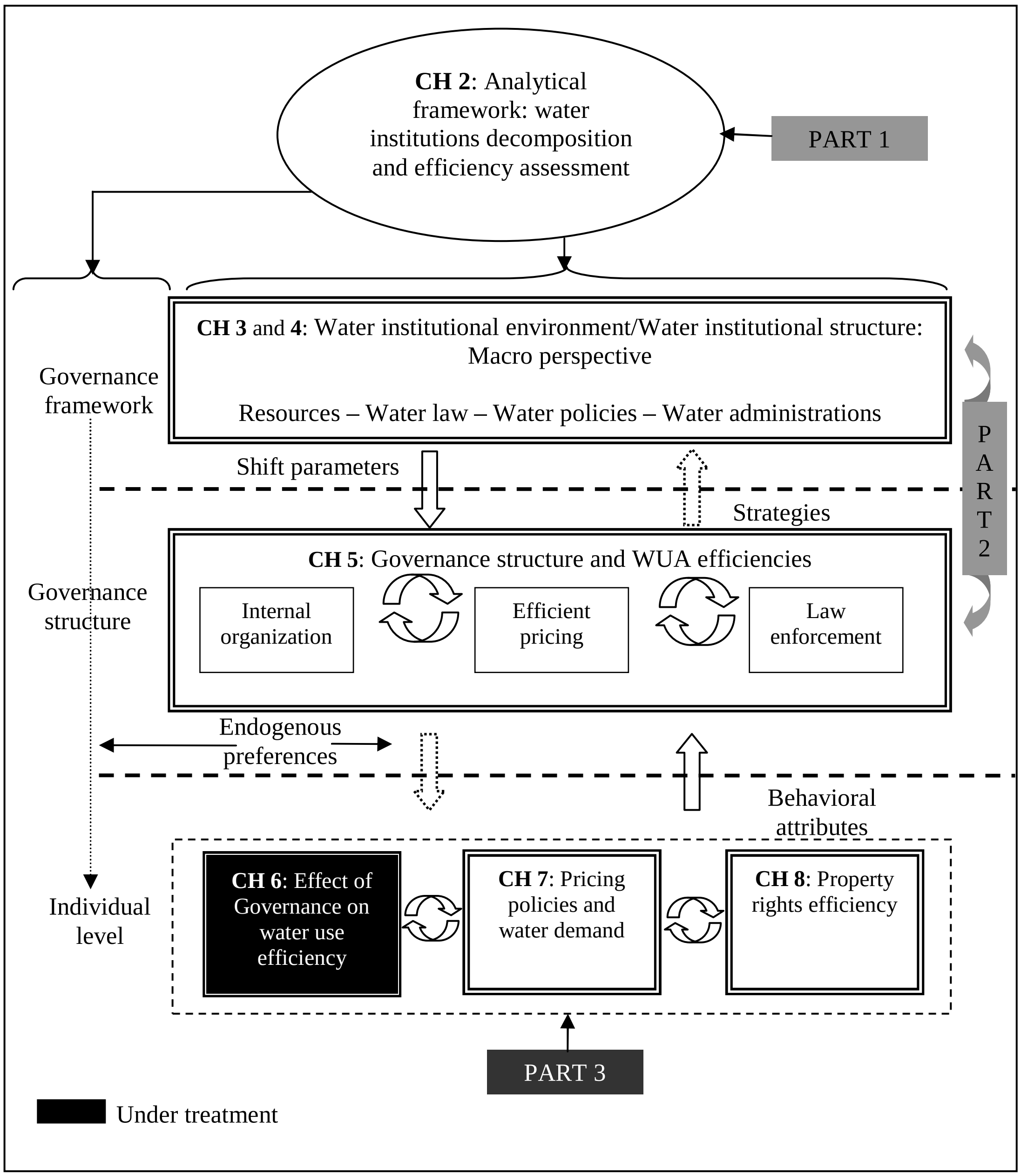
Most results found this chapter were inline with WUA problems identified in other studies and cited in chapter 4, section 4.5.3. Particularly, we show that managerial, financial and technical problems affect the performances of WUA in Cap Bon region. This may have deep repercussions on the socioeconomics of the farming systems. In the rest of the thesis, we will try to see how WUA performances affect the farmers' behaviour and perception.

More precisely, in this chapter, we have shown that an improvement in the organizational, managerial, and technical performance of WUAs could have significant benefits for the irrigation sector in Tunisia. Results observed have the following implications for the rest of our dissertation:

- We believe that insecurity in water supply stimulates farmers to overuse water when they gain access to it. Thus, improvements to the technical attributes of the WUA, in order to enhance its water delivery performance will have a direct effect on water use efficiency at farm level. In addition, WUAs in Tunisia now have a new legal statute permitting and encouraging them to contribute to the technical extension of farmers in their regions. Accordingly, WUAs can play a crucial role in increasing the efficient use of water at plot level.

- Low WUA efficiency is synonymous with the waste of financial resources that could be saved by the association. Given the fact that water fees are calculated on the basis of WUA expenses, a reduction in these expenses will then result either in lower water prices (affecting the water demand functions of farmers) or higher irrigation cost recovery rates.

- Improving WUA inefficiencies can also make farmers more willing to pay higher water rates in order to contribute to the recovery cost. Farmers realizing that their managers are wasting WUA resources will be far less motivated to contribute.


CH 2: Analytical framework: water institutions decomposition and efficiency assessment
PART 1
CH 3 and 4: Water institutional environment/Water institutional structure: Macro perspective
Resources – Water law – Water policies – Water administrations
Governance framework
Shift parameters
Strategies
P A R T 2
CH 5: Governance structure and WUA efficiencies
Internal organization
Efficient pricing
Law enforcement
Governance structure
Endogenous preferences
Behavioral attributes
CH 6: Effect of Governance on water use efficiency
CH 7: Pricing policies and water demand
CH 8: Property rights efficiency
Individual level
PART 3
Under treatment

Chapter 6. Effect of local irrigation water governance on farmers' water use efficiency

Abstract

This chapter is composed of two main parts. In the first part, we calculate irrigation water use efficiency (IWUE) at farm level for three different agricultural systems in Tunisia. Two irrigated systems from the Cap Bon region, in addition to the irrigated greenhouses horticultural system (Teboulba region in the central-coastal part of Tunisia), were selected for this purpose. In the second part, we empirically test the relationship between local irrigation governance and the various efficiencies calculated at farm level. We compare overall farming and IWU efficiencies between different groups of farmers belonging to two neighbouring irrigated areas in the Cap Bon region. The non-parametric Data Envelopment Analysis (DEA) model was used for the different efficiency calculations. Statistical tests were then conducted to assess the significance of variability in farming efficiency and IWUE between governance structures. Furthermore, this variability was also assessed between groups of farmers who differ regarding their perceptions of some specific governance attributes. The purpose of this was to identify which attributes of the governance structure are the most important. The efficiency scores calculated reveal a weak (around 50% on average) IWUE level for all systems studied. Results also show that the local governance structure for irrigation management is a determinant of both overall and water use efficiency. This result was in line with literature attesting that the technical and economic performance of water management is determined by - and not determinants of - the way in which water is governed. The chapter concludes that good local irrigation governance is necessary to make other institutional aspects of water demand management more effective.

Part of this chapter is submitted as:
Frija, A., Speelman. S., Chebil, A., Buysse, J. Van Huylenbroeck, G. (submitted). Impact of local irrigation governance on overall and water use efficiencies of the irrigated agricultural systems: case study from Tunisia. *Water international*

Part of this chapter is accepted as:
Frija, A., Chebil, A., Speelman. S., Buysse, J. Van Huylenbroeck, G. (accepted). Water use and technical efficiencies in horticultural greenhouses in Tunisia. *Agricultural Water Management, DOI:* 10.1016/j.agwat.2009.05.006

6.1. Introduction

Governance structure is considered in this dissertation as the set of systems that control decision making with regard to water management and water service delivery (Moriarty *et al.*, 2007). We assume that it comprises the technical, economic, administrative, financial and social aspects of local irrigation water management (Brooks, 2004). Since WUAs are considered as the gatekeeper for WDM at the local level, we can evaluate governance structures on the basis of how well WUAs perform with respect to their organizational and technical functions, and also through the perceptions of farmers regarding these functions. After assessing WUA efficiency in the previous chapter, it was clear to us that, even if the same administrative and organizational structure is applied to all WUAs, their performance would still vary significantly. This chapter tests empirically, the relationship between local irrigation governance and the efficiency of irrigation systems in Tunisia, in particular, the overall farming[24] and irrigation water use (IWU) efficiency at farm level. Recent studies call for a new approach which considers WDM institutions as a larger part of the water demand strategy. From this perspective, more emphasis should be paid to the improvement of governance structures and decision making processes, alongside support for technical, economic and legal aspects. In fact, technical, economic and legal issues are determined by – rather than determinants of – the way in which water is governed (Brooks, 2004). "Good governance" of irrigation water will accordingly result in better performance of various technical, economic and legal determinants of water management.

Our objectives in this chapter will therefore be twofold: Firstly, we intend to calculate the farming and IWU efficiency levels in our study areas in order to give some idea as to the current state of resource use in the Tunisian irrigated systems. Secondly, we aim to compare the effect of different "*local irrigation governance structures*" on the calculated farming and IWU efficiency scores. Our hypothesis here is that, with other factors held constant, the performance of individual water management could be linked to the quality and effectiveness of the local irrigation governance structure within which the farmer is operating (Tren and Schur, 2000) (Fig

[24] For the remainder of the dissertation, farming efficiency will refer to the overall technical efficiency of the agricultural production process at farm level.

6.1). Furthermore, using farmers' perceptional information as to particular governance attributes (Fig 6.2), the key elements and characteristics of local irrigation governance that affect farming and IWU efficiency levels, can also be determined.

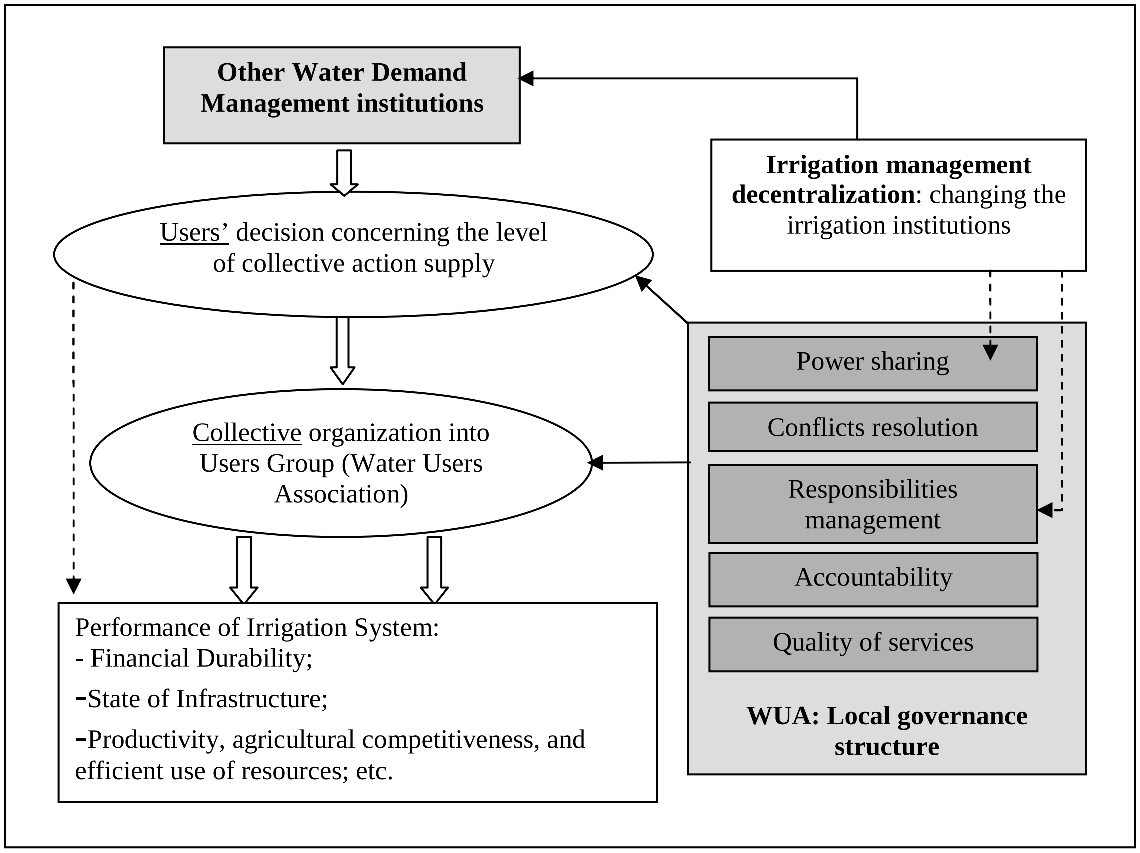


Fig 6. 1. Governance structure and performance of irrigated systems

Fig 6.2 presents a simplified conceptual framework for the current chapter. Accordingly, this chapter will be divided into two main parts. In the first one, we shall focus on the calculation of IWUE. Farming efficiency and IWUE for three agricultural systems will be calculated and discussed. In the second part, we select only Cap Bon's neighbouring systems for the comparative institutional analysis, where we shall focus on the effect of the governance structure, and farmers' perceptions, on their IWUE.

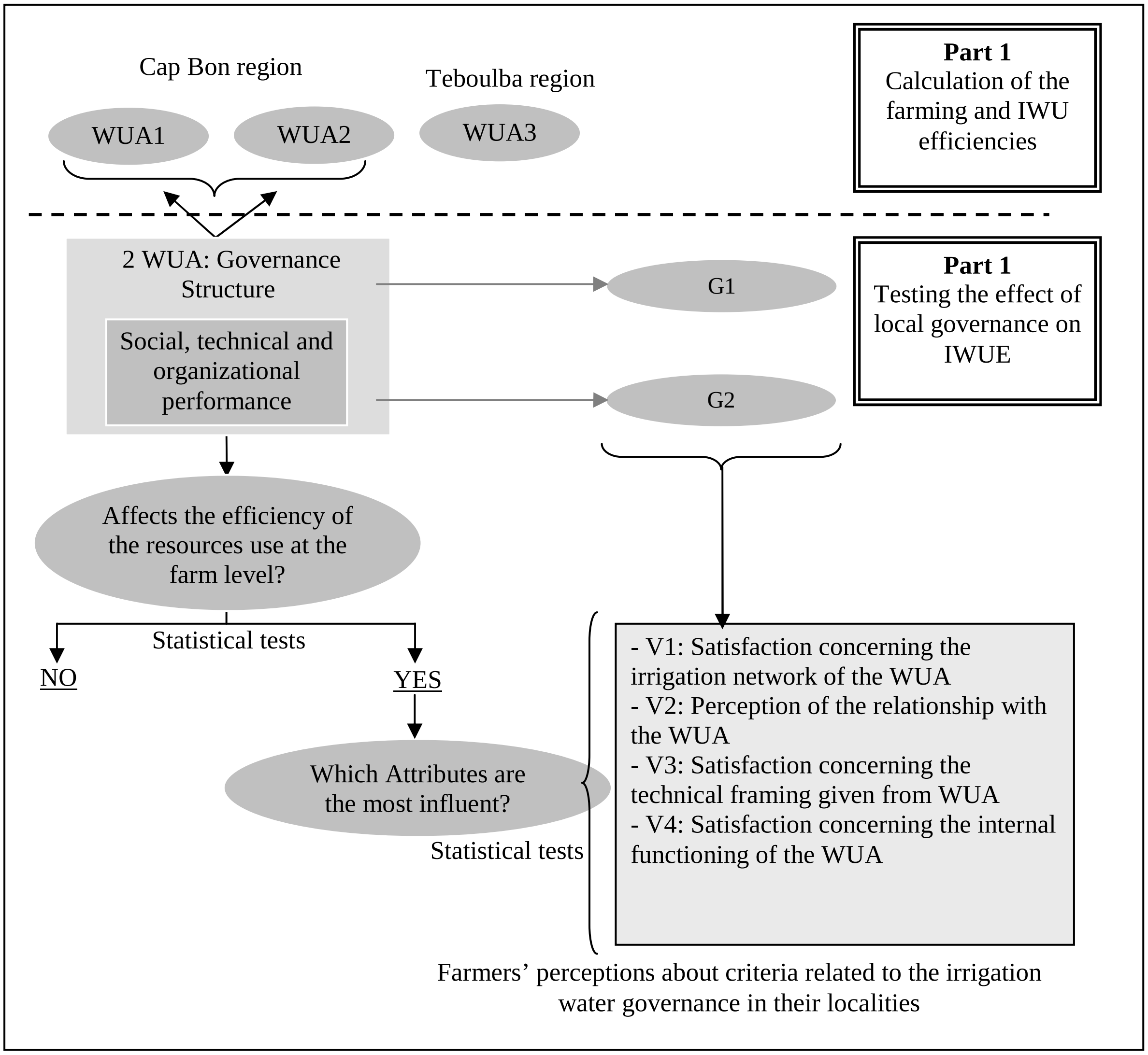


Fig 6. 2. Conceptual framework for the chapter (G denotes the group of farmers surveyed; V denotes the perception-based variables)

6.2. Water use efficiency at farm level

Concerns regarding the efficient use of water resources at farm level in Tunisia have been addressed in three ways (Al Atiri, 2004): (i) modernizing the management of collective irrigation systems by enhancing the role played by water users' associations and by promoting user participation in all aspects of management (ii) reformulating the water pricing system by introducing a cost recovery objective and (iii) developing incentives to enhance and promote the adoption of water saving technology at farm level. However, results concerning the efficiency of water use at farm level remain low, according to MARH sources and some recent research studies (Dhehibi *et al*., 2007; Albouchi *et al*., 2005).

In this section, we contribute to the evaluation of water use efficiency in Tunisian agriculture by calculating the IWUE at farm level in three Tunisian agricultural systems: Lebna Barrage (LB) and Fondok Jdid (FJ) in the Cap Bon region (governorate of Nabeul; Fig 6.3) and small-scale irrigated greenhouse production systems in Teboulba region (governorate of Monastir; Fig 6.4).

6.2.1. Methodology

We used the same Data Envelopment Analysis (DEA) methodology, already described in chapter 4. But in this chapter irrigated farms are considered as DMUs. Once DMU is defined, we shall specify input and output vectors in order to calculate their relative farming and IWU efficiency scores. Input and output specifications for each of the identified regions differ according to the data available. Farmers in Teboulba will be considered separately when calculating their efficiency scores. On the other hand, both farmer groups in FJ and LB will be considered together in the same sample simulation. We anticipate that different institutional, technical and physical attributes of both FJ and LB are homogenous because of their neighbouring locations (i.e. relating to the same regional administration). The concept of DEA subvector efficiency, presented in the previous chapter, will also be considered in this chapter for the calculation of IWUE scores (Speelman *et al*., 2008).

6.2.1.1. DEA specifications

In the agricultural sector, increasing the level of inputs does not always result in a proportional increase in the level of output produced (Speelman *et al*., 2008). For instance, when the amount of water used is increased, there is not necessarily a linearly proportional increase in crop volume. For this reason, a variable returns to scale option might be more suitable (than a constant scale specification) for efficiency measures in agricultural systems (Rodriguez-Diaz at al., 2004b) and will thus be used in this application.

An input-orientation is chosen for the calculation of both farming and IWU efficiencies. In fact, in the context of increasing water scarcity, it is more relevant to consider possible decreases in water use, instead of increases in output (Diaz Rodriguez *et al.*, 2004a). Besides, since farmers have overall control of their inputs, recommendations on the input levels used are feasible and more appropriate.

Recapitulating, it means that for the three selected systems, a BCC (Banker *et al*., 1984) input-oriented DEA model, in addition to a BCC subvector DEA model will be used for the calculation of overall farming and IWU efficiency levels respectively (see chapter 5 for a standard form of DEA and subvector-DEA models[25]).

6.2.1.2. Case study and data collection

- *Cap Bon region*

The study was conducted in the Cap Bon region. The decision to use this region is justified by its importance in terms of national production, crop diversification, extension of irrigated perimeters and water scarcity. The increasing competition for water between users (agriculture, industry and tourism) in Cap Bon clearly demonstrates the relative and increasing shortage of this resource.

The total agricultural land area in the Cap Bon region is approximately 256 500 ha, of which 183 000 ha comprise arable land, 22 500 ha forestry and 51 000 ha grassland. Cereals occupy the highest proportion, in terms of cropped area, with a land area of 53,000 ha, vegetables occupy 35,000 ha, olive trees (for olive oil) 23,500 ha, citrus trees 13,450 ha and other crops about 6,300 ha (CRDA Nabeul, 2006).

The irrigated sector in the Cap Bon region has experienced considerable development. It represents 13.3% of Tunisian irrigated land, occupying second place at a national level in terms of irrigated land area. 71% of these irrigated areas belong to small and medium-sized farms. Intensively irrigated land amounts to approximately 47,600 ha - 12% of the total for the whole country, 19,100 ha of which are situated within public irrigation perimeters (DGEDA, 2006).

[25] See also Speelman *et al*., 2008; and Lilienfeld and Asmild, 2007 who use such subvector models for the calculation of water use efficiency.

Our data was collected, during the period March-May 2007, from 62 randomly selected farmers belonging to the FJ and LB neighbouring areas in the Cap Bon region. Each area is managed by one WUA. The dataset includes 18.7 % (30 farmers) and 30 % (32 farmers) of the total adherent farmers to FJ and LB WUAs, respectively (Table 6.1). Characteristics of both associations are presented in Tables 6.1. LB and FJ WUA were selected from the set of WUAs used in chapter 4, where we evaluated the efficiency of all WUAs operating in Cap Bon. Efficiency scores for both WUAs are also provided in Table 6.1.

The questionnaire used in the LB and FJ irrigated areas consisted of the following sequences: (i) farmer identification (socio-economic and demographic characteristics); (ii) farm identification (cultivated crops, quantities and costs of inputs; quantities and values of outputs, etc.); (iii) identification of water use, source and quality; and (iv) evaluation of farmers' attitudes and perceptions concerning local irrigation water governance (functioning of their WUA).

Table 6. 1. Basic characteristics of LB and FJ WUAs

	Fondok Jdid	Lebna Barrage
Province	Grombalia	Mida
Rainfall (mm)	400-600	400-500
Date of creation	1998	1996
Irrigated surface (Ha)	1025	409
Source of water	aquifers, North water transfer	Lebna dam, north water transfer
Distribution mode	on request	On request
Price[26] (TND/m^3)	0.048	0.068
Irrigation technology	Drip, sprinkle, gravity	Drip, sprinkle, gravity
Main crops	Vegetables, cereals, Grapes	Vegetables, cereals
Engineering efficiency	51%	18.6%
Managerial efficiency	32%	84%
Number of members	161	108
Sample	30	32

Source: Groupements de Développement Agricole (2006). Rapports d'activités, GDA.

Selecting cases for comparison in ways that help to isolate institutional factors is a very important consideration for comparative analysis. In our case, the two selected areas belong to the same governorate. A technological homogeneity is assumed to exist between them. Also, in both areas,

[26]Average exchange rate at the time of data collection 1 TND = 0.55 €

the main crops planted are the same and farmers have full rights to plant any crop they choose. Other characteristics, such as precipitation and soils, are also assumed to be the same between both areas. The main differences that can be distinguished are: land structure (Table 6.2 and Fig 6.5), access to ground water, and local irrigation governance generated from the organizational and technical performance of the WUA responsible for irrigation demand management in each area.

Based on the governance definition established in this dissertation, the two areas can be considered as clearly different in terms of the technical and organizational attributes of their local irrigation governance. In fact, the engineering efficiency of LB WUA was found in chapter 4 to be very low (18.6%), in contrast to its organizational and managerial efficiency, which was found to be around 84% (Table 6.1). FJ WUA has opposite performances; its engineering efficiency was around 52% whilst its managerial efficiency was only around 30%.

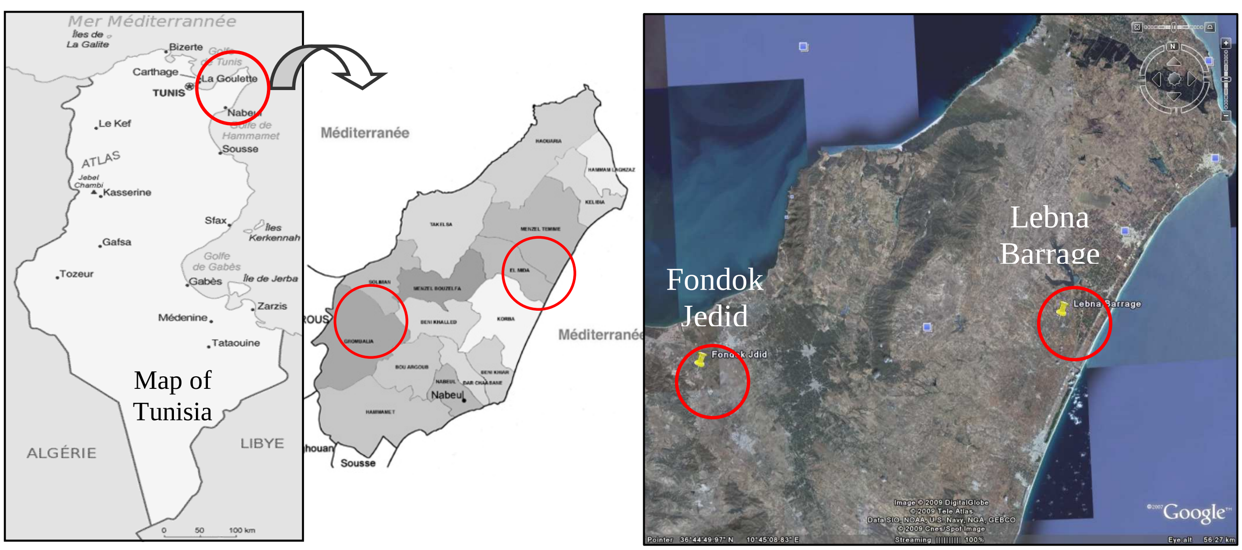


Fig 6. 3. Location of FJ and LB irrigated systems: Cap Bon region

One output and five inputs were chosen for the calculation of farming efficiency in FJ and LB. Output consisted of total farm income generated from irrigation activity, whilst inputs are: labour, volume of water consumed, fertilizers, land, and capital. Labour is assessed in terms of the number of working days; water consumption is expressed in terms of cubic metres[27]; and fertilizers in terms of kg applied[28]. Land and capital are considered as fixed inputs. The amount of capital used for our calculation only includes the machinery and water saving installations existing on the farm. Basic statistics for the farmers' inputs/outputs are shown in Table 6.2.

Table 6. 2. Descriptive statistics of the inputs/outputs used in the DEA models (LB and FJ areas)

		FJ area		LB area	
Variable	Dimension	Mean	SD	Mean	SD
Output	TND	17615.8 (1750*)	23982.5	5645.2 (2010*)	12163.4
Land	ha	10	19.7	2.8	4.6
Capital	TND	5798.3	7142.5	3619	2673
Labor	Days	225.1	391.1	93.5	188
Water	M^3	19819.5	36736.8	13789.1	23683.7
Fertilizers	Kg	4890	7024.5	8589.8	37873

** Average revenue per hectare*
SD: Standard Deviation

- *Teboulba region*

The decision to use the Teboulba irrigated system in the study is motivated by the socio-economic importance of greenhouse production in this region, the constraints on water resources and the high price of irrigation water (triple the price for water in the LB area and one of the highest prices in the country). Another motivation for the decision of including Teboulba system, is to provide a more diverse overview of irrigation water use efficiency in different Tunisian regions. The Teboulba case study will not be considered in the second part of this chapter.

In Teboulba, we collected our data from small-scale greenhouse farmers in the region, which is located in the eastern central area of Tunisia (Fig. 6.4). This region belongs to the Nebhana irrigation district where water scarcity is an important issue. The total agricultural land area in Teboulba is approximately 1914 ha, of which 600 ha are irrigated. The governorate of Monastir includes almost 39% (572 ha) of the total land area used for unheated greenhouses in Tunisia.

[27] The pricing method applied in the region is volumetric pricing. In each farm, water meters are installed and individual water consumption is measured and charged by the water users' association

[28] Main fertilizers used in the study region are the ammonium nitrate and the Di-Ammonium-Phosphate (Dap). For the efficiency calculation, both quantities (in kg) used by a farmer were agregated and considered in a same vector.

Teboulba region provides almost one third of the total production for this governorate (Regional administration of Agricultural Development; Monastir, 2004).

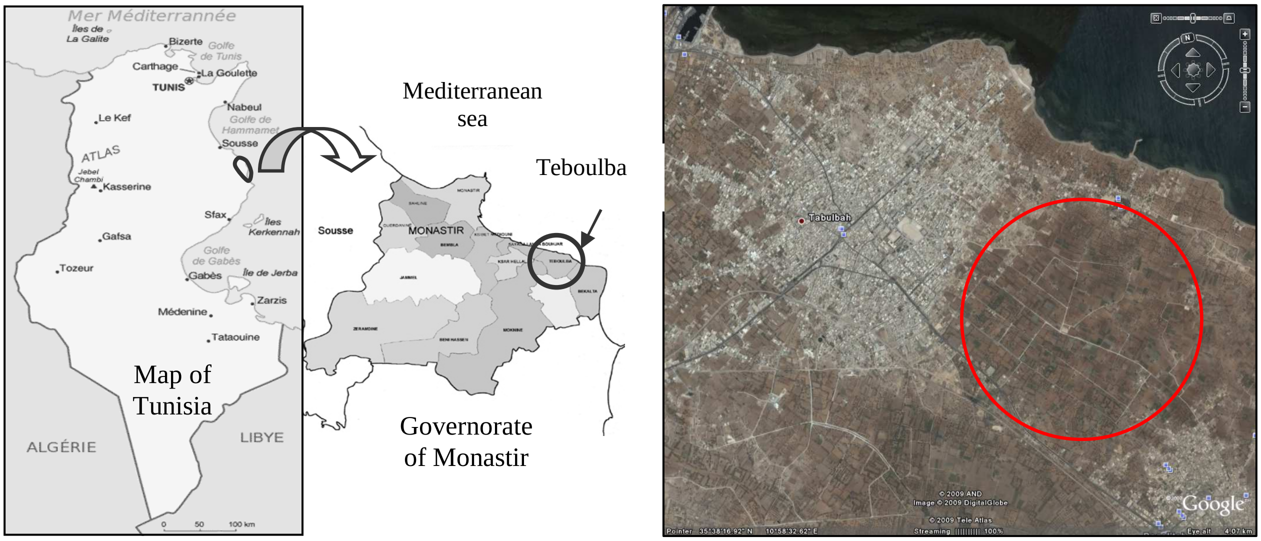


Fig 6. 4. Location of Teboulba region

The agricultural sector in Teboulba is dominated by rain-fed olive plantations for olive oil production. Greenhouses, which can easily be integrated with olive plantations, were largely developed after the establishment of the water transfer programme that commenced in the early 1980s. Water is transferred from the northern and central parts of the country to the southern and coastal areas, where fresh water resources are scarce. In view of its coastal situation, bordered in the east by the Mediterranean Sea, fishing is an important economic activity in the region.

Irrigation water prices in Teboulba are some of the highest in Tunisia. The price is approximately 0.15 TND m^{-3}, whilst supplies in some other regions of Tunisia are priced at a minimum rate of 0.04 TND m^{-3}. Volumetric water pricing is applied in the region. A water meter is installed at each farm and individual water consumption is measured and charged by the WUA.

In Teboulba, greenhouses are made from a plastic covering installed on metal ropes. Farmers do not use heating systems inside the greenhouses. Standard greenhouse covered surface area is between 420 and 540 m^2 (Agence de Vulgarisation et de Formation Agricole, AVFA, 2002). Each farm has a tank for water storage, which is normally supplied with water from a well or a public source. The tank is either directly connected to the greenhouses using plastic water pipes or drip irrigation systems, or connected through a fertigation unit, which allows irrigation water to be mixed with liquid fertilizers. Within our survey, all farmers who own a fertigation unit connect it using drip irrigation. According to our findings two main types of "irrigation systems" can be distinguished in the region. These comprise either a drip irrigation system linked to a fertigation unit, or a system using only plastic pipes and without any specific technology for conserving water.

We collected data in October 2005 from randomly selected 47 farmers who own 16.2 % (97.6 ha) of the total irrigated land area and hold 13.8 % (276 greenhouses) of the greenhouses located in the region of Teboulba (2060). Farmers mainly produce tomatoes, melons and peppers. Our questionnaire contained two main sequences relating to farmer and farm identification (production structure and input use). To limit the number of inputs/outputs used in the DEA, total output (production quantity) was converted into monetary values. The inputs considered are: land (hectares), irrigation water (m^3) and labour (number of workers present on the farm during one year). Basic statistics for the sample are shown in Table 6.3.

Table 6. 3. Basic statistics for data used in the DEA Models in Teboulba region[29]

	Total Output (Tunisian Dinars)	**Inputs**		
		Land (ha)	Water (m^3)	Labour (man/year)
Average	7863.75	0.294	4008.57[30]	5.697
Standard Deviation	5577.14	0.178	2920.80	4.713
Minimum	1309	0.05	350	0.5
Maximum	24923	0.85	10000	22

Source: survey

[29] Data from Teboulba system was collected in an earlier research project using different questionnaire. For this reason, we were not able to use the same inputs/outputs vectors in both Cap Bon and Teboulba regions.

[30] Average water use per ha, for main cultivated crops under green houses, in Tunisia is between 7000 and 10000 m^3. This is in average a volume between 350-500 m^3 /greenhouse (APIA: see http://www.tunisie.com/APIA/broch%20sous%20abri.pdf)

6.2.2. Results

6.2.2.1. Cap Bon region

- *Descriptive results: socio-economic and structural differences between the FJ and LB areas*

With regard to land structure, our survey shows that in the selected sample, the average size per farm is much lower in LB in comparison with the FJ area. Most of the farms in LB (72%) are small farms (less than 2.5 ha in size) whilst 38% of the farms in FJ are medium and large sized farms (Fig 6.5). The effect of size on farming and IWU efficiency levels will be tested (in the second part of this chapter) together with some other socioeconomic variables.

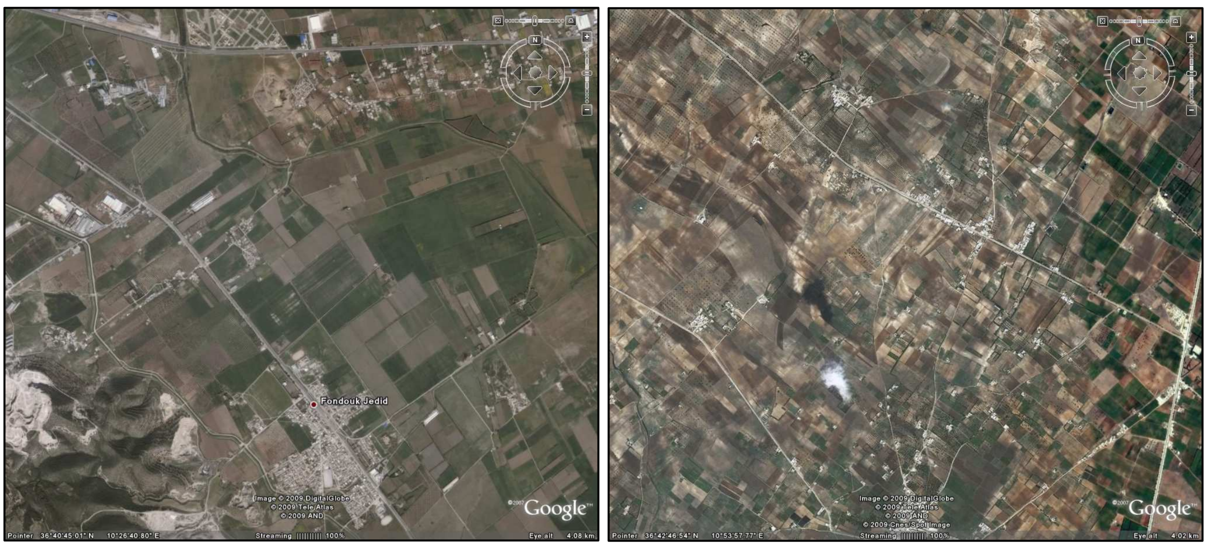


Fig 6. 5. Aerial photos taken from the same altitude for FJ (left) and LB (right) showing differences in farm structure (Source: Google Earth)

In FJ the survey shows that 98% of farmers have a well which they can exploit. When water is needed urgently, some farmers in FJ can pump water from their aquifer, whilst those of LB do not have this option (public water distributed by the WUA is the unique source of irrigation water in LB). Of the farmers in FJ, 26% do not use their well for various reasons, such as the salinity of the water or high pumping costs. Therefore, we decided to divide farmers from FJ into two different groups: FJ1 and FJ2. FJ1 contains 22 farms (73% of total FJ sample) in FJ who use both ground and public water, whilst FJ2 comprises 8 farms (27% of total FJ sample) that use only public water purchased from the WUA. By drawing this distinction, more appropriate comparisons between regions and groups can be provided, since the difference between LB and FJ relating to the conjunctive use of water will be removed by using the FJ2 group for this comparison.

In line with both WUAs' efficiency scores, as measured in chapter 5, our survey reveals that in LB 84% of the surveyed farmers are satisfied with the internal functioning of their association, whilst 76% of the farmers in FJ are not satisfied in respect of this last point. In the same sense, 100% of the LB farmers estimate that they have a good relationship with the administrative members of their association, whilst less than 80% of farmers in FJ indicated that they have a similarly good relationship. This shows that some problems occur in FJ WUA between farmers and WUA managers.

With regard to perceptions concerning the technical attributes of water management, 36.4% of the surveyed farmers in LB were not satisfied with the irrigation network in their WUA, whilst almost 93% of FJ farmers were satisfied concerning this point. Extension services, providing technical information, were also found to be insufficient according to 76% and 24% of LB and FJ farmers respectively.

- *Overall farming and water use efficiency*

Farming and IWU efficiency scores for the selected areas were calculated using the General Algebraic Modeling System (GAMS) to solve the DEA models described in section 6.2.1. All farmers from LB and FJ were considered in the same set and a common frontier was drawn for all of them.

Table 6.4 and Figure 6.6 present a comparison of average farming and IWU efficiency levels between FJ1, FJ2, and LB. It shows that all FJ2 farmers, who only use public water from the WUA, are located on the efficient frontier with regard to their farming efficiency when assuming a VRS. Their average IWUE is also the highest for all groups.

Table 6. 4. Overall farming and IWU efficiency scores per group of farmers in the Cap Bon region

	Average FE			Average IWUE		
	CRS	VRS	SC	CRS	VRS	SC
FJ1	0.570	0.814	0.512	0.436	0.569	0.585
FJ2	0.592	1.000	0.592	0.500	0.693	0.807
All FJ	0.581	0.852	0.670	0.437	0.579	0.800
LB	0.344	0.546	0.640	0.131	0.290	0.781
Average (all sample)	0.459	0.694	0.661	0.282	0.432	0.790

For all following tables, SC denotes scale efficiency, FE denotes Farming efficiency and expresses the technical efficiency of farmers calculated from standard DEA model; IWUE, denotes Irrigation Water Use Efficiency.

Farming efficiency scores in Table 6.4 indicate that, under the VRS assumption, farmers in our sample could reduce their input use by 30%, on average, whilst producing the same observed output quantity. Also, the average IWUE was found to be around 43% under the VRS assumption. This implies that the observed output level could be maintained whilst using the currently observed values of other inputs and 57% less irrigation water. Results also indicate that some scale inefficiencies occur in the studied systems. These inefficiencies affect the farming efficiency to a larger extent than the IWU efficiency.

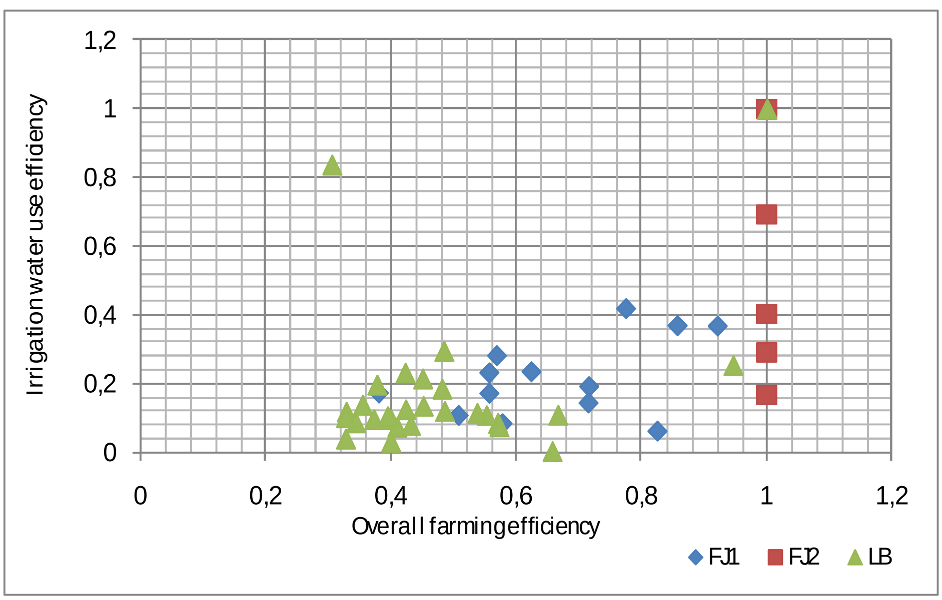


Fig 6. 6. Distribution of individual farms according to their farming and IWU efficiency scores

In order to determine the relationship between IWUE and technical efficiency, we used a pairwise correlation test to investigate equality between both efficiency vectors. The test was statistically significant. Table 6.5 shows that under both CRS and VRS assumptions, technical efficiency and IWUE are highly and positively correlated. This finding proves that efficient water use could lead to an improvement in overall farming efficiency.

Table 6. 5. Results of correlation test « pair-wise correlation » between farming and IWUE efficiencies (Cap Bon sample)

	FE (CRS)	FE (VRS)	IWUE (CRS)	IWUE (VRS)
FE (CRS)	1			
FE (VRS)	0.702***	1		
IWUE (CRS)	0.835***	0.579***	1	
IWUE (VRS)	0.625***	0.779***	0.642***	1

****: significant at 1% level*

6.2.2.2. Teboulba region

The frequency distribution for the obtained efficiency scores calculated using the Teboulba' farm-sample is reported in Table 6.6.

Table 6. 6. Frequency distribution of technical and irrigation water use efficiency levels in Teboulba

	Farming efficiency				IWUE			
	CRS		VRS		CRS		VRS	
Efficiency level (%)	Number of farms	% of farms	Number of farms	% of farms	Number of farms	% of farms	Number of farms	% of farms
0<E<=25	0	0	0	0	24	51.1	14	29.7
25<E<=50	13	27.6	5	10.6	10	21.2	12	25.5
50<E<=75	19	40.4	19	40.4	4	8.5	4	8.5
75<E<=100	15	31.9	23	48.9	9	19.1	17	36.2
Average	67.3		75.6		41.8		52.6	
Scale Efficiency	0.88				0.949			

E denotes efficiency level.

Table 6.6 shows that many farms are operating at an overall farming efficient level with regard to their overall production process. Under the VRS assumption, more than 89% of farms have a technical efficiency higher than 50%. Scale efficiency is approximately 0.9, indicating that the majority of farms operate at an efficient scale. On the other hand, the average IWUE score in the sample was only 41.8% and 52.6% under the CRS and VRS assumptions respectively. The IWU scale efficiency is also quite high, showing that IWUE in the study area is not affected by the scale of the operation. Results regarding IWUE suggest that farmers could save substantial amounts of water by improving their IWUE.

Table 6.7 illustrates the farming efficiency level and the IWUE for three groups of farmers identified as follows - (i) the most efficient overall (i.e. farming efficiency between 75% and 100%), (ii) the next most efficient (farming efficiency between 50% and 75%), and (iii) the least efficient (farming efficiency between 0 and 50%). The Table shows that the average IWUE is always lower than the average farming efficiency for production as a whole. In fact, whilst the average farming efficiency is around 92% for the most efficient group, the average IWUE for this group is only around 80%. For the least efficient group, the average farming efficiency obtained is 45%; however, the IWUE for this group is only 11.4%.

Table 6. 7. Average efficiency levels for selected farm groups (Teboulba)

	Farming efficiency (CRS) (average)	IWUE (average/CRS)
Group 1 (75%<FE<100%)	92.5%	79.9%
Group 2 (50%<=FE<75%)	63.3%	30.4%
Group 3 (0<=FE<50%)	45%	11.4%

FE denotes farming efficiency under CRS assumption

Figure 6.7 depicts the cumulative efficiency distributions, confirming that under CRS and VRS specifications, the proportion of farmers with poor IWUE scores is always higher than the proportion of those having poor scores for overall farming efficiency.

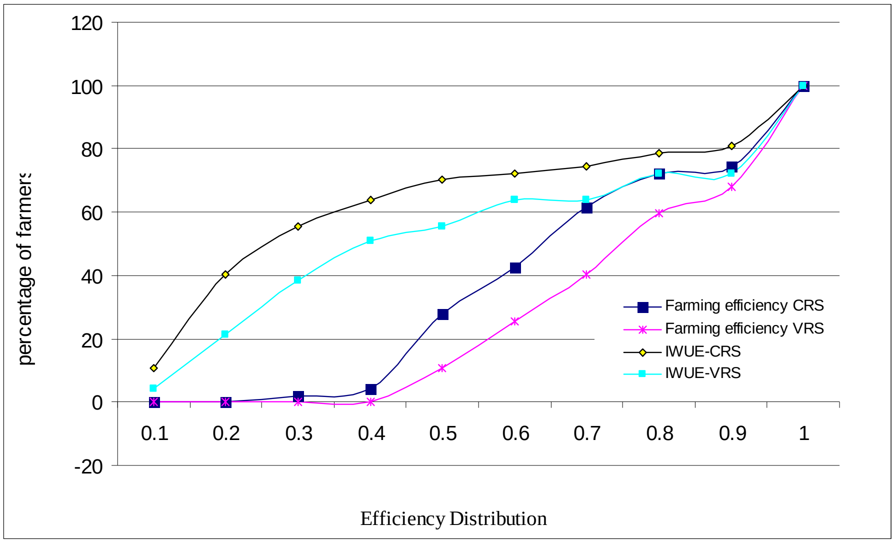


Fig 6. 7. Cumulative efficiency distribution for both farming and irrigation water use efficiencies

A pairwise correlation test investigating the level of equality between both efficiency vectors was also made for the Teboulba sample. The test was statistically significant (Table 6.8) under both CRS and VRS assumptions. It shows, once again, that overall farming performance and use of water resources are highly and positively correlated.

Table 6. 8. Results of correlation test « pair-wise correlation » between farming efficiency and IWUE (Teboulba sample)

	FE (CRS)	FE (VRS)	IWUE (CRS)	IWUE (VRS)
FE (CRS)	1			
FE (VRS)	0.858***	1		
IWUE (CRS)	0.845***	0.704***	1	
IWUE (VRS)	0.821***	0.935***	0.754***	1

****: significant at 1% level*

6.2.3. Discussion: weak water use efficiency level in irrigated areas of Tunisia

Average IWUE calculated for both of the Cap Bon irrigated systems was around 43% under the VRS assumption. This shows that, on average, 57% of irrigation water could be saved by farmers without reducing current output levels. Also, contrary to expectations, farmers in FJ are, on average, more efficient in terms of irrigation water use. These farmers pay lower water rates than LB farmers and have access to private groundwater sources with sometimes lower prices than public water. Farmers in FJ who only use public water (FJ2 group) are the most efficient in terms of farming and irrigation water use efficiency. They draw the frontier for efficient farms in the sample. This shows that the source of water and the pricing tool are not sufficient to induce higher performance for water use efficiency.

The low value of IWUE, and its variability between various groups in the Cap Bon region (Fig 6.6) show, however, that there is considerable scope for increasing water conservation. This result also shows that, even if the same formal administrative and organizational directives are applied in similar areas, the results in terms of farming and IWU efficiency levels can be different. Many authors identified similar variability in water use between neighbouring irrigated schemes. Some of them attribute these differences to institutional design and local irrigation management (Tren and Schur, 2000; Hermans *et al*., 2006, etc.).

Assuming a VRS, the average IWUE in the greenhouse production systems of Teboulba region was around 52%, which is also very low. This implies that the observed quantity of marketable fruit and vegetables produced in greenhouses could be maintained in the area by using the observed values of other inputs, whilst using 48% less irrigation water.

Substantial water inefficiencies in Tunisia (47%) were also reported by Dhehibi *et al*., (2007) for irrigated citrus production systems in Cap Bon. Albouchi *et al*., (2005) found that IWUE in the Kairouan region (the main agricultural area in the central part of Tunisia) was approximately 53%. Chebil *et al*., (2007), using the same sample of Teboulba farmers as we used in our study, found that farmers are willing to pay higher prices for irrigation water if this were to improve distribution and delivery services. Thus, Tunisia still has much to do in order to improve the use and sustainability of its water resources, starting at the farm level.

Considering the difference in water prices between the Teboulba and Cap Bon systems, the pricing tool seems to be insufficient as a means of increasing water use efficiency.

As shown in Tables 6.5 and 6.8, farming efficiency for the farms in our sample is positively and highly correlated with IWUE at farm level. Thus, apart from the impact on water conservation, efforts made to rationalize water use also had an important impact on the sector’s productivity. In addition, our results demonstrate that the potential exists to improve IWUE, both on farms with a high level of technical efficiency and those with a low level of efficiency (see Table 6.7 for the

Teboulba case).

The "National Irrigation Water Saving Programme", introduced in 1995 to encourage irrigators to invest in water saving technology, generated higher measures of IWUE and improved farmers' incomes in Tunisia (Al Atiri, 2004). This programme, which provides subsidies ranging from 40% to 60% of the purchase price of modern irrigation equipment, has been an inducement for many farmers to invest in water saving technology (Ministère d'Agriculture et des Ressources Hydrauliques, 2004). In 2004 the areas equipped with water saving technology in Tunisia represented only around 75% of the total irrigated area (Agency of Agricultural Investments Promotion, 2004). However, an effort should be made to encourage farmers with limited resources to adopt these techniques (Albouchi *et al.*, 2005). In addition, more research is needed to evaluate related factors that could enhance the effects of IWUE-improvement policies (e.g. pricing policies, technology adoption, participation, etc.). In this sense, the next section will focus on the study of the relationship between local irrigation governance, approximated by WUA performance, and farmers' efficiency.

6.3. Local irrigation governance and IWUE

As introduced in section 6.1, recent studies call for a new approach which considers WDM institutions as a larger part of the water demand strategy. From this perspective, more emphasis should be paid to the improvement of governance structures and decision making processes, alongside support for technical, economic and legal aspects. Brooks (2004) argue that technical, economic and legal issues are determined by – rather than determinants of – the way in which water is governed. Accordingly, "good governance" of irrigation water will result in better performance of various technical, economic and legal determinants of water management. In the current section, we try to investigate if there is any significant statistical relationship between the local irrigation governance and the individual farmers' performance in our study area. Enlightenment of this relationship could have a lot of benefit on how to manage efficiently water at the local level (enhancing the effectiveness of local water demand management tools).

6.3.1. Methodology

This section is mainly based on some statistical tests (Kruskal-Wallis) and on the application of the Tobit model presented in the previous chapter. The aim is to identify relevant and significant variables, including local irrigation governance, which can explain the variance in efficiency scores observed between groups of farmers in the Cap Bon region. Farmers will also be grouped based on their perceptions concerning some attributes relating to the functioning of their WUA. Some of these attributes are technical whilst others relate to the internal management of the WUA and to the relationship between the farmers and the managers of their WUA. The Kruskal-Wallis test will be used to identify any significant variability in farming and IWU efficiency levels between perception-based groups.

6.3.2. Results

6.3.2.1. Socioeconomic determinants of farming and water use efficiency

Several socioeconomic variables are expected to affect the technical efficiency of farmers. Hereby, we regressed a *Tobit* model in order to explain both the farming and IWU efficiency scores calculated for Cap Bon farmers. Table 6.9 below lists the explanatory variables (i.e. those relating to farmer characteristics and farm structure) tested in this regression.

Table 6. 9. Definition of potential explicative variables of farming and IWU efficiency scores in Cap Bon region

Variable	Definition of the variable	LB (Mean)	FJ (Mean)	Total
- Age of the manager (years)	In years	37	57	41
- Education level (% secondary or higher)	- 1 for secondary or higher level, - 0 otherwise	30	73	55
- Experience (in years)	Date of starting irrigated activity	12	19.5	16
- Agriculture is a unique source of revenue (%)	1 if agriculture is unique source of revenue 0 otherwise	88	67.7	88
- Land size	Size of the farm in ha	2.8	10	6.1

Source: survey

The results of this regression show that almost none of the selected socioeconomic variables could be considered as a determinant of irrigation water use efficiency at farm level in the Cap Bon systems (Table 6.10). The weak pseudo R^2 also shows that the variables used in this regression explains little the variability in the explained variables. Farming efficiency is only partly explained by the farmers' level of education.

Land structure, which is one of the main differences between the FJ and LB systems, was also integrated into the *Tobit* regression as an explicative variable. However, its effect on both farming and IWU efficiency vectors was not significant.

Table 6. 10. Effect of socioeconomic variables on farming and IWU efficiencies: Tobit model results

Explanatory socioeconomic variables	Explained variables#			
	FE		**IWUE**	
	Estimate	*P*-Value	Estimate	*P*-Value
- Age	0.008	0.083*	0.110	0.116
- Schooling	0.020	0.040**	0.005	0.678
- Experience	-0.0001	0.990	0.003	0.851
- Main activity	0.119	0.309	0.322	0.082*
- Land size	0.0023	0.959	-0.066	0.316
- Constant	0.186	0.354	-0.048	0.867
σ^a	0.344	0.042	0.516	0.062
Pseudo R2	0.181		0.083	
Log-Likelihood	-32.86		-51.05	
LR(χ^2)	14.42		9.08	
P> χ^2	0.013**		0.106	
Number of observations	62		62	

, **, * = significant at 10%, 5%, and 1% level respectively.*
a For σ the standard error is reported instead of the P-value.
 # VRS scores are used in this test

6.3.2.2. Variance in efficiency between LB and FJ

Average values of farming and IWU efficiency were shown to be clearly different between FJ1, FJ2, and LB. Here, we statistically test this variability. The statistical significance of differences in farming and IWU efficiency between the three farm groups is assessed using a non-parametric Kruskal-Wallis (K-Wallis) test. The K-Wallis statistical test belongs to the "Tests for Several Independent Samples Procedure" category, which compares two or more groups of cases for one variable, in order to see if they belong to the same population. A non parametric test is required because the technical efficiencies are effectively censored between zero and one (Oude Lansink & Bezlepkin, 2003). In our case, from K-Wallis one-way analysis of variance, we might learn that the three selected groups of farmers do or do not differ in terms of average efficiency scores.

The statistical significance of differences in average efficiency scores between farm groups is presented in Table 6.11. It shows that all P-values are below 0.01, which indicates that the efficiency of different groups significantly differs in terms of farming and IWU efficiencies under both CRS and VRS assumptions, at the critical 1% level. Further analysis with regard to potential governance-related factors that could explain these differences is presented below (Table 6.12).

Table 6. 11. Kruskal-Wallis tests for differences in farming and IWU efficiencies between FJ1, FJ2, and LB

Test	Hypothesis		Test result	P-Value
<u>FE</u>				
CRS	H0: $\theta^1_{FE} = \theta^2_{FE} = \theta^3_{FE}$	H1: $\theta^1_{FE} \neq \theta^2_{FE} \neq \theta^3_{FE}$	8.792***	0.010
VRS			23.184***	0.000
<u>IWUE</u>				
CRS	H0: $\theta^1_{IWUE} = \theta^2_{IWUE} = \theta^3_{IWUE}$	H1: $\theta^1_{IWUE} \neq \theta^2_{IWUE} \neq \theta^3_{IWUE}$	15.352***	0.000
VRS			13.966***	0.000
<u>FE</u>				
CRS	H0: $\theta^{1+2}_{FE} = \theta^3_{FE}$	H1: $\theta^{1+2}_{FE} \neq \theta^3_{FE}$	7.914***	0.004
VRS			17.928***	0.000
<u>IWUE</u>				
CRS	H0: $\theta^{1+2}_{IWUE} = \theta^3_{IWUE}$	H1: $\theta^{1+2}_{IWUE} \neq \theta^3_{IWUE}$	12.381***	0.000
VRS			10.967***	0.000

Subscript i in this Table refers to farm type, with i=1,...,3 referring to FJ1, FJ2, and LB types, respectively; 1+2 refers to all FJ farmers taken together within a unique group

6.3.2.3. Variance in efficiencies between farmers' perceptions-based groups within whole sample

Here we use farmers' perceptions on criteria relating to irrigation water governance in their localities as proxy variables in order to elucidate the effect of main governance attributes on farming and irrigation performance. Explicitly, we seek to test whether there is any significant variability in the calculated efficiency scores between groups of farmers who are differentiated by their level of satisfaction regarding the organization of and services provided by the WUA to which they belong.

Stakeholders' perceptions were widely used as important information for the empirical analysis of institutional performance (see Knack and Keefer 1986; Cukierman *et al.,* 1998; Gray and Kaufmann 1998; Barrett and Graddy 2000, etc.). Relevant information drawn from this type of data is used regularly both by individuals and society to make important social, economic, and political decisions (Saleth and Dinar, 2004).

The surveyed perceptions taken into consideration in this application are:

- V1: Satisfaction concerning the collective irrigation network of the WUA (Binary variable: satisfied / non-satisfied);

- V2: Perception as to the farmer's relationship with the WUA managers: (Binary variable: good/bad);

- V3: Satisfaction concerning the technical services (mainly extension) provided by the WUA (Binary variable: satisfied / non-satisfied);

- V4: Satisfaction with regard to the internal functioning and organization of the WUA (satisfied / non-satisfied).

V1 and V3 are "technical-oriented perceptions" whilst V2 and V4 are "organizational and managerial-oriented perceptions". Results of the statistical K-Wallis test concerning the variability of farming and IWU efficiency scores between these perception-based groups are presented below.

Table 6. 12. Kruskal-Wallis tests for differences in farming and IWU efficiencies between different farmers' perception groups (whole sample considered)

	Test	Hypothesis		Test Result	P-Value
FE	CRS assumption	H0: $\theta_{FE}^{CRS,V1} = \theta_{FE}^{CRS,V'1}$	H1: $\theta_{FE}^{CRS,V1} \neq \theta_{FE}^{CRS,V'1}$	2.452	0.117
		H0: $\theta_{FE}^{CRS,V2} = \theta_{FE}^{CRS,V'2}$	H1: $\theta_{FE}^{CRS,V2} \neq \theta_{FE}^{CRS,V'2}$	2.810*	0.093
		H0: $\theta_{FE}^{CRS,V3} = \theta_{FE}^{CRS,V'3}$	H1: $\theta_{FE}^{CRS,V3} \neq \theta_{FE}^{CRS,V'3}$	3.429*	0.064
		H0: $\theta_{FE}^{CRS,V4} = \theta_{FE}^{CRS,V'4}$	H1: $\theta_{FE}^{CRS,V4} \neq \theta_{FE}^{CRS,V'4}$	1.844	0.174
	VRS assumption	H0: $\theta_{FE}^{VRS,V1} = \theta_{FE}^{VRS,V'1}$	H1: $\theta_{FE}^{VRS,V1} \neq \theta_{FE}^{VRS,V'1}$	10.613***	0.001
		H0: $\theta_{FE}^{VRS,V2} = \theta_{FE}^{VRS,V'2}$	H1: $\theta_{FE}^{VRS,V2} \neq \theta_{FE}^{VRS,V'2}$	0.021	0.886
		H0: $\theta_{FE}^{VRS,V3} = \theta_{FE}^{VRS,V'3}$	H1: $\theta_{FE}^{VRS,V3} \neq \theta_{FE}^{VRS,V'3}$	4.015**	0.045
		H0: $\theta_{FE}^{VRS,V4} = \theta_{FE}^{VRS,V'4}$	H1: $\theta_{FE}^{VRS,V4} \neq \theta_{FE}^{VRS,V'4}$	2.669	0.100
IWUE	CRS assumption	H0: $\theta_{IWUE}^{CRS,V1} = \theta_{IWUE}^{CRS,V'1}$	H1: $\theta_{IWUE}^{CRS,V1} \neq \theta_{IWUE}^{CRS,V'1}$	2.452	0.117
		H0: $\theta_{IWUE}^{CRS,V2} = \theta_{IWUE}^{CRS,V'2}$	H1: $\theta_{IWUE}^{CRS,V2} \neq \theta_{IWUE}^{CRS,V'2}$	0.161	0.688
		H0: $\theta_{IWUE}^{CRS,V3} = \theta_{IWUE}^{CRS,V'3}$	H1: $\theta_{IWUE}^{CRS,V3} \neq \theta_{IWUE}^{CRS,V'3}$	2.281	0.131
		H0: $\theta_{IWUE}^{CRS,V4} = \theta_{IWUE}^{CRS,V'4}$	H1: $\theta_{IWUE}^{CRS,V4} \neq \theta_{IWUE}^{CRS,V'4}$	3.202*	0.073
	VRS assumption	H0: $\theta_{IWUE}^{VRS,V1} = \theta_{IWUE}^{VRS,V'1}$	H1: $\theta_{IWUE}^{VRS,V1} \neq \theta_{IWUE}^{VRS,V'1}$	8.930***	0.002
		H0: $\theta_{IWUE}^{VRS,V2} = \theta_{IWUE}^{VRS,V'2}$	H1: $\theta_{IWUE}^{VRS,V2} \neq \theta_{IWUE}^{VRS,V'2}$	0.161	0.688
		H0: $\theta_{IWUE}^{VRS,V3} = \theta_{IWUE}^{VRS,V'3}$	H1: $\theta_{IWUE}^{VRS,V3} \neq \theta_{IWUE}^{VRS,V'3}$	1.897	0.168
		H0: $\theta_{IWUE}^{VRS,V4} = \theta_{IWUE}^{VRS,V'4}$	H1: $\theta_{IWUE}^{VRS,V4} \neq \theta_{IWUE}^{VRS,V'4}$	0.353	0.552

Subscripts V1 to V4 refers to farmers groups with positive perception according to a given criteria (presented below), Subscripts V'1 to V'4 refers to farmers groups with negative perceptions,

The results presented in Table 6.12 show that average VRS farming and IWU efficiencies are significantly different between the satisfied and the non-satisfied farmers with regard to the technical functioning of their WUA's irrigation network. It also shows that VRS farming efficiency is significantly different between satisfied and non-satisfied farmers concerning the extension services provided by their WUA. This implies that farming and IWU efficiencies are statistically linked to the "technical-oriented perceptions" of farmers.

6.3.2.4. Variance in efficiency scores between farmers' perceptions-based groups within each WUA

In order to go into further detail, we performed the same test as above (for VRS scores) whilst considering each WUA group separately. Results are presented in Table 6.13.

Table 6. 13. Kruskal-Wallis tests for differences in farming and IWU efficiencies between different farmers' perception groups within each WUA

Test(#)		Hypothesis		Test Result	P-Value
FJ group	FE	H0: $\theta_{FE}^{1,V1} = \theta_{FE}^{1,V'1}$	H1: $\theta_{FE}^{1,V1} \neq \theta_{FE}^{1,V'1}$	- (##)	-
		H0: $\theta_{FE}^{1,V2} = \theta_{FE}^{1,V'2}$	H1: $\theta_{FE}^{1,V2} \neq \theta_{FE}^{1,V'2}$	2.713*	0.099
		H0: $\theta_{FE}^{1,V3} = \theta_{FE}^{1,V'3}$	H1: $\theta_{FE}^{1,V3} \neq \theta_{FE}^{1,V'3}$	3.645*	0.056
		H0: $\theta_{FE}^{1,V4} = \theta_{FE}^{1,V'4}$	H1: $\theta_{FE}^{1,V4} \neq \theta_{FE}^{1,V'4}$	1.753	0.1855
	IWUE	H0: $\theta_{IWUE}^{1,V1} = \theta_{IWUE}^{1,V'1}$	H1: $\theta_{IWUE}^{1,V1} \neq \theta_{IWUE}^{1,V'1}$	-	-
		H0: $\theta_{IWUE}^{1,V2} = \theta_{IWUE}^{1,V'2}$	H1: $\theta_{IWUE}^{1,V2} \neq \theta_{IWUE}^{1,V'2}$	2.326	0.127
		H0: $\theta_{IWUE}^{1,V3} = \theta_{IWUE}^{1,V'3}$	H1: $\theta_{IWUE}^{1,V3} \neq \theta_{IWUE}^{1,V'3}$	1.125	0.288
		H0: $\theta_{IWUE}^{1,V4} = \theta_{IWUE}^{1,V'4}$	H1: $\theta_{IWUE}^{1,V4} \neq \theta_{IWUE}^{1,V'4}$	4.141**	0.041
LB group	FE	H0: $\theta_{FE}^{2,V1} = \theta_{FE}^{2,V'1}$	H1: $\theta_{FE}^{2,V1} \neq \theta_{FE}^{2,V'1}$	1.336	0.247
		H0: $\theta_{FE}^{2,V2} = \theta_{FE}^{2,V'2}$	H1: $\theta_{FE}^{2,V2} \neq \theta_{FE}^{2,V'2}$	-	-
		H0: $\theta_{FE}^{2,V3} = \theta_{FE}^{2,V'3}$	H1: $\theta_{FE}^{2,V3} \neq \theta_{FE}^{2,V'3}$	-	-
		H0: $\theta_{FE}^{2,V4} = \theta_{FE}^{2,V'4}$	H1: $\theta_{FE}^{2,V4} \neq \theta_{FE}^{2,V'4}$	1.460	0.226
	IWUE	H0: $\theta_{IWUE}^{2,V1} = \theta_{IWUE}^{2,V'1}$	H1: $\theta_{IWUE}^{2,V1} \neq \theta_{IWUE}^{2,V'1}$	0.594	0.441
		H0: $\theta_{IWUE}^{2,V2} = \theta_{IWUE}^{2,V'2}$	H1: $\theta_{IWUE}^{2,V2} \neq \theta_{IWUE}^{2,V'2}$	-	-
		H0: $\theta_{IWUE}^{2,V3} = \theta_{IWUE}^{2,V'3}$	H1: $\theta_{IWUE}^{2,V3} \neq \theta_{IWUE}^{2,V'3}$	-	-
		H0: $\theta_{IWUE}^{2,V4} = \theta_{IWUE}^{2,V'4}$	H1: $\theta_{IWUE}^{2,V4} \neq \theta_{IWUE}^{2,V'4}$	2.026	0.154

 # VRS scores are used in this test; ##: V is not binary variable within the group; Subscripts V1 to V4 refers to farmer groups with positive perceptions according to a given criterion (presented below), Subscripts V'1 to V'4 refers to farmer groups with negative perceptions, Subscripts 1 and 2 refers to the FJ and LB areas respectively.

An interesting finding in this Table 6.13 is the average VRS-IWUE which is significantly different between satisfied and non-satisfied farmers in FJ with regard to the internal functioning of their WUA. Unfortunately, V1 which is significant in Table 6.12 can not be used as binary variable inside the FJ group because almost all farmers are satisfied.

6.3.2.5. Variance in efficiency scores according to individual investment in water saving technology within each WUA

Here, we consider each group of farmers separately, and then we divide each group into two sub-groups according to the binary variable: "investment done in water saving technology". A K-wallis test for studying the variability of farming and IWU efficiencies between these sub-groups was conducted (Table 6.14). Results show that whilst perception-based data did not explain the variance between various efficiency vectors inside LB, farming and IWU efficiency scores for LB farmers showed significant differences between farmers according to their investment in irrigation water saving technology. The effect of this variable inside the FJ group was not highly significant.

Table 6. 14. Kruskal-Wallis tests for differences in farming and IWU efficiencies between farmers according to their investment in water saving technology (within each WUA)

	Test	Hypothesis		Test result	P-Value
FJ group	FE				
	CRS	H0: $\theta^1_{FE} = \theta^2_{FE}$	H1: $\theta^1_{FE} \neq \theta^2_{FE}$	5.947*	0.014
	VRS			0.291	0.589
	IWUE				
	CRS	H0: $\theta^1_{IWUE} = \theta^2_{IWUE}$	H1: $\theta^1_{IWUE} \neq \theta^2_{IWUE}$	3.880*	0.048
	VRS			0.141	0.707
LB group	FE				
	CRS	H0: $\theta^1_{FE} = \theta^2_{FE}$	H1: $\theta^1_{FE} \neq \theta^2_{FE}$	3.056*	0.080
	VRS			8.036***	0.004
	IWUE				
	CRS	H0: $\theta^1_{IWUE} = \theta^2_{IWUE}$	H1: $\theta^1_{IWUE} \neq \theta^2_{IWUE}$	1.888	0.169
	VRS			5.813*	0.015

Subscript i in this Table refers to farm type, with i=1,2 referring to farmers who have invested in water saving technology during the past three years and those who have not invested.

6.3.3. Discussion

Table 6.10 shows that socioeconomic differences between farmers in our sample do not significantly explain the calculated IWUE. Even land structure, which is one of the main structural differences between the FJ and LB areas, was not found to be significant when integrated into the Tobit model. Even though, Table 6.11 shows that average (both CRS and VRS) farming and IWU efficiency scores are significantly different between the selected groups FJ1, FJ2, and LB. Although the three latter groups are located in neighbour areas, they still are different from each other regarding the sources of irrigation, the dependence on public provision and WUA monitoring, the performances of WUA managing their areas, the water price charged to farmers, etc. Thus, combined results from tables 6.10 and 6.11 show that IWUE is at least partially dependent, on the local institutional context in which farmers are operating.

The perception-based information used in our statistical tests (Tables 6.12 and 6.13) identifies some of the local irrigation governance attributes that can further explain the variability of farming and IWU efficiency levels between farmers in our sample. In fact, taking the entire sample together, we found that the average IWUE is highly and significantly different between the satisfied and the non-satisfied farmers with regard to the technical functioning of the irrigation network managed by their WUA. Furthermore, average farming efficiency was significantly different according to both technical-oriented perceptions V1 and V3. Organization and managerial-oriented perceptions of farmers do little to explain these differences when all of the samples are taken together. However, when considering the FJ groups separately, the results of the same test reveal that the average IWUE for farmers belonging to this latter WUA significantly differ according to farmers' satisfaction as to the internal functioning and organization of their WUA. It should be remembered that the FJ WUA has a very low managerial efficiency whilst its engineering efficiency is high. Combined results for these two tests again stress the significant relationship between local irrigation governance and individual performance in managing water resources at farm level. It also shows that both technical and organizational attributes of governance are important for improving the IWUE at farm level.

Further analyses are necessary in order to further explain the causality effect between farmers' perceptions and their performance on the one hand and the WUA performance on the other.

6.4. Concluding remarks

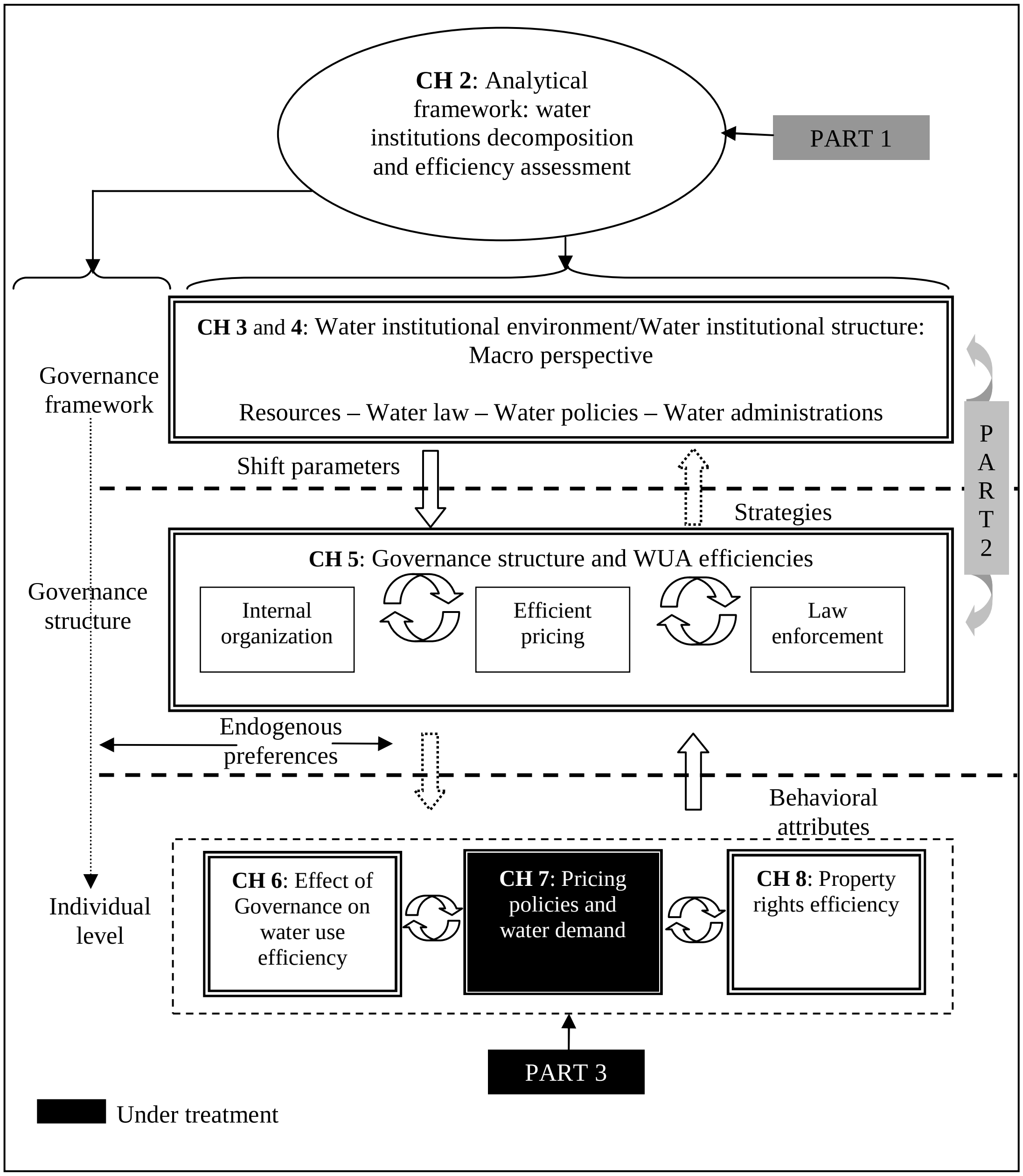
A number of concluding remarks can be drawn from the current chapter.

Firstly, IWUE in Tunisia was found to be low compared to the efforts made for improving it. Two important implications of this latter result can be discussed. On the one hand, hope is raised that important water conservation in Tunisia can be achieved if more efforts are mobilized in order to further improve this index. On the other hand, the highly significant correlation found in our study between IWUE and overall farming efficiency indicates that such efforts will have a considerable positive effect on the overall competitiveness of Tunisian agriculture.

Secondly, the hypothesis concerning the possible overuse and waste of water by farmers in situations where insecurity of water supply exists was proved in this chapter. In fact, farmers belonging to the LB WUA, which has the lower engineering efficiency score and where problems of water reliability are frequent (according to our survey), were the least efficient in terms of water use. Thus, we can confirm that improvements in the technical attributes of WUAs to enhance their water delivery performance will have a direct effect on water use efficiency at farm level.

Thirdly, in Table (5.4) we showed a highly significant correlation between engineering and managerial efficiencies for the WUA. In addition, Table 6.13 shows that groups of FJ farmers, classified according to their perception as to the internal functioning of their WUA, were significantly different in terms of IWUE. These combined results prove that managerial efficiency of the WUA and its internal organization and functioning can also have a direct, as well as an indirect, effect on the IWUE at farm level.

Finally, a considerable amount of money is spent in Tunisia on various programmes intended to improve IWUE at farm level (e.g. subsidies for the adoption of irrigation water saving technology). However, as mentioned in chapter 3 (section 3.13.3, b), the “Cellules de promotion des GDA” which support the functioning of WUAs do not have sufficient resources and are sometimes incapable of assisting all the WUAs in their regions. From the current study, we conclude that a reallocation of a proportion of the financial resources towards strengthening the structure and training of WUA staff and managers could also have a high impact on improving the IWUE at farm level. Also, similarily to Zekri and Easter (2007), the current study recommends the reform of WUA according to new models that can ensure efficiency and transparency.


CH 2: Analytical framework: water institutions decomposition and efficiency assessment
PART 1
CH 3 and 4: Water institutional environment/Water institutional structure: Macro perspective
Resources – Water law – Water policies – Water administrations
Governance framework
Shift parameters
Strategies
P A R T 2
CH 5: Governance structure and WUA efficiencies
Governance structure
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Efficient pricing
Law enforcement
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Individual level
CH 6: Effect of Governance on water use efficiency
CH 7: Pricing policies and water demand
CH 8: Property rights efficiency
PART 3
Under treatment

Chapter 7. Pricing policies and impact on water demand in the study area: A DEA-Based methodology for the estimation of individual input demand functions

Abstract

This chapter estimates individual demand functions employing the information hidden in individual producer's technical efficiency. This information is extracted through the development of an inverse DEA model. The empirical results for Tunisia show that farmers who are more technically efficient have less elastic irrigation water demand functions; these farmers would adjust demand only to a limited extent and they can afford the water price. In contrast, water pricing significantly affects those that a least efficient. These farmers shift towards a different cropping pattern using significantly less water and more land when the price of water increases. Thus higher water prices would threaten this category's livelihood if their efficiency is not improved. Incentives and support policies need to be provided in order to help them shifting toward more productive pattern and non toward an extensive one. This shifting is not always easy task for least efficient and small size farmers who face a lot of constraints. However, if the technical efficiency of these farmers were to improve, then water saving objectives will be difficult to reach since their demand will also become highly inelastic. The findings have important implications in view of the objectives of Tunisia water policy which include: full cost recovery, continuity of the irrigation activity, and water saving at the national level.

7.1. Introduction

According to the neoclassical economic theory, a farmer in an irrigated area would respond to an increase of water prices by reducing his consumption (Gómez-Limón and Riesgo, 2004). This results in a negatively sloped demand curve. Saved water could be either used by other more productive farmers, or reallocated to more productive agricultural and non-agricultural uses. Theoretically, such reallocation of the resource would certainly contribute to an increase in the overall fficiency of its use. In this respect, the apparent misuse and waste of irrigation water, in the context of low and subsidized water prices, causes many authors to advocate a more prominent role of economic incentives in encouraging efficient water use (Russell *et al*., 2007; Bar-Shira *et al*., 2006 ; Becker and Lavee, 2008; Perry, 2001; Speelman, 2008). Irrigation water pricing is then often regarded as a main tool to achieve a better level of water resource valorization (Singh, 2007). The importance of irrigation water prices can be twofold. Firstly, farmers will be more aware about the economic importance of the water and its scarcity and secondly, they provide incentives to farmers to think about shifting their crop pattern towards a more productive one (Easter and Liu (2007); Perry (2001).

The foregoing topic has received considerable attention in the applied literature. The practical importance of the price tool has been reviewed and criticized in many empirical studies of irrigation water demand functions, especially in arid countries (e.g., Gómez-Limón and Riesgo, 2004; Berbel and Gómez-Limón, 2000, Varela-Ortega *et al*., 1998). These studies show that water pricing would not always stimulate the desired changes in water use due to the low elasticity of demand for irrigation water. A reduced effect is also expected if the cost of water is small relative to total costs. Besides, the implementation of the pricing instruments could also probably engender collateral effects such as a decrease in agricultural income and labor demand in rural areas.

More specifically, Gómez-Limón and Berbel (2000) show that volumetric water pricing is an inadequate *single* instrument for managing the demand of irrigation water as it does not significantly reduce demand. Based on empirical irrigation water demand functions for three Spanish irrigated areas, these authors point out that consumption is not reduced significantly until prices reach such a level that farm income and agricultural employment are negatively affected.

In a similar vein, Berbel and Gómez-Limón (2000) argue that for water pricing to work properly, the revenues collected from farmers need to be used for environmental and water saving technologies. Supported by empirical evidence from three large irrigated Chinese districts with different socioeconomic and physical settings, Liao *et al.* (2007) find that water pricing as such is unlikely to be a successful instrument for improving the irrigation efficiency and the financial sustainability of irrigation systems. They however indicate that pricing reforms can improve water management when it is tailored to fit with the specific contexts of irrigation systems and is coupled with improvement in management transparency. In the same respect, Molle *et al*. (2008) show that "while operation and maintenance costs can be recovered, higher water prices have limited potential for achieving gains in irrigation efficiency". They also argue that "substantial increases in water prices can be expected to raise overall economic efficiency by motivating farmers to intensify cultivation, adopt higher value crops, improve technology, or rent out their land to investors. However, such strategies are constrained by the lack of capital and credit, and pervasive risk, notably regarding marketing. Pricing policies, thus, are best implemented together with positive incentives that reduce capital and risk constraints, and offer attractive cropping alternatives or exit options with compensation".

All results mentioned in this brief literature review stress the necessity of a set of parallel policies to help improve the productivity of irrigation water to go in tandem with water pricing. Purpose of these parallel policies is to improve the technical efficiency of farmers making them able to pay higher water rates. From a policy perspective this means that improved insight is required in the interaction of (a) economic incentives (water pricing), and (b) additional programmes to support the adoption of best management practices and water saving technologies.

This chapter addresses the issues discussed above for Tunisia. In Tunisia, the government first started to implement water pricing in the irrigated areas in the 1970's. The main objective was to cover the operation and maintenance (O&M) costs of the irrigation systems as a first step and to cover the full production cost of water in a later stage. Other more general objectives were to improve the valorization of the irrigation water by inducing a more efficient use of the resource, and to reduce the total volume of water consumed by the agricultural sector (80% of the total water consumption in the country) in order to face the forecasted imbalance between water supply and demand at the country level. However, the low level of farmers' revenue at that time was a main constraint for the introduction of water pricing. Thus, the government has developed a set of policies intended to improve the technical capacities and the productivity of farmers in parallel to the pricing policy. Subsidies for water-saving-technology adoption and enhancement of the extension services are the main examples. By 2004 the areas equipped with water saving technologies in Tunisia represented about 75% of the total irrigated area (Agency of Agricultural Investments Promotion, 2004). However, these subsidies have not resulted in significant water saving at the national level. In fact water saved was used to intensify the existing irrigated system (Bachta *et al*., 2000; Al Atiri 2007).

This chapter contributes to the literature in three ways. First, we develop a framework of the irrigated farm where inefficiency in production prevails and several production practices are available. The micro-economic framework shows the impact of water pricing and educational assistance to farmers on water demand in the situation of inefficiency. From the framework we hypothesize that improvement of farmers' technical capacities will lead to a more inelastic demand of irrigation water. This is in line with findings by many authors in the field of irrigation economics (Varela-Ortega *et al*., 1998; De Fraiture and Perry, 2002) who find most efficient farmers valorize irrigation water to the best and will be more able to support higher irrigation prices than the less efficient farmers. In addition, we hypothesize that small size farms face more constraints to improve their technical performances and will be negatively affected by increases of irrigation prices. Consequently, when small scale farms are predominant, water pricing could threat the sustainability of the irrigated activity in a specific region or country.

The second objective of this chapter is to present an empirical analysis to test our hypotheses for Tunisia. We build a normative inverse Data Envelopment Analysis model in order to estimate the differential impact of higher water prices on water and other inputs. The advantage of the inverse DEA model is its capacity to estimate individual demand functions by using the information hidden in the technical efficiency score of a particular farmer. We use our model in order to estimate water and other inputs demand functions for farmer groups distinguished by their technical efficiency level. We then test the differential impact of the increasing prices of irrigation on demand of water and other inputs for different types of farmers. The results are aggregated by different farm sizes and by different regional Water User Associations (WAU).

7.2. Methodology

From the exposition in previous section, it follows that farm specific difference in technology and in efficiency are crucial to evaluate impacts of water pricing. Past studies however commonly assume producers behave rationally in terms of profit maximization in accordance with neoclassical economic theory (e.g., Gómez-Limón and Riesgo, 2004; Liao *et al*., 2007).

According to the normative mathematical approach, farmers would use their water allowances depending on the productivity (marginal value of water) that water generates in their farms taking into account the soil and climate conditions. Such models mainly provide prediction of changes in cropping patterns resulting from different water pricing policies. Most of these models use predetermined fixed ratios between inputs and outputs, assuming that substitution between different production factors is minimal or even non existent. This drawback can be overcome by using non-linear methods incorporating some production functions (or engineering production functions estimated from biophysical models) in the mathematical model (see for instance Zekri and Herruzo, 1994; Mimouni *et al*., 2000). This remains a complicated task which needs large amount of data.

In this study, we provide a novel data-driven methodology which takes into account the previous models' disadvantages and develop a normative inverse-DEA model that allows estimating the effect of water pricing on various inputs demand at the level of the individual farm. Moreover, the model allows for changes in the relative-use of the production factors (including factors substitution and complementarily) when the irrigation water price changes. Furthermore, the model does not need any prior functional or parametric specification. All results are provided at an individual level allowing case-by-case information for policy and decision makers.

The model application consists of following three steps: (a) calculation of the efficiency score for each farm using a standard DEA model, (b) calibration of an inverse DEA model for each farm based on the individual efficiency measures as a representation of the production technology in order to, and (c) application of the inverse model to simulate the impact of water pricing policies on farm specific water demand.

7.2.1. Inverse DEA model

In recent years there have been a number of papers written on various "inverse optimization problems" mainly in the fields of geophysical sciences, medical imaging, and traffic equilibrium development[31] (Ahuja and Orlin, 2001). When dealing with an inverse optimization problem, we need to use an optimal solution to determine parameters' values. More precisely, we calculate the parameter values of a system that create a feasible but not optimal solution and we adjust these parameter values as little as possible so that the feasible solution becomes the optimal one (Wei *et al.*, 2000). This principle of "inverse optimization problems" is often applied in the broad literature of calibrated or positive mathematical programming (See Buysse *et al.*, 2007). Zhang and Cui (1996) were the first to inverse a Data Envelopment Analysis (DEA) optimization model. By doing so, they tried to answer the following question: if the k[th] DMU shall continue its operation in the next period, no matter whether it is efficient from a DEA viewpoint, and if the unit plans to increase its outputs by Δy^k and asks for an increment Δx^k of input, the supervisor of this and other parallel DMUs must decide how much additional resource to give to the unit k such that an increment Δy^k can let the unit at least maintain its current efficiency status.

Despite its use in various domains, the DEA model was never applied, to our knowledge, in the economic field for solving problems of performance forecasting or of resource allocation. The current work is a second application of the inverse DEA model for the estimation of irrigation water demand functions (see Speelman *et al.*, 2008).

Based on Wei *et al.*, (2000) we present our inverse input-oriented DEA model as follows:

Suppose a set of n DMUs, $\{DMU_j : j = 1,2,...,n\}$, which produce multiple outputs $y_{rj}(r = 1,2,...,s)$, by utilizing multiple inputs $x_{ij}(i = 1,2,...,m)$. Let the inputs and outputs for DMU_j be $X_j(x_{1j}, x_{2j},...,x_{mj})$ and $Y_j(y_{1j}, y_{2j},...,y_{sj})$, respectively. $X_j > \mathbf{0}$, and $Y_j > \mathbf{0}$ for all

[31] see Ahuja and Orlin 2001 and Tarantola 1987 for more details about applications of the inverse optimization

$j = 1,2,...,n$. When a DMU_0, $0 \in \{1,2,...,n\}$, is under evaluation, then we can consider the following generalized BCC (Banker *et al.* (1984)) DEA model (1):

$$\begin{aligned} & Min\ \theta \\ s.t.\quad & \sum_{j=1}^{n} X_j \lambda_j \le x_0 \theta \\ & \sum_{j=1}^{n} Y_j \lambda_j \ge y_0 \qquad\qquad (1) \\ & \sum_{j=1}^{n} \lambda_j = 1 \\ & \lambda_j \ge 0\ \ \forall, j = 1,...,n \end{aligned}$$

Suppose now that we solve the model (1) for each DMU and obtain a value of technical efficiencies (θ) for each of them. Then we may consider the following question: if the efficiency index θ for a DMU_0 remains unchanged, but the DMU_0 is obliged to decrease its output level, by how much should the inputs of the DMU_0 decrease? To reply to this question suppose the outputs of DMU_0 are decreased from Y_0 to $\beta_0 = Y_0 - \Delta Y_0$, where the vector $\Delta Y_0 > \boldsymbol{0}$. We need then to estimate the input vector $\alpha_0^* = (\alpha_{10}^*, \alpha_{20}^*, ..., \alpha_{m0}^*) = x_0 - \Delta x_0$, $\Delta x_0 \ge 0$ provided that the efficiency index of DMU_0 is still θ.

Suppose DMU_{n+1} represents DMU_0 after changing the inputs and outputs. We can then consider the following mathematical program (2) in order to calculate the efficiency of DMU_{n+1}:

$$\begin{aligned} & Min\ \theta^t \\ s.t.\quad & \sum_{j=1}^{n} X_j \lambda_j + \alpha_0^* \lambda_{n+1} \le \alpha_0^* \theta^t \\ & \sum_{j=1}^{n} Y_j \lambda_j + \beta_0 \lambda_{n+1} \ge \beta_0 \qquad\qquad (2) \\ & \sum_{j=1}^{n} \lambda_j = 1 \\ & \lambda_j \ge 0\ \ \forall, j = 1,...,n;\ \lambda_{n+1} \ge 0 \end{aligned}$$

If the optimal value of the problem (2), θ^t, is equal to the efficiency index of DMU_0 calculated in program (1), θ, we say that the efficiency index is unchanged when the outputs are decreased to β_0 and the inputs are decreased to α_0^*. We can then write $\text{Eff}(\alpha_0^*, \beta_0) = \text{Eff}(x_0, y_0)$.

As discussed in model (1), θ represents the relative efficiency of the DMU_0 under the present technology. Such technology conditions are not supposed to change within the short term. Using this technology information in addition to model (2), we can then present the following model (3) (adapted from Wei *et al.*, 2000; Yan *et al.*, 2002). Model (3) provides estimation about the needed changes in the inputs combination when a reduction of the output level is expected.

$$
\begin{aligned}
& Min\ (\alpha_{1,0}, \alpha_{2,0}, \ldots, \alpha_{m,0}) \\
& s.t.\quad \sum_{j=1}^{n} X_j \lambda_j \le \alpha_0 \theta \\
& \qquad \sum_{j=1}^{n} Y_j \lambda_j \ge \beta_0 \\
& \qquad \sum_{j=1}^{n} \lambda_j = 1 \qquad\qquad\qquad\qquad (3) \\
& \qquad \alpha_0 \le x_0 \\
& \qquad \lambda_j \ge 0 \ \forall, j = 1, \ldots, n;
\end{aligned}
$$

Where β_0 and α_0 are defined as before, and θ represents the technology of DMU_0 already estimated from program (1).

7.2.2. Specification of the Inverse DEA model for an input demand estimation

Assume $p_i = (p_1, p_2, \ldots, p_m)$ the prices of the mth input and $p \neq 0$. Suppose also that y_0 is expressed in a monetary term as being the net revenue of farmers. Then we propose the following weighted sum model (4):

$$
\begin{aligned}
& Min \ \sum_{i=1}^{m} p_{sim} .\alpha_{i,0} \\
& s.t. \quad \sum_{j=1}^{n} X_j \lambda_j \leq \alpha_0 \theta \\
& \qquad \sum_{j=1}^{n} Y_j \lambda_j \geq y_0 - \sum p_{sim} \alpha_{i,0} \\
& \qquad \sum_{j=1}^{n} \lambda_j = 1 \\
& \qquad \alpha_{0,terre} \leq x_{0,terre} \ \forall, p_{sim} \geq p_i \\
& \qquad \lambda_j \geq 0 \ \forall, j = 1,...,n;
\end{aligned}
\tag{4}
$$

The two unknown variables in this model are $\alpha_{i,0}$ and λ_j. The rest of parameters are known or calculated before simulation. p_i and p_{sim} are the original and the simulated input price vectors respectively and y_0 is the farmers net revenue expressed in monetary term. The rest of parameters are defined by models 1, 2 and 3. The weighted sum model assumes a fixed technical efficiency while allowing the *DMU* to adjust its allocative efficiency when input prices change (Figure 7.1 and 7.2). The output constraint indicates that we would like to obtain at least the total amount of revenue that is currently being obtained (by the farmer) minus the extra cost due to the change in the input combination. The input constraint can be read as if we would be prepared to radially reduce inputs in order to achieve the amount of revenue (described above), This reduction would be done according to the same way described by the farmer technology. Of course, this technology is initially determined by reference to a set of peer DMUs weighted according to an optimal λ_j combination. This set of peer DMUs can change when P_{sim} changes, indicating that when relative prices change, another DMU could be more useful in describing the optimal behavior of the farmer (under simulation) while preserving his initial technology frontier.

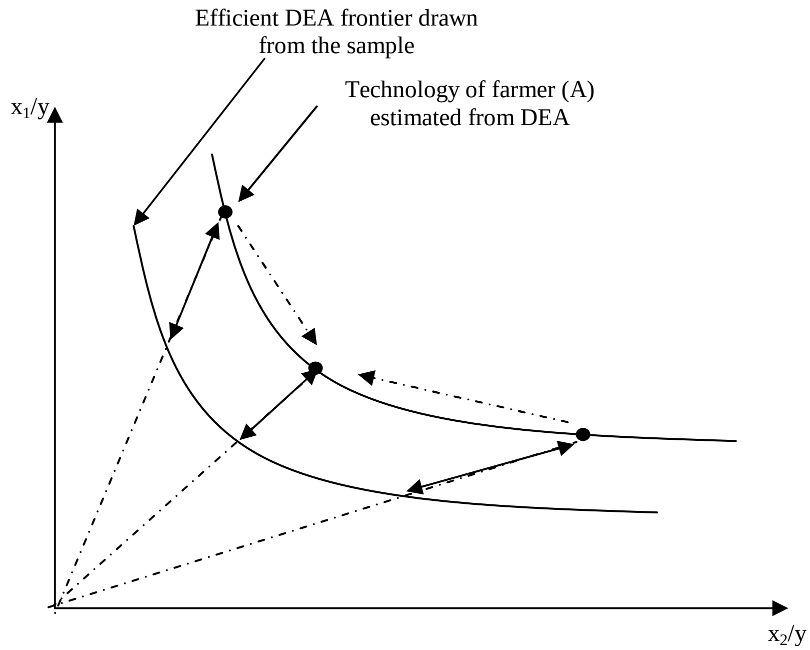


Fig 7. 1. Efficient technical frontier in the sample, and farmer (A)' technology drawn from information concerning his technical efficiency level

Figure 7.1 shows the DEA frontier drawn for the entire sample in addition to the technology of the farmer (A). Figure 7.1 also shows how the farmer (A) will change his position on the isoquant when input prices (p1 and/or p2) change.

The input price ratio is represented in Figure 7.2 by the line RR'. By running the model (4), we will look for a position on the isoquant of farmer (A) which minimizes the farmer's input cost taking into account the new input price ratio. This minimization is equivalent to a maximization of the allocative efficiency of the farmer. Farmer (A) will try to minimize his input cost until a level where his technical production function doesn't allow any lower input cost.

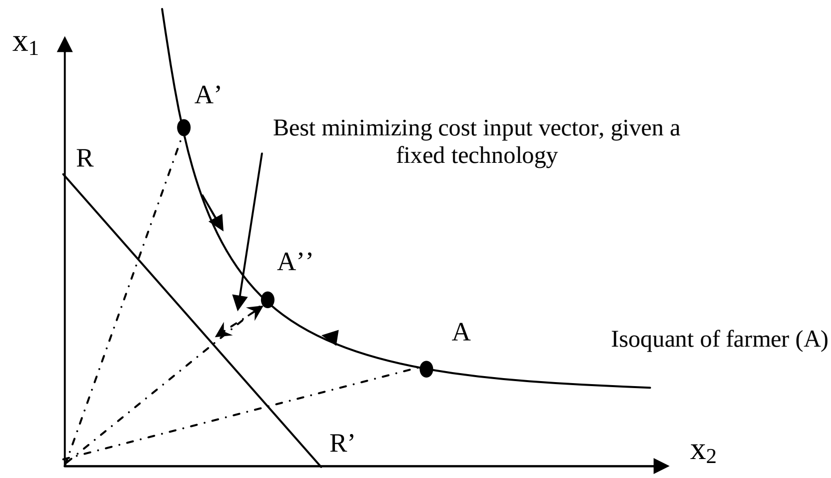


Fig 7. 2. Minimization of the input cost in model (4)

The model (4) used for irrigation water pricing assumes that the input combination of the farmers can change when irrigation prices go up. However, a constraint was added to this model in order to keep the total simulated cultivated area less than the initially cropped surface currently observed for each farmer. This constraint excludes any possibility for farmers to use more land than what they are currently holding. The following numerical example provides a validation of the model (4).

7.2.3. Validation

Suppose a sample of 5 *DMUs* which use two inputs (x_1, x_2) to produce a unique output (y). Let p_1 and p_2 be the prices of inputs 1 and 2 respectively. Inputs and outputs of the 5 *DMUs* as well as their technical, allocative and economic efficiencies (calculated from standard DEA models) are presented in Table 7.1. p_1 =0.1 and p_2= 0.03 are considered for the calculation of these latter efficiencies.

Table 7. 1. Numerical example: Inputs, outputs and various efficiencies of the DMUs sample

	y	x_1	x_2	p_1	p_2	θ	*AE*	*CE*
DMU1	1	1	2	0.01	0.03	1.000	1.000	1.000
DMU2	2	6	2	0.01	0.03	1.000	1.000	1.000
DMU3	2	7	9	0.01	0.03	0.857	0.412	0.353
DMU4	1	6	4	0.01	0.03	0.500	0.778	0.389
DMU5	2	7	2	0.01	0.03	1.000	0.923	0.923

AE and CE denote allocative and cost efficiencies respectively.

Now suppose that prices p_1 and p_2 will change from (0.01, 0.03) to (0.05, 0.01). By including this new price vector in model (4) and running it for the DMU (3) we obtained the following input/output combination: (y'= 1.711 x'_1=5.315 and x'_2=2.334). Using this latter combination in addition to the initial data of the rest of DMUs (Y', x'_1, x'_2), we run the standard DEA models and we obtain the following results.

Table 7. 2. New inputs, outputs and efficiencies of the DMUs after changing the relative price ratio

	Y'	x'_1	x'_2	P'_1	P'_2	θ'	AE'	CE'
DMU1	1	1	2	0.05	0.01	1.000	1.000	1.000
DMU2	2	6	2	0.05	0.01	1.000	1.000	1.000
DMU3	1.711	5.315	2.334	0.05	0.01	0.857	1.000	0.857
DMU4	1	6	4	0.05	0.01	0.500	0.412	0.206
DMU5	2	7	2	0.05	0.01	1.000	0.865	0.865

Table 7.2 shows that technical efficiencies calculated for all DMUs (based on the new input combination of DMU 3) do not change. The results of model (4) show also that DMU3, not being able to improve its technical efficiency in the short run, will try to allocate the inputs more efficiently when the relative prices of these inputs change.

7.2.4. Limits of the model

Model (4) is calibrated using the technology information hidden in the observed technical inefficiency term θ. This allows simulating the management capacity of each farmer, estimated relatively to the best manager of the sample. However, the main limitation of model 4 is related to the fact that the output (revenue in our case) elasticity is only based on the reductions of the input use induced by the increases in irrigation prices. This limitation could be resolved by specifying a more flexible output function which, for instance, accounts for some other attributes or integrates the risk behavior of the farmer. Unfortunately, such information is not available. However, the calculation of the output elasticity in our model is not our main interest. Moreover, in model 4 the impact of an increase in irrigation rates on the input combinations is not related to the output behavior. Therefore we believe we can use model (4) for estimating water and inputs demand.

Another limitation of the model is related to its normative nature: the model maximizes the allocative efficiency of the farmers since the beginning of the simulation. In fact, given the technical capacity of each farmer, the margin for improving his allocative efficiency is limited. In reality, not all farmers are maximizing their allocative efficiency given their current technical capacity. This limitation could be surmounted by providing a positive version of the model (4).

7.2.5. Data

The data set used in this chapter is the same one collected from FJ and Lb WUA. However, due to the specific empirical validation needed in this chapter, farmers will be grouped according to:

- their technical efficiency level: three groups were selected in order to emphasize the differences in water demand elasticity between the most and least efficient farmers,

- their size: farmers of the sample were also grouped into three size-groups in order to show the differences in water demand elasticity between the largest and the smallest farms, and

- their WUA: farmers were finally grouped into two groups, according to the WUA to which they belong, allowing the comparison between both irrigated areas.

It is important to mention that both public and groundwater were aggregated into an unique input vector when simulating demand functions for efficiency and size-based groups. However, these two types of water were considered as separate vectors when calculating the input demand functions for FJ WUA. For this area, we then derived both public and groundwater demands.

7.3. Results

7.3.1. Input demand functions per efficiency-group

In order to distinguish the differential impact of the increasing water pricing on various farmers-groups by technical efficiency level, we divided the 62 farmers of our sample into three groups defined as following: (i) group1: farmers with an efficiency score between 0-50%; group2: farmers in the efficiency range of 51%-75%; and group3: farmers who’s the efficiency level is on the 76%-100% interval. By running the model (4) for each farmers and summing the new water demands (corresponding to each of the tested prices) of farmers in each group, we obtained the irrigation demand functions represented in Figure 7.3.

It is clear from Figure 7.3 that the group which will be affected the most by an increasing irrigation water prices is the less efficient one. Water use per ha for this last group passed from 2083.5 m3/ha to 1757 m^3/ha (-15.5 %) when irrigation water prices changes from 0.048 TND/m^3 to a price of 0.448 TND/m^3 supposed to cover all variable and fixed production costs of the irrigation water. This could be interpreted by a shift toward more water-valorizing crops or simply by allocating more surfaces in the farm to rain feed crops.

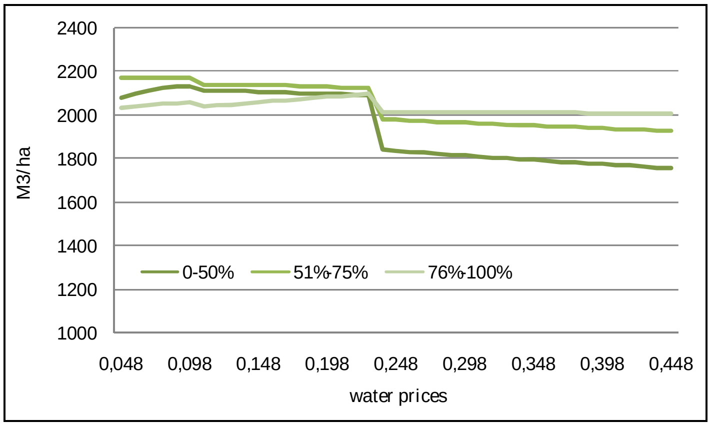
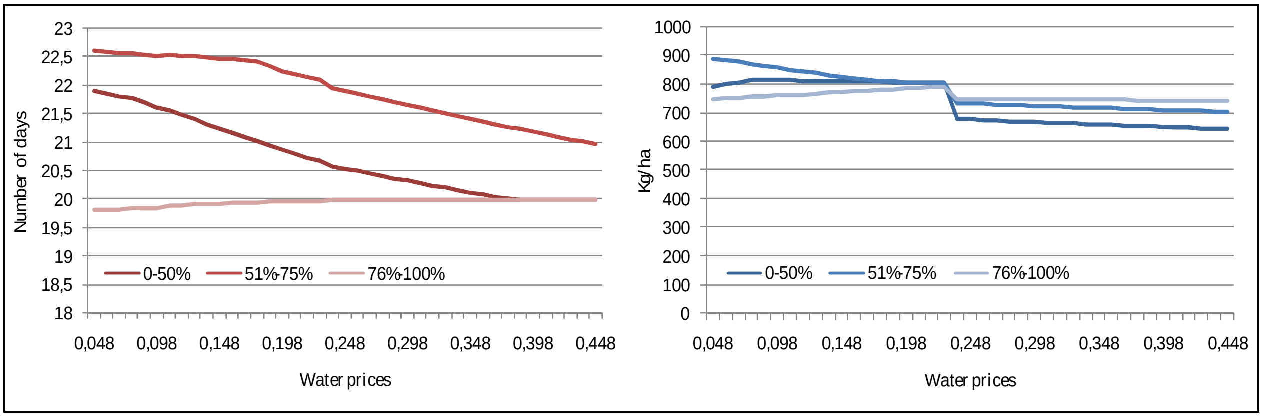


Fig 7. 3. Average water use per hectare for each efficiency-group

Water demand per ha in the second and third groups were reduced by 11% and 1.3% respectively. The most efficient group will almost not react to irrigation water prices.

Concerning fertilizers use, all efficiency-groups show a downward sloping demand functions when the irrigation prices increases. This decrease however is not significant for the case of the most efficient group while it can reach around 200Kg/ha for groups 1 and 2. Figure 7.4 also shows that for the most efficient farmers, water and labor are substitutable. In fact, labor demand increased for this latter group while it decreased for the less efficient framer groups.



(a) (b)

Fig 7. 4. Average Labor (a) and fertilizers (b) use per ha for different efficiency-group

7.3.2. Input demand functions per size-category group

In order to see if the irrigation pricing policy has any differential impact on various farm-size-groups, we selected the following three groups of farmers based on their size (Table 7.3). For each size-group and irrigation price, individual inputs demand were summed and represented in the Figures 7.5 and 7.6.

Table 7. 3. Different farm size groups selected in Cap Bon region

Groups	Percentage in the sample	average surface/farm (ha)	average Technical efficiency
Size> 6 ha	20%	23.7	0.85
2 ha< size<= 6 ha	36%	3.3	0.59
0 < size<= 2 ha	43%	1.2	0.69

Figure 7.5 shows that small-size farms will be the most affected by higher irrigation prices. Their water demand decreases by 33% when the price of water equals a full cost recovery price. Our calculations also show that the total land use, of all farmers in this group, will increase with 15.3% for this same price change. In contrats, the large-size group (which is more efficient, Table 7.3) decreases its total water use by 13% and the cropped area by 17%. In fact this interaction explain that water demand/ha is rather inelastic for this group of farms.

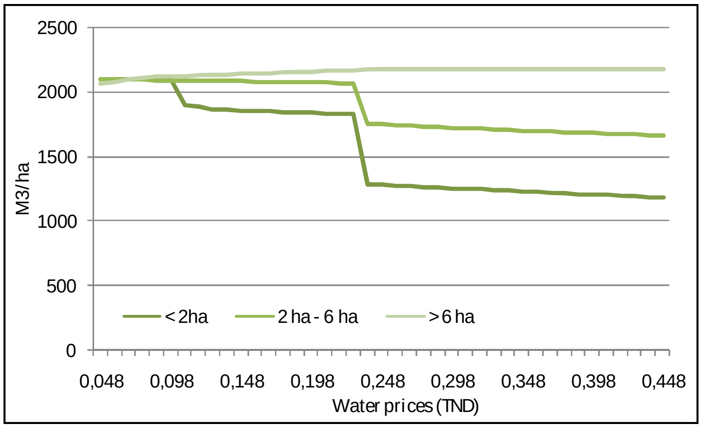


Fig 7. 5. Average per hectare water use for each size-group

The largest farmers will neither reduce the level of labor and fertilizers use per ha. This proves that these farmers are close to the maximum intensification level permitted by the currently available technology in the region. By keeping their level of water and other inputs use/ha constant and reducing their cropped area at the same time, these farmers are in fact reducing the scale of their operation. We also notice that a water price of 0.220 TND/m3 leads to parallel jumps in both fertilizers and water demand curves.

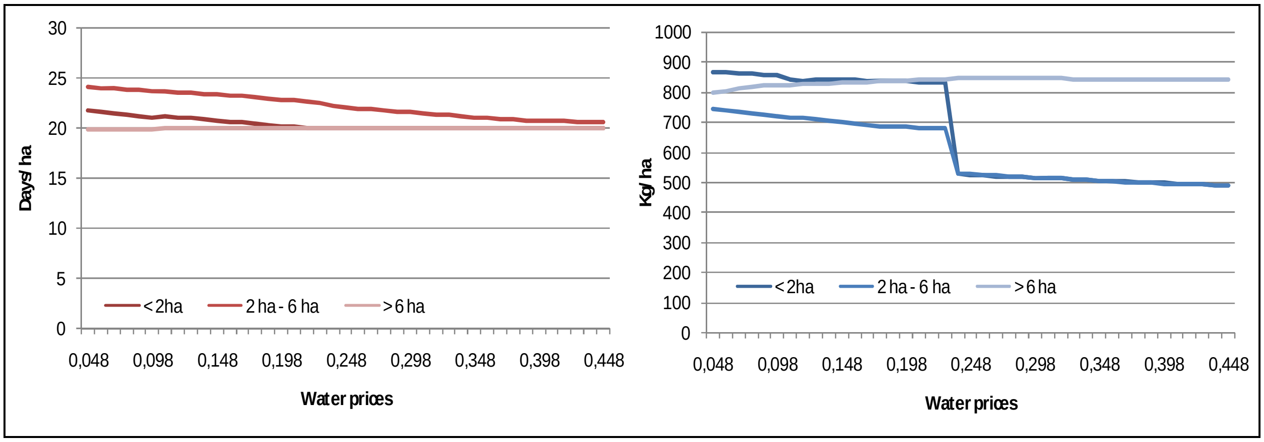


Fig 7. 6. Average Labor (left) and fertilizers (right) use per ha for different size-goups

7.3.3. Comparison of input demand between FJ and LB areas

As mentioned above, public and groundwater were considered as two different inputs when simulating the water demand functions in FJ. However, they were aggregated in the same input vector for the case of LB where all farmers only use public water supplied by the WUA.

Figure 7.7 shows the trend of total irrigation water used in both WUA when irrigation prices increases.

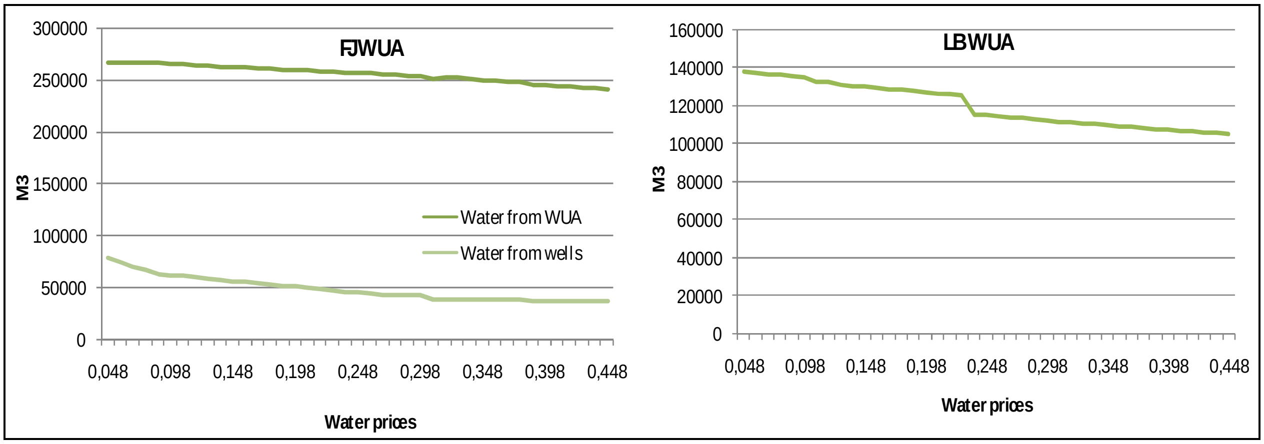


Fig 7. 7. Total water consumption in both FJ and LB

From Figure 7.7 it appears that public and groundwater are complementary inputs since the demand of both decreases with an increase in the irrigation prices of public water. This is opposite to the expectation of probable increasing pressure on groundwater aquifer when public water prices increase. Despite the fact that current water pumping cost (around 0.033 TND/m^3) is much lower than the public water price (0.068 TND/m^3), farmers in FJ, even those holding a well, continue using water from public sources[32]. This complementary relationship could be due to the high salinity of groundwater in the studied region. Farmers may have to mix public and groundwater to obtain water with an sufficient average quality at lower price.

Total water demand in FJ decreased by 14.2% when irrigation prices increased from 0.048 to 0.440 TND. However, total water consumption in LB decreased with 24% for the same price change. Average cropped area per farm and water consumption per ha in both areas are shown in Figure 7.8.

[32] According to our survey

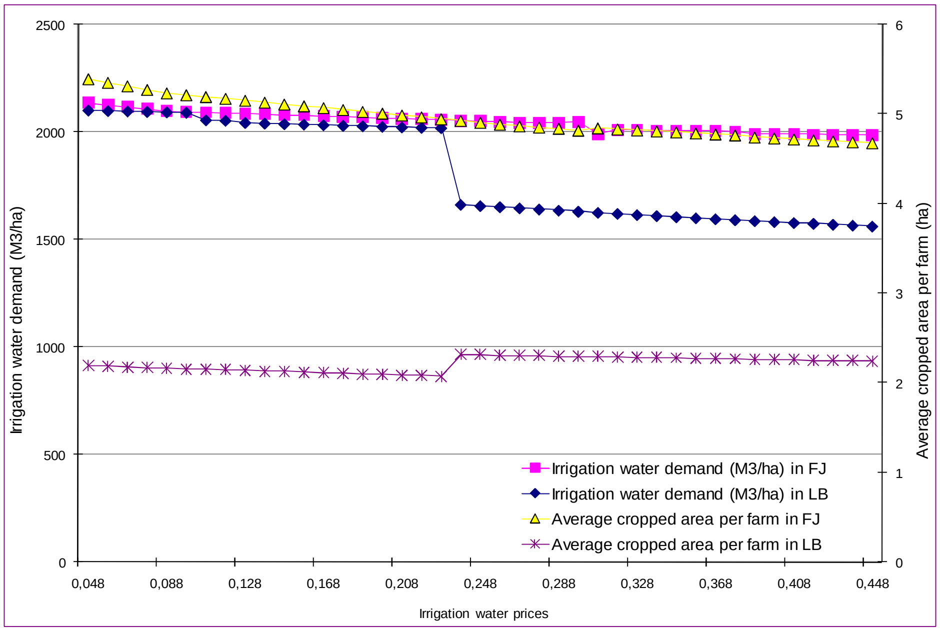
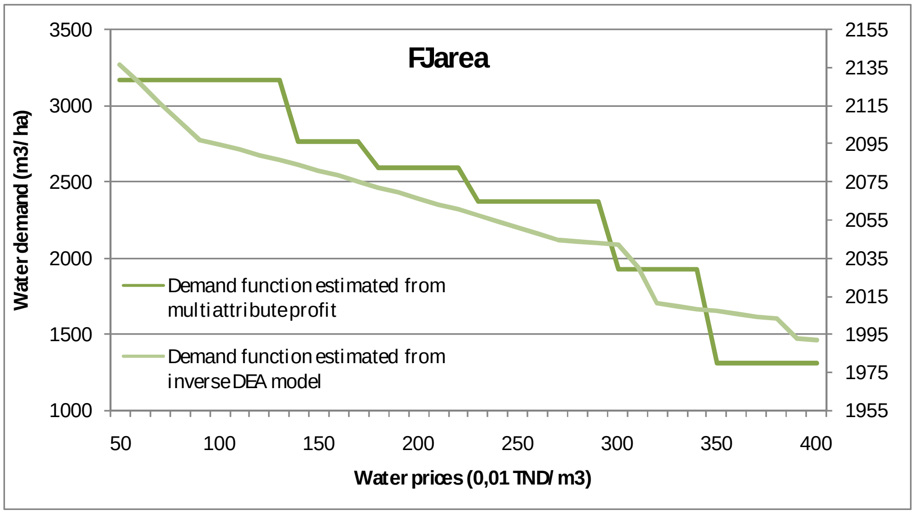


Fig 7. 8. Irrigation water and land demand functions in both FJ and LB WUAs

At the current water price (0.048 TND/m^3), FJ farmers consume on average 2136.6 m^3/ha which is almost the same optimal level that can be consumed in LB (2099.8 m^3/ha) under the assumption that farmers are maximizing their allocative efficiencies. However, the response to in increase in the irrigation prices is markedly different in the two areas. In FJ, the water demand/ha was found to be inelastic while demand decreased considerably in case of LB. In this second area, an inelastic price segment of the water demand curves was recorded. This segment coincides with prices at which farmers are insensitive to water price increases. When irrigation price reaches 0.228 TND/m^3 (almost triple of the current price), LB farmers suddenly decreased their irrigation water demand. This decrease is accompanied with an increase in the average cropped area from 2 ha to 2.3 ha per farm. This shows that a substitutability relationship exists between water and land factors in LB.



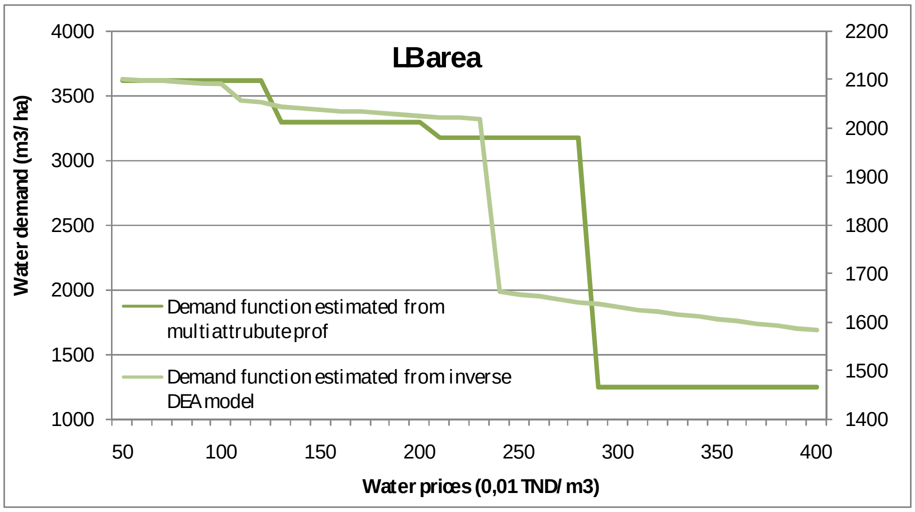


Fig 7. 9. Comparison between water demand functions estimated (using the same data sample) from a multi-attribute utility function (Chebil *et al*., 2008) and from inverse DEA model

The increases of irrigation prices results in a loss of agricultural employment in LB (Figure 7.10). According to the findings in the latter section, the small-size farms reduced their level of labor use as a reaction to the price change. The fertilizers demand is again similar to the water demand functions. The increase of irrigation prices will not affect the use of fertilizers in FJ. By contrast, LB farmers will reduce the use of this input by 26% in average.

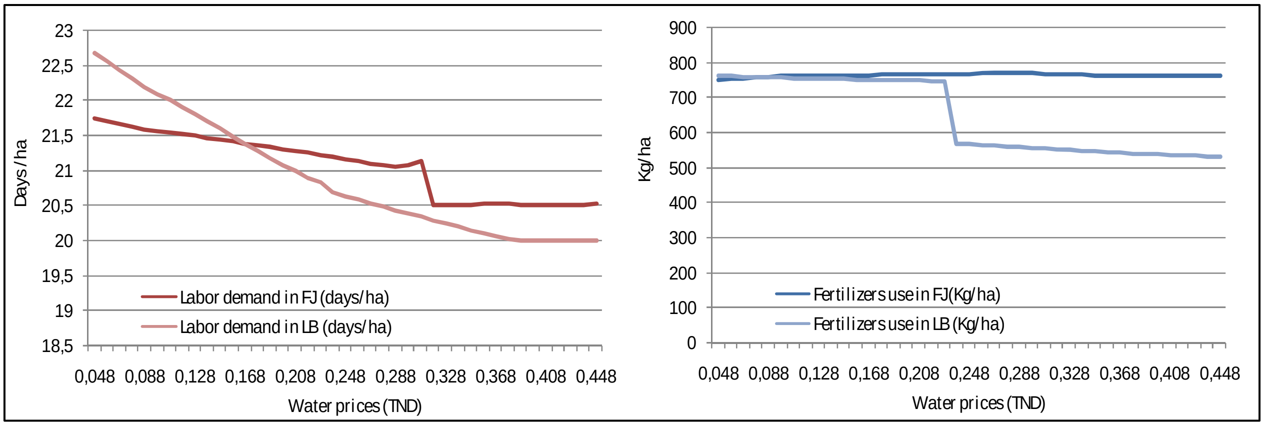


Fig 7. 10. Labor and fertilizers demands for various irrigation prices in both WUA

7.4. Discussions

This result that water demand elasticity is higly dependent on technical efficiency/technology is in line with findings of Varela-Ortega *et al*. (1998) who compare the price elasticity of water demand in three regions in Spain. They conclude that in the 'old' irrigation schemes where water application techniques are relatively inefficient, the response to increasing water charges is much higher than in the modern systems with drip irrigation technique. The authors conclude that the technical endowment in an agricultural district has a major effect on its response to water pricing. Albiac *et al*. (2007), Gómez-Limón & Riesgo (2004), and Berbel & Gómez-Limón also report very low elasticities of irrigation demand in some case studies from Spanish irrigated systems. For their study on the Tunisian case (Kairouan region in the central part of Tunisia), Poussin el al., (2008) found as well that a major increase (50%) in the cost of water affected only a minority of farms (in terms of revenue), who are consuming only 17% of the total irrigation water in the region.

Fertilizers and irrigation water demands show a very similar trend in all demand functions estimated. According to these observations, a complementary relationship between the latter two factors exists in the studied area. We also found in our results that water and labor are likely to be substitutable inputs; such was the case for the most efficient and the largest farmers in our sample. These results are consistent with empirical studies that examine inputs interactions in irrigated agriculture both through field experiments (e.g., Prihar *et al*., 1989; Thompson *et al*.,

2000) and modeling analysis (e.g., Bartolini *et al*., 2007; Chebil *et al*., 2004; Cai *et al*., 2008). Complementary relationship between water and fertilizers in Tunisia was reported by Chebil *et al*. (2004) when they studied the technical progress of the irrigated systems in Teboulba region. The latter authors also found substitutable relationship between water and labor factors. Besides, Cai *et al*. (2008), in their study of the substitution between water and other agricultural inputs when irrigation prices increases in the Maipo River basin in Chile, found monotonous substitution relationships between water and irrigation investment, labor, machinery and pesticides, respectively. In this latter study, a clear complementary relationship between water and fertilizers was also demonstrated.

The irrigation demand functions obtained for FJ and LB are in line with the simulation results of Chebil *et al.,* (2008) using a multi-objective programming model at the aggregated level using the same data used in this study (Figure 7.9). Their objective function integrates the risk behavior (calculated from secondary data about regional yields and prices) in addition to profit maximizing objective. Our inverse-DEA model is able to reproduce an almost identical pattern without prior functional or parametric specifications of farm behaviour. Also, our model used a minimum amount of data. Moreover, optimal results obtained from the inverse-DEA model for each farm are not optimal in an absolute sense but relatively to the best performer in the sample, which is a clear advantage compared to other normative models.

Comparison of the trend in inputs demand functions between FJ and LB, when a similar irrigation pricing policy is applied in both regions, reveal many important findings. A first remark concerns the conjunctive use of public and groundwater in FJ area. In fact, these two types of water were unexpectedly found to be complementary. Currently, the average pumping cost in FJ is around 0.033 TND/m^3. Despite the fact that this cost is much lower than the cost of public water distributed by WUA (0.068 TND/m^3), most of the farmers are presently combining both resources. According to our survey, 98% of farmers in FJ district have a well in their farms and 32.3% of these wells provide salty water (more than 1.5 g/liter). 36% of farmers in FJ consider the quality of water as the main irrigation constraint. According to this, the complementary relationship between both types of water looks to be justified and specific to the context of our study area. This result could not be generalized.

Another remark concerns the changes in land structure in both regions as consequence of the pricing policy. In FJ, the average cropped area per farm decreased with 13% (from 5.4 ha/farm to 4.7 ha/farm) when irrigation price changed from the current situation to a cost recovery price level. This decrease of the land use is also accompanied with a decrease in the water and labor demand. All of this shows clearly that, in average, FJ farmers will reduces their scale of operation as response to the irrigation pricing policy simulated. By contrast, farmers in LB increased their land use while reducing their irrigation water, fertilizers and labor demands. As argued before, this trend can only be explained by a shift toward less water consuming crops, or by devoting a largest part of the farm for extensive rainfall crops. As presented in Figure 5, smaller farmers (less than 2 ha), currently use around 2102 m^3/ha of irrigation water reduce their consumption to 1180 m^3/ha (56% of current optimal consumption) when irrigation prices reach the cost recovery level. For the same price change, small farmers also reduced their fertilizers and labor use by 43% and 8%, respectively. However, their average cultivated land per farm increased by 15%. This implies a shift toward a more extensive agricultural pattern.

Knowing that in average FJ farmers are more efficient and larger than LB farmers, the previous remark emphasises the probable threat for the irrigated activity in Tunisia of an increasing of water prices beyond a certain limit. The smallest and less efficient farmers will in fact shift toward more extensive systems while the most efficient and the largest farmers will starts to reduce the scale of their operation. We also have to remark that these changes are supposed to happen when farmers are maximizing their allocative efficiency, which is not always the case in real contexts.

7.5. Conclusions

The main results of our study can be summarized as follows:

- Results of our simulations show that farms' **technical efficiency level** is important factor deeply affecting the elasticity of their water demand. The advantage of the inverse DEA model developed in this study is its capacity to estimate individual demand functions by using the information hidden in the technical efficiency score of a particular farmer. We used this model in order to estimate water and other inputs demand functions for farmer groups distinguished by their technical efficiency level.

- Under the assumption of allocative efficiency for a given available technology, farmers who are most technically efficient will have the least elastic irrigation water demand. The most efficient farmers are better at valorizing water resources. Thus they are able to afford higher irrigation prices than their less efficient colleagues.

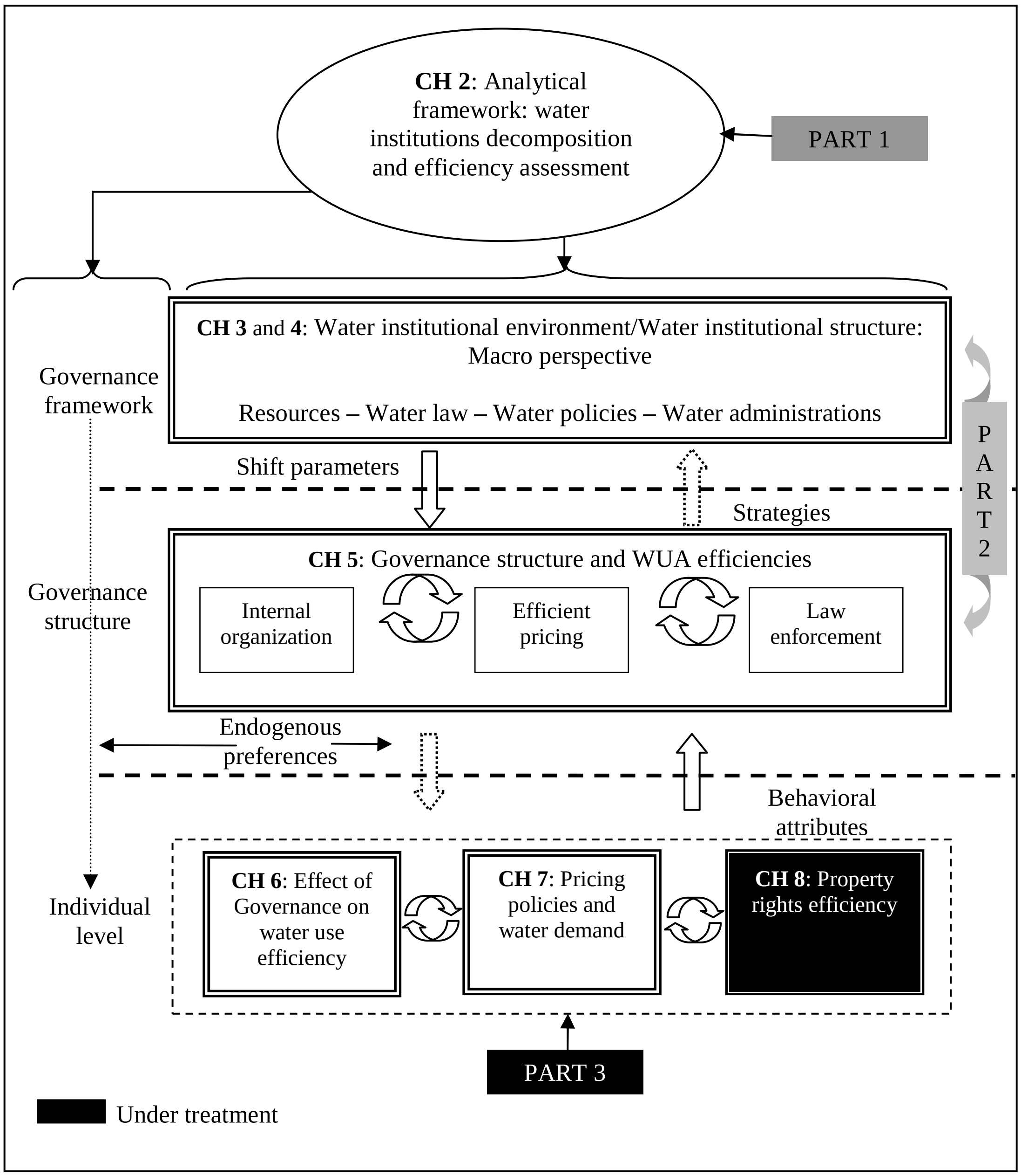
- A full cost recovery strategy will threat the livelihood of the small irrigated schemes if their technical efficiency will not improve (small farmers were found to be the less efficient and most elastic to water prices). These farmers will shift toward a cropping pattern using less water and more land when the price of water increases. More facilities such credit access, training programs, market integration, etc. are needed to support these small-size farmers which are generally more constrained to improve their technical efficiency. These facilities will have also to support farmers shifting toward more productive patterns of production (benchmark in a region), and non toward an extensive less productive one. A shift toward more productive patterns is however not always easy especially for the small size farmers due to constraints they face. If latter farmers will not be able to "jump" on the best performing frontier, then their financial sustainability will be in real threat.

- If the technical efficiency of these farmers could improve, then water saving objectives will be difficult to reach since their demand will become highly inelastic. This could in fact threat the sustainability of the irrigated activity which is crucial for the national development and food safety. This last conclusion does not assume any technological improvement in the long run for the most efficient farmers. However, if the currently most efficient farmer would have access to an advanced water-saving technology, then his efficient frontier could shift towards another more efficient pattern to ensure both water saving and irrigation intensification.

The implications of these main result are very important for the Tunisian context. As discussed in the introduction, the Tunisian water policy has three main objectives: full cost recovery, continuity of the irrigation activity, and water saving at the national level. Our empirical findings suggest that the current water pricing plus education policy is not suited to achieving these three objectives simultaneously. Specifically, according to our results improvement of technical efficiency and the currently available technologies will make water demand functions more and more inelastic.

Further research will address farmers adjustment opportunities in more detail. Gardner (1983, cited in Ray, 2001) states that if water prices rise to reflect its opportunity cost, a rational farmer will have any or all of the four following responses: the farmer demands less water and leaves land fallow; applies less water to the crop accepting some yield loss; switches to less-water-demanding crops; and/or invests in more efficient irrigation techniques. The changes in the inputs use combinations in our study show that farmers are indeed moving toward different cropping patterns but these are not necessary more water-valorizing patterns. More investigations have to be done in order to find toward which system farmers are shifting. The revenue function and the "normative" quality of the inverse DEA model would have to be reconsidered in order to reflect this reality in a more positive sense.

- Also, due to its normative nature, the model assumes maximum allocative efficiency of the farmers. But in fact, given the management capacity of each farmer, the margin for improving his allocative efficiency might be restricted. Thus in reality, not all farmers are maximizing their allocative efficiency given their current technical capacity. This limitation can be overcome by providing a positive version of model (4) by specifying a more flexible output function which, for instance, accounts some other attributes such as the farmer's risk attitude.



CH 2: Analytical framework: water institutions decomposition and efficiency assessment
PART 1
Governance framework
CH 3 and 4: Water institutional environment/Water institutional structure: Macro perspective
Resources – Water law – Water policies – Water administrations
P A R T 2
Shift parameters
Strategies
Governance structure
CH 5: Governance structure and WUA efficiencies
Internal organization
Efficient pricing
Law enforcement
Endogenous preferences
Behavioral attributes
Individual level
CH 6: Effect of Governance on water use efficiency
CH 7: Pricing policies and water demand
CH 8: Property rights efficiency
PART 3
Under treatment

Chapter 8. Contingent Valuation for institutional efficiency on changes to water property rights and farmers' willingness to pay (WTP) for water

Abstract

This chapter assesses the economic value of changes to the characteristics of farmers' property rights for irrigation water in Tunisia. Changes to the characteristics of the "water access right" and "water delivery right" were integrated into three scenarios: better "allocation reliability", "quantification of the right" (quotas system), and "transferability of the right" (market system). The valuation was conducted using the Contingent Valuation Method through the elicitation of individuals' willingness to pay (WTP). Results show positive willingness to pay values for all scenarios. However, farmers in the studied region appear willing to pay more for changes to the "water access right", and more specifically, for the transferability option. Furthermore, their perceptions concerning the organization and functioning of the water users' association, to which they belong, in addition to their own productivity, appear to significantly affect their willingness to pay. The probability of accepting higher water prices in LB, if water reliability improves, was found to be higher than in the FJ area. This could be due to the low engineering performance of LB WUA.

Parts of this chapter are accepted as

Frija A, Chebil A, Speelman S, Van Huylenbroeck G. 2008. Effect of changes in the institutional structure of irrigation water property rights on the willingness to pay of farmers for water: case of Tunisia. XIIth Congress of the European Association of Agricultural Economics (EAAE-2008), Ghent, 26-29 August 2008, Belgium.

8.1. Introduction

Few studies have reviewed the relationship between legal rights and the economic allocation of goods (Levy and Friedman, 1994; Runge, 1986; Platteau, 2000; 2003). In fact, it is interesting to explain how different kinds of property right systems affect individual behaviour as well as the functioning and efficiency of the economic system. Property rights can be defined as "the claims, entitlements and related obligations among people regarding the use and disposition of a scarce resource" (Furubotn and Pejovich 1972). In general, the importance, definition and enforcement of property rights increase in relation to the scarcity of a given resource. As a resource becomes scarcer and competition increases, property rights can clarify expectations and thereby reduce conflict and interaction between users over the resource. Demsetz (1967) notes that the primary function of property rights is to guide incentives towards the achievement of better internalization of externalities. Where incentives are absent, or not well defined, uncertainty arises, and this affects decision making by the property right holder.

Property rights can, however, be better understood as overlapping "bundles" of rights (Meinzen-Dick *et al.*, 2004). These bundles of rights can be broadly defined as rights of use, access and withdrawal, control or decision-making rights to manage the resource, exclude others from its use, or transfer the resource to others (Schlager and Ostrom, 1992). This latter definition provides an important set of descriptive criteria for property rights that will be further used in this chapter. Property rights for a specific resource can be less complete than described above. For example, owners may derive only some value from an asset, exclude only some people from using it, or transfer only certain uses of it for a specified time period. Often, irrigation water property rights belong to this type of incomplete property right (Libecap, 2005).

On the other hand, a very consistent approach for classifying property right regimes is based on the nature of the decision-making entity holding the right to use a particular resource (Challen, 2000). Thus, private property corresponds to a single decision-making entity, such as an individual person or firm; common property to a finite collective entity such as a cooperative group; state property to a government entity; and open access to the absence of any entity with decision-making power over the resource. It is also possible to encounter situations where multiple entities simultaneously hold decision-making power over a resource. Ostrom (1990) defines this property right hierarchy as a system of nested institutions.

When devolution programmes do transfer rights over irrigation water to users' groups or local government, that institution becomes the gatekeeper determining individuals' rights over the resource (Meinzen-Dick *et al*., 2004). In the case of irrigation water, after failing to effectively manage irrigation systems centrally, many governments are now undertaking decentralization and devolution programmes to transfer management responsibility to local government and users' groups. Taking into account the fact that these groups, generally known as Water Users' Associations, become the gatekeepers who determines individuals' irrigation property rights, two important aspects relating to property rights in irrigation management decentralization programmes should then be analyzed. The first one concerns the composition and characterization of the property rights transferred. In other words what exactly is transferred in terms of the water resource and the services relating to that resource ("Water access right" and its characterization)? The second aspect relates to the operation of the transfer itself: how well are the property rights transferred from the collective to the individual level ("Water delivery right" and its characterization)? The response to these questions identifies the individual's property right for irrigation water and, consequently, their decision making, which is a function of the set of incentives provided by this right.

Characteristics of the "water access right" are generally defined and enforced through legal constitutional rules. Specification as to the transferability of the right, the duration, frequency and quantification of the right can be considered as examples of such characteristics. On the other hand, performance of the water delivery system is the main determining factor for the "water delivery right"[33] specification. Various performance indicators were proposed in the literature (Bos, 1997; Molden *et al*., 1998; Perry, 1996; Rao, 1993; Sakthivadial *et al*., 1999). Adequacy, efficiency, supply reliability and equity are performance objectives considered when evaluating

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[33] This terminology on "water access right" and "water delivery right" is acquired from the Australian Water Act 2007 (NO. 137, 2007) - SECT 4: available on line on http://www.austlii.edu.au/au/legis/cth/num_act/wa200783/s4.html . This terminology is also used in some research papers; see Shi, T. (2006).

irrigation water delivery systems. For example, the reliability criterion expresses the ability to provide water at the right time and in the right place. Unreliable water delivery is quoted as a major reason for the low performance of irrigation systems (Unal *et al*., 2004). A similar conclusion can be drawn for the other performance criteria. Low levels for these indices may cause confusion and conflict between farmers, leading to a low economic return from water.

8.2. Context and motivation for the study

In Tunisia, the "water access right" is simply a usage right for a certain water volume relative to the size of land owned (Al Atiri, 2007). This institutional change happened during a period of fundamental institutional reforms in the Tunisian water sector. The objective of this PR shifting was to give the public authorities full rights for water allocation between users. After a period of central water resource management, where public administration was directly responsible for water allocation, the resource began to be allocated through local decisions made by WUAs[34]. Water PR is then typically transferred from the public to the local level, and then to the individuals who use it for irrigation. WUAs do not have the right to hold water resources, but only to reallocate the resource within their localities.

According to this scheme, we can distinguish two main components of the PR system currently applied in Tunisia. These are:

- "Water access right": defined at the constitutional level, as described above; it relates water property to the public authority. From an individual perspective, this component mainly concerns the security of the right (e.g. ownership, tenure, quantification of the right, etc.) and includes any legal definition in relation to the taking or use of water as prescribed by the Tunisian regulations.

- "Water delivery right": defined as a right to have water delivered via an infrastructure operator, represented in our case by the WUAs, which have the legal right in Tunisia to

[34] In most of the regions

use irrigation infrastructure at the local level. This component relates to water supply reliability and WUA performance.

Considering the first component, the Tunisian PR system does not allow for any trading of entitlements or allocations. Water entitlements generally relate to the size of land owned, but in practice, it is not possible for farmers to have a clear idea as to the quantification of their right[35] (quota). Given the water shortages being faced by the country, and taking into account the benefits (economic and environmental) of such secured (quotas) and transferable (market) entitlements, we sought in this study to investigate the possible benefits of shifting the current “water access right” in Tunisia towards a more flexible right based on an individual transferable quota system. It is well known that water markets constitute an incentive to farmers, as they can expect potential benefits from selling or buying water between them. As proved by a number of studies around the world, water markets are seen by many policy makers as an important tool in improving the efficiency of water resource allocation. For irrigated agriculture in Tunisia, the study of water market benefits shows different results. In fact, Zekri and Easter (2004) find that water trading has only a minor effect on farmers’ income whilst Bachta *et al.* (2004) show that water trading between farmers will result in improvements to the productive efficiency of water and therefore higher overall revenue[36]. Hamdane (2002) argues that water markets are suitable in the case of Tunisia where water shortages and high demand occur. However, he also mentions that this alternative requires fundamental and costly institutional reforms for it to be implemented.

It is thus interesting to gain information on farmers’ willingness to pay for such institutional changes, because this information should be integrated into the cost-benefit calculation for institutional alternatives. Nevertheless, in cases where competitive markets for property rights are absent, no information is available as to the economic value of specific rights, nor on the associated marginal return. In such situations, stakeholder preferences for change could be indirectly estimated using non-market methods (by the creation of a hypothetical market) (Garrod

[35] Quantification of the right is also called “entitlement security”

[36] These two studies were done for two different regions in Tunisia.

and Willis, 1999). Contingent Valuation (CV) using the concept of willingness to pay (WTP) and/or willingness to accept (WTA) is such a method often used to elucidate the outcome of policy reforms and changes. Based on hypothetical scenarios, we used the WTP estimation of farmers for a transferable quota system in Tunisia (instead of the current usage right) in order to elucidate the potential gains that might arise from such institutional change. The main assumption here is that this institutional change corresponds to an increase in the utility of the irrigators (more secure rights from which they can draw benefits even if they do not use it for their own purposes) as well as the overall benefit for society (economic value and optimal allocation of water). The evaluation criterion consists of comparing the resulting economic value with the price currently charged to irrigators. Any deviation is considered as economic rent which is wasted.

Concerning the “water delivery right”, the earlier literature review presented in chapter 3 and 4, in addition to the results identified in chapters 5 and 6, show that technical and organizational problems, with regard to the functioning of the WUA, still occur and affect the perceptions of the irrigators (Makkaoui, 2006; Ben Salem, 2005; Chraga and Chemakh 2003). We also show that a significant relationship exists between farmers’ perceptions concerning the functioning of their WUA, and their level of irrigation water use efficiency. This latter result could be implicitly understood as an expected positive willingness to pay, by farmers, for a better “supply reliability” for their water delivery right, over time. Thus, in this study, our objective is also to investigate the possible economic gains, in terms of farmers’ utility and social welfare, that could be generated by improving supply reliability. We assume that low supply reliability performance negatively affects the perceptions of farmers (as is the case for the LB area, cf. chapter 6) and thereby impacts on their efficient use of the resource. We also assume that WUAs can charge higher rates for water if this delivery right could be improved. The evaluation criterion here is also based on the deviation between the current water price charged to farmers and their WTP for such improvements. More details as to the specific institutional scenarios that will be tested in this study will be presented in the next methodological section.

8.3. Methodology

The economic value of particular, less substitutable goods or resources, including various public goods, differs according to the property right regime specified for it. The WTA/WTP ratio, for environmental and natural resources, depends on the individual's perception concerning the property regime for these resources (Garrod and Willis, 1999; Horowitz and McConnell., 2002). People's willingness to pay is higher when their property right over a given resource is clearer and more stable (Levy and Friedman, 1994; Arcuri, 2002, Herrera *et al.,* 2004). In this study we assume that the opportunity for property right enhancement can be evaluated by non-market methods and assessed by estimating and aggregating individual preferences. The CV method is used to assess farmers' WTP. In the past, few studies have applied CV for assessing the effects of property right improvements in cases where markets for such rights are non-existent. To our knowledge, the most important one is that of Herrera *et al.* (2004) who undertook an efficiency analysis of property rights in Ecuador and found that the WTP of farmers is positive when improvements to their rights are proposed. Stated preference methods were also applied by Chebil *et al*. (2007) to assess the efficiency of an irrigation delivery system in Tunisia. They found that irrigators were willing to pay more than current water rates if the stability of their rights were to be improved. Also, Speelman (2009) tried to reveal how efficient the current water right regime in South Africa is by economically valuing possible improvements in the definition of water rights. However, they used Contingent Ranking (CR) method, a form of choice experiment belonging also to stated preferences techniques, to value the possible outcome of policies intended to improve water rights. CR is a survey-based technique for modelling preferences for goods, where goods are described in terms of their attributes and the level these take. By including price as one of the attributes of the good, willingness to pay can be indirectly calculated from people's rankings (Speelman *et al.* 2009). Their results indicate that for the smallholders, there are significant economic gains attached to a possible improvement of the water rights.

In this paper, we hypothesize that an institutional change to the characteristics of irrigation water property rights increases farmers' willingness to pay for the water resource. We hereby propose that in the case of Tunisia, the current water property right bundle is inefficient and that an improvement in the characteristics of water usage rights, can generate an additional economic rent. The evaluation criterion consists of comparing the resulting water economic value with the current price paid by irrigators. Any positive deviation from the price is considered as a potential economic rent.

8.3.1. Contingent Valuation Method

8.3.1.1. Description of the method

Contingent Valuation is a questionnaire based valuation technique that allows respondents to express their preferences for goods and services (Garrod and Willis 1999). It allows the creation of a hypothetical (contingent) market environment to simulate transactions for a given non-market good or service. Willingness to pay and willingness to accept compensation with respect to a specific good are directly obtained from the respondents. CV is conceptually based on the theory of economic welfare, which assumes that the behaviour of rational individuals towards a change in their environment can be assessed through observed changes to their individual utilities.

Principal techniques used to design questions concerning WTP (or WTA) include: the open ended format; dichotomous choice; bidding games; and payment card forms. In this study the single bounded dichotomous choice format is used. The single-bounded approach is, in fact, the same as the close-ended format first introduced by Bishop and Heberlein in 1979, where pre-tested values of WTP are used to ask people to accept or reject proposed values for the resource in a hypothetical market.

Despite its potential usefulness, the application of CV is still regarded with scepticism, perhaps because of the hypothetical nature of the exercise, as well as the biased estimates that sometimes result from this method (e.g., Zendehdel, 2008; Horowitz and McConnel, 2002; Diamond and Hausman, 1994). Zendehdel (2008) summarize general drawbacks of individualistic valuation methods including stated preferences methods (mainly CV and choice experiment) and revealed preferences methods (mainly travel cost and hedonic pricing methods). These drawbacks were according to him mostly related to (i) the individual nature of questions related to goods qualified as public, (ii) the complexity of environmental criteria and social groups, (iii) the plurality of environmental values, while we try to assess only a value related to some specific attributes of the good, and to (iv) the ordinality of stakeholders' preferences towards environmental services. Mitchell and Carson (1989) point out some specific common drawbacks to most of the studies using CV methods, such as inadequate attention paid to substitutes, budget constraints of the respondent, embedding effect and strategic bias. Similarly, other key failures result from the elicitation method used, question position, and information provision (see e.g. Diamond, *et al*., 1993 and O'Doherty, 1996; Tisdell, 1999), which can influence responses. However, precautions can be taken to reduce bias. In particular it is recommended that the WTP surveys pay specific attention to explanatory variables such as income, price of substitutes, environmental attitudes, etc. (for more details see Barton, 1998).

8.3.1.2. Elicitation of WTP value from dichotomous answers: Theoretical model

Estimation of WTP using a contingent valuation survey involves the choice of elicitation format, as well as an empirical model that can be applied according to any assumptions about the nature of the distribution of WTP. It has been argued that dichotomous choice question formats used in this study are superior to open-ended ones (e.g. see the recommendations of the Blue Ribbon Panel, Arrow *et al*., 1993) although they need more sophisticated econometric techniques to estimate WTP (Carson, 1997). Moreover, assumptions concerning the distribution of WTP are crucial when inferring the required welfare measure (Kriström, 1990). According to Clinch and Murphy (2001), and Hanemann and Kanninen (1996), different econometric specifications for WTP can generate very different results.

Using Random Utility Theory (RUT), Hanemann (1984) demonstrates that it is possible to obtain social welfare measures (mean and median WTP) from a dichotomous choice elicitation format. According to Hanemann, the main assumption is that the utility function has some components, which are unobservable and are treated as stochastic. The individual utility function can be written as:

$$U(Y,S,Q)+\varepsilon \qquad (1)$$

where Y is individual income, S is a vector of socio-economic indicators; Q is the current set of characteristics of the environmental asset and ε is a random disturbance term.

The consumer will accept paying a given amount of money (A) for a change in one or some of the current characteristics of the environmental assets if:

$$U(Y - A, S, Q_1) + \varepsilon_1 \geq U(Y, S, Q_0) + \varepsilon_0 \qquad (2)$$

where ε_1 and ε_0 are identically and independently distributed random variables with zero means.

The actual amount that the respondent is willing to pay is not observed directly. The assumption is that if the individual states he is willing to accept the bid amount, then his WTP must be greater than the bid, or, when the answer for the stated amount is 'no' his WTP is assumed to be lower than the bid. Let WTP* represent the unobserved willingness to pay, which is assumed to follow a distribution F(θ), where θ is a vector of parameters, and form an indicator (I) that takes a value of '1' for 'yes' responses and '0' for 'no' responses. The probability of observing a 'yes' response ($P(I = 1)$) when the interviewee has been offered a bid equal to A_i is:

$$P(I_i = 1) = P(WTP^* > A_i) = 1 - F(A_i, \theta) \qquad (3)$$

Whereas the probability of observing a 'no' answer is:

$$P(I_i = 0) = P(WTP^* < A_i) = F(A_i, \theta). \qquad (4)$$

With respect to this structure, only the bid amount and the answer given by the respondent (yes or no) are needed for the analysis. Either a *logit* or a *probit* model - both of which are binary choice models – can then be constructed in which the dependent variable is the answer given by the individual and the explanatory variables are a constant and the WTP bid.

The *logit*[37] model assumes that the probability function F(.) is logistic. This function can be presented as following by equation (5):

$$P_i(I_i = 1) = \frac{1}{1 + e^{-x_i^{'}\beta}} \qquad (5)$$

Assuming linearity for the utility function, the expected WTP equals the median, and Hanemann (1994) demonstrates that this value can be expressed as:

$$E(WTP) = -\alpha / \beta \qquad (6)$$

Where α and β are the coefficients estimated in the *logit* model corresponding respectively to the constant term and the explanatory variable containing the proposed bid. This Hanemann model has been tested and used extensively in CV research (see Kriström, 1993).

8.3.2. Simulated scenarios

Three scenarios have been identified, making assumptions concerning the two main components of irrigation water property rights, as defined in the introduction. These are the "water access right" and the "water delivery right". Enhancement of the "water delivery right", through improvement of water reliability, in addition to a shift in the current usage right towards a clearer and transferable "water access right" are the guiding principles for our three scenarios (Table8.1).

The reliability could be enhanced through improvements in WUA efficiency and functioning. This characteristic is formulated in a separate scenario termed "allocation reliability". This scenario is relevant as most farmers are worried by irregularities in water delivery at times when they need water urgently[38].

[37] A generalized logit model will be used in our work. In fact, this model specification allows us to model the respondent choices according to their individual characteristics.

[38] Given that WUAs performances differ, the PR attributes and the results can be different from one sample of users to another, according to the WUA performance. Thus, our study and results are specific for the region and the WUAs studied.

The second scenario is called the “clarity” scenario, and assumes that the “water access right” will be quantified. This will ensure better security for farmers’ current entitlements to water. We propose that farmers are allowed in advance to have an idea as to the quantity of water available to them during the irrigation season.

The third scenario relates to the transferability of the access right. However, a right that is not quantifiable cannot also be transferable. For this reason, this third scenario assumes a transferability option that can be added to the second scenario. It will be called the “clarity + transferability” scenario.

For each scenario, different price bids (0.02 TND/m^3; 0.04 TND/m^3; 0.06 TND/m^3; 0.08 TND/m^3 and 0.1 TND/m^3) are proposed to the farmer, who has to accept or reject them.

Table 8. 1. Property rights and attributes used for building CV scenarios

PR component	Attribute of the component	Name of the scenario
“Water access right”	• “security of the entitlement”: quantification	• “clarity scenario”
	• “transferability of the entitlement”: market	• “clarity + transferability”
“Water delivery right”	• “supply reliability”	• “allocation reliability”

8.3.3. Data

The dataset used in this chapter is the same one collected from farmers of the FJ and LB WUAs. However, responses for all 62 farmers were considered in the same set when deriving the WTP values for institutional changes. However, a dummy variable was integrated into the extended logit model in order to detect the effect of the WUA to which farmers belong, on their WTP. This variable is expected to have a significant effect on WTP for improvements to the “water delivery right” of LB farmers. Table 8.2 presents the main descriptive statistics from the survey data, including the demographic and economic characteristics used as explanatory variables in the extended logit model.

Table 8. 2. Explanatory variables of WTP

Variables	Mean	S.D.
- Age in years	49.31	13.05
- Years of formal schooling	8	5.86
- Gross Margin/hectares (TND/ha)	1788.44	1274.12
- Irrigated Area in hectares	5.42	11.78
- Water consumption in cubic meters	5818.6	4534.05
- Satisfaction concerning the functioning of WUA (percentage of yes responses)	56	-

Source: survey

8.4. Results and discussion

8.4.1. Willingness to pay

The estimation of the dichotomous question was made using Stata 9 software. Table 8.3 shows the coefficients of the estimated Hanemann models. These coefficients permit calculation of the mean for the willingness to pay for each scenario using equation (7). Table 8.3 shows that the WTP for an improvement in the reliability of irrigation water provision in the studied area is around 0.0143 TND/m^3 (29.7% and 21% of current water prices in FJ and LB respectively). The value obtained shows that water delivery reliability is a problem that affects farmers in the studied areas. However, this is still a very low value compared to what water prices would be if the government plans to increase rates as a means of recovering water costs.

Table 8. 3. Estimation of the Hanemann model with only the bid price as independent variable

Dependent Variable: Willingness to pay (binary choice)			
	"Allocation reliability" model (1)	"Clarity" model (2)	"Clarity + transferability" model (3)
Independent Variables			
Constant	0.7677 (0.30)	0.3426 (0.46)	1.6661 (2.54)**
Bid price	-53.66 (-2.86)***	-50.4143 (-2.51)**	-45.7663 (-3.59)***
WTP (TND)	0.0143	0.0068	0.0364
Log-likelihood LR	-25.80 11.37***	-23.40 9.66***	-34.39 17.40***

*, **, *** *= significant at 10%, 5%, and 1% level respectively.*

Most of the positive WTP for better stability in the usage PR, were recorded in the LB area, where the current price of water is higher compared to FJ. This could be explained by the descriptive characteristics of both studied areas. In fact, it should be remembered that 98% of farmers in the FJ district have a well which they are able to exploit, whilst this proportion is only around 2% in LB. In cases where water is needed urgently, some of the farmers in the FJ region can pump water from their aquifers whilst those in LB have no such option.

Quantification of water access rights at the beginning of the irrigation season looks to be a non-acceptable change for farmers. Recorded WTP for this scenario was positive but very low (0.0068 TND/m^3). New aggregated prices become 0.054 TND/m^3 and 0.074 TND/m^3 respectively in the FJ and LB areas, which corresponds only to an increase of 14.1% and 10% respectively in the current price charged to farmers.

Finally, relevant results concerning WTP for farmers were recorded after adding the transferability option for their water access rights to the second scenario. WTP for this scenario was around 0.0372 TND/m^3 (77.5% of the current price in FJ and 54.7% of current prices charged in the LB area); aggregated price results in both regions become 0.083 TND/m3 and 0.105 TND/m3 in FJ and LB respectively. This last value indicates that an institutional change to improve the usage right characteristics corresponds to an increase in the utility for the consumer. Positive gaps between the resulting economic value of the WTP for transferable water rights and the price currently charged to irrigators can be considered as a potential economic rent. However, this economic rent is again considered to be of low value compared to the expected trend for prices in Tunisia.

8.4.2. Reasons for WTP responses

In order to identify which characteristics affect the farmers' WTP, an extended logit model, regressing a set of explanatory variables, was estimated. The explanatory variables chosen were: age of the farmer (in years), schooling (number of years), Gross Margin (GM) per hectare (in TND), irrigated area (in hectares), the Water Users' Association to which the farmer belongs (dummy variable), satisfaction with the WUA to which the farmer belongs (dummy variable), and total consumption of water (cubic metres).

Table 8. 4. Results of the estimated extended logit model

Dependent variable: Willingness to pay (binary choice)			
	"Allocation reliability" model (1)	"Clarity" model (2)	"Clarity+transferability" model (3)
Independent Variables			
	Coefficient	Coefficient	Coefficient
Constant	-8.635 (-1.76)*	-5.678 (-1.60)	-7.96 (-2.09)**
Bid price	-103.006 (-2.30)**	-92.655 (-2.78)***	-71.92 (-2.15)**
AGE (years)	0.064 (0.83)	0.054 (0.91)	0.037 (0.73)
SCHOOLING (N° of years)			0.438 (2.27)**
Gross Margin /Ha (Productivity)	0.00145 (2.45)**	0.0014 (2.50)**	0.0017 (2.69)***
IRRIGATED AREA (ha)	-0.377 (-2.00)**	-0.416 (-1.92)*	0.057 (0.64)
WUA (dummy variable: 1: Lebna Barrage; 0: Fondok Jdid)	3.21 (1.66)*	1.621 (0.98)	-2.25 (-1.03)
SATGIC (satisfaction about the internal functioning of the WUA)	6.797 (2.87)***	3.94 (2.55)**	
CEAU (total water consumption m3)			0.0004 (2.28)**
- Log-likelihood	-11.62	-23.405	-34.39
- LR	39.74***	9.66***	17.40***
- MC Fadden R-squared	0.36101	0.51497	0.83952
- Percentage of correct predictions	94.02 %	89.55 %	91.04 %
Info Criterion (minimum values):			
- Akaike	0.5558	0.6177	0.63003
- Schwarz	0.5267	0.5682	0.5984

*, **, *** = *significant at 10%, 5%, and 1% level respectively.*

Table 8.4 shows the effect of each explanatory variable, cited above, on the acceptance of the bid price in each model. As predicted by theory, the bid price is negatively correlated to the WTP value for all models. Total aggregated Gross Margin (GM) per ha is positively and highly correlated to the WTP value for all models. An important finding concerns the negative and significant correlation between total irrigated area and WTP in the allocation reliability and clarity models (models 1 and 2). This suggests that when irrigated areas are larger, farmers' WTP for an improvement to the reliability of the water supply and for clarification of their property right at the beginning of the irrigation season, decreases. This finding indicates that larger farmers seem to have no problem with water provision or water property rights in general. This reinforces a result found by Chraga and Chemakh (2003) concerning the special treatment of larger farmers' demand within WUAs, because of their social standing and power. On the other hand, this variable positively affects the WTP for institutional change towards a water market, but this effect is not significant.

The dummy variable relating to the satisfaction of farmers, concerning the internal functioning of their WUA, affects their WTP for the first two scenarios, both significantly and positively. This variable could be implicitly interpreted as the trust and confidence farmers have towards the managers of their associations. If a farmer is not satisfied with the internal functioning of his WUA, he will not be willing to pay higher water rates, even for an improvement in water supply reliability. Total water consumption and the number of years of schooling are two variables which positively and significantly affect WTP in the third model, implying that high water consumers and the most educated farmers are willing to pay more for transferable water access rights. Also, one can argue that in FJ water is available through wells which makes that a water market is not significant in these circumstances. However, we found in previous results that even in FJ, all of the farmers who have a well, also use public water provided by their WUA. We also show that most farmers in this area use public and groundwater complementarily due to water quality problems. Thus, from a water quality perspective, a water market could still be of interest in FJ.

8.4.3. Analysis of the probability of acceptance

In this section we seek to analyze the effect of relevant explanatory variables regressed in the extended logit model, on the probability of acceptance of higher prices for irrigation water in the studied areas. Two sub-scenarios (increase in the gross margin per ha, and imporvement in satisfaction concerning the functioning of the WUA) were evaluated under each of the main scenarios presented in section 3.2. The initial mean values for the studied sample, described in Table 8.2, are taken as the initial situation, and then equation (5) is calculated for the following changes:

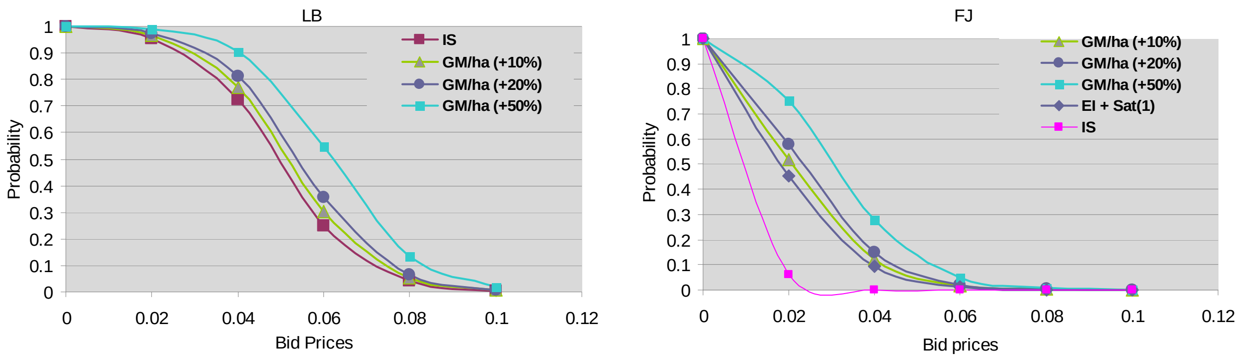
i) Initial situation plus changes in satisfaction dummy variable (from 0 to 1) for farmers in the FJ area. We have indicated that only 26.4% of FJ farmers are satisfied as to the internal functioning of their WUA, whilst this rate is around 84.5% in LB. For this reason, the initial situation in the FJ area is regarded as unsatisfactory while it is regarded as satisfactory in LB.

ii) Initial situation plus an increase of 10, 20 and 50% in the gross margin per hectare, reflecting an increase in the farmers' productivity after the development of a national agricultural policy intended to improve this index. The current subsidy provided for the adoption of water saving technology in Tunisia is an example of such a policy. This latter policy improved water use efficiency in addition to the total productivity of the main irrigated crops in Tunisia during the last decade (Al Atiri, 2007).

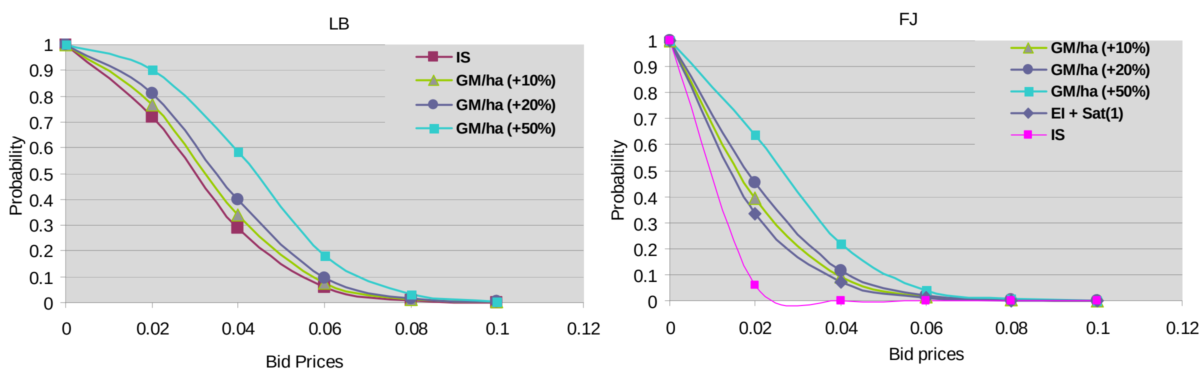
Figure 8.1 shows some interactions in terms of the probability of accepting a bid against the price bid in TND per cubic meter (additional price increases are represented in the Figure) for the different sub-scenarios mentioned above. This Figure confirms the results found in the previous section by showing that there are always higher probabilities of accepting scenario 1 than 2, in both regions. It also shows that an improvement in the perception of farmers concerning the internal organization and functioning of their WUA and improvements in productivity are important factors to consider by policy maker when increasing the price of irrigation water.

Considering both regions under the first two scenarios, it is clear that there is more chance that higher water prices would be accepted in the LB area than in FJ. It is interesting to note that, under the "allocation reliability" scenario, a change in the satisfaction variable for farmers in the region of FJ increases the probability of accepting a price increase of 0.02 TND from near 0 to more than 40%. When productivity would also increase with 20% on average this further increases the probability of accepting a price level of 0.02 TND to around 60 %. The descriptive results of the survey could explain this difference. About 36.4% of farmers in LB are complaining about the WUA's irrigation network, whilst this rate is only around 7% in FJ. Furthermore, 15% of farmers in LB consider a lack of water at times when they need it urgently, as the main irrigation constraint. In FJ however, 36% of farmers consider the quality of water as the main irrigation constraint. In fact, 98% of farmers in the FJ district have a well which they are able to exploit, whilst this proportion is only around 2% in LB. In cases where water is needed urgently, some of the farmers in the FJ region can pump water from their aquifers whilst those in

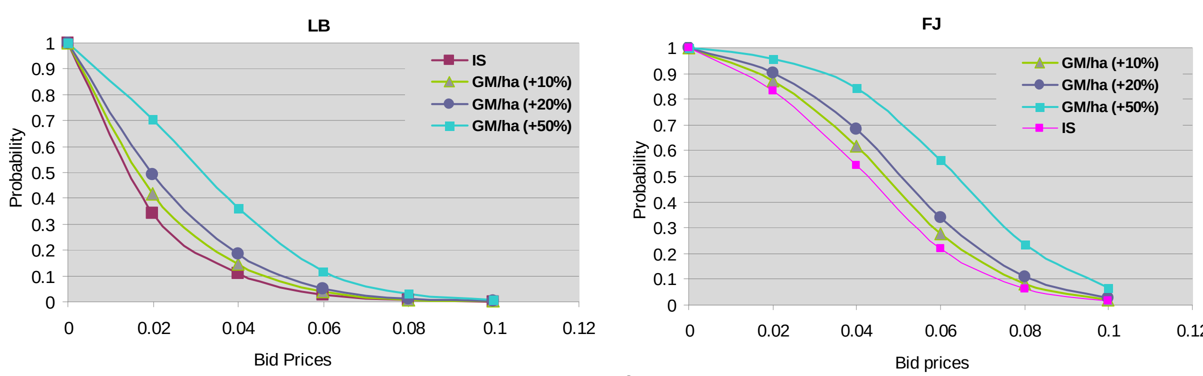
LB do not have this option.



a. Allocation reliability scenario



b. Clarity scenario



c. Clarity + transferability scenario

Fig 8. 1. Effect of productivity and organizational environment on the predicted probability of accepting the bid prices. (IS: Initial Situation; GM/Ha: Gross margin per hectare)

In the third scenario (clarity + transferability of the right) explicative variables of WTP, different from those regressed in models 1 and 2, were used (see Table 8.4). The same former set of variables was also used in this section in order to calculate the probability of acceptance of transferable rights. This means that a comparison between trends for curves in the first two scenarios (a and b in Figure 8.1) and the trends in the last scenario (c, in Figure 8.1) is not valid. However, comparison between both regions is always possible. By contrast to the probability of acceptance of first both scenarios, Figure 8.1.c shows that the transferability option is most likely to be accepted in FJ than in LB. The same effect of productivity on the probability of acceptance of a certain water price was also proved for the third scenario, where improvements in productivity generate a higher probability of farmers' accepting higher water rates for transferable rights.

It is important to point out that, despite the fact that in this section distinctions and differences between willingness to pay in the two studied regions were shown, the results could have been still better if we had derived the willingness-to-pay separately for each group of farmers. This option may better reflect the effect of some specific conditions on farmers' decision making. However, this study was limited by the size of the sample and the absence of a large dataset by region.

8.5. Conclusion and policy implications

From the analysis of farmers' WTP for changes to irrigation property rights, the following points were identified:

- The value of improving irrigation water access and delivery rights in terms of allocation reliability, clarity and transferability in the Cap Bon region in Tunisia is respectively 25%, 12%, and 65% higher than the current average water rates. The Contingent Valuation Method has been shown to be reliable for assessing the value of property rights for irrigation water. The findings from this research[39] shed light on the importance of analysis of opportunity costs for any institutional policy change before making the decision to change.

[39] In addition to the research done by Herrera *et al*. 2004 and by Speelman *et al*. 2009

- The current system of irrigation property rights in Tunisia can actually be considered as relatively inefficient. Improved systems containing more efficient attributes of property rights could help to achieve higher rates of cost recovery. However, a cost-benefit exercise would always be necessary before confirming this conclusion.

- In terms of WTP, transferable water rights were found to be the most attractive for farmers in our study area. However, it should be emphasized that, for market forces to work, water PR must be legally defined and enforceable, fully specified, exclusive, and transferable. Nevertheless, trading is only one way to provide incentives to water users, and not all water property rights encourage trading to the same degree. More importantly, as water problems involve such diverse interests, uses, and values, resolving them relies on legal and political institutions more than markets alone.

- Many factors were found to be explicative of the farmers' WTP. The bid price, gross margin per hectare, total irrigated area, water consumption level per hectare, and satisfaction concerning the organization and functioning of the WUA are some of the most important ones. This proves that farmers' perceptions concerning their local water governance strongly affects their willingness to pay higher rates for water and to accept changes. It is therefore necessary to improve the confidence, transparency and accountability inside WUAs before proposing pricing policies.

The test for the probability of acceptance reveals the following important points:

- Comparing the trend for curves a and b (Fig 8.1), it appears that farmers in the LB area are more willing to pay for improvements in water supply reliability and for a quantification of their right than FJ farmers. This is in line with results found in chapter 6, and shows that improvements in WUA performance in terms of water delivery is an important factor inciting farmers to accept higher irrigation rates. It is clear that the perfection of this process leads to a higher valuation of irrigation water by farmers. This result confirms results found by Chebil *et al*. (2007) in the case of the Teboulba irrigation system in Tunisia. The latter authors also derived a positive WTP by farmers for an improvement in the services and reliability of the irrigation water allocation provided by their local WUA.

- The satisfaction (concerning the internal functioning of the WUA) variable strongly affects the probability of higher price acceptance in the FJ area. Also, improvements in productivity have a more positive effect on the probability of acceptance in LB than in FJ (see the trend for the curves in Fig 8.1, a and b). This is a logical result which confirms results found in the other chapters of the dissertation. In fact, LB farmers are less efficient in terms of their production processes than FJ farmers. In addition, their level of GM/ha is lower than for FJ farmers.

Chapter 9. General Conclusion

9.1. Introduction

Tunisia suffers from seasonal and annual aridity. Some of the most important challenges that the country has to face during the 21st century are: population migration, increasing urbanization, and rising water demand. Together with increases in per capita income, these three factors increase demand for water for food production and domestic purposes. During the past four decades, these changes have already put immense pressure on water institutions, as water demands have increased heavily in all sectors and particularly in agriculture. Consequently, many water institutions have effectively operated in “supply mode” for much of the second half of the 20th century. Their main objective has been to provide as much water as possible to meet the growing demand. Fortunately, Tunisian policy makers have, since the beginning of the seventies, been aware about the future risk of imbalance between water supply and demand (around 2030). A water demand management strategy has been integrated in all national development plans since the early 1970’s. The objective since then was to establish a more rational and efficient use of water resources in all sectors. Many water demand laws, policies and administrations were instituted for this purpose. Currently, a wide variety of institutions are operating in place - at different levels, and with different fields of operation - and need to be coordinated throughout the water sector in Tunisia.

Our general objective in this dissertation was to show that, not only do the existence and functioning of institutions for water demand management matter, but also their performance and effectiveness. According to this, we sought to prove that by designing and implementing high performing institutions, and by improving the functioning of existing ones, Tunisia can greatly improve the efficiency of agricultural water use. We assumed that the performance of irrigation institutions can be assessed using the “institutional decomposition” and “comparative institutional analysis” frameworks developed among others by Saleth and Dinar (1999, 2004)..

Our approach for decomposing irrigation water institutions in Tunisia was based on the IDA framework (Saleth and Dinar, 1999, 2004) which distinguish three main components of water institutions: components relating to constitutional choice rules: water laws; components relating to collective-choice rules: water policies; and components relating to operational rules: water administrations. In addition to this decomposition, in our analysis we also distinguished between the three layers of institutions according to the scheme proposed by Williamson (1996) who differentiated between the "*governance framework*", "*governance structure*", and "*individual level*". In this dissertation, we mainly focused on the individual level, as we believed that the final outcomes of irrigation institutions could be assessed.

According to the IAD framework, each of the three above mentioned components can be divided further into many inter-related aspects. For our empirical evaluation, we only selected the following aspects: water property rights, water pricing policies and cost recovery strategy, and functional, regulatory and accountability capacities of the local water organizations (from the components - water laws, water policies, and water administrations, respectively).

With regard to the methodology applied, we typically identified and used indirect evaluation approaches to assess the comparative efficiency of irrigation water' institutional aspects. In each empirical application we mainly relied on one (or more) of the three following gaps: (i) gap between current institutional aspects and other hypothetical ones (that have to be realistic and already applied in other contexts: regions or countries, e.g. comparison between quantifiable and non-quantifiable "water access rights"). It is however clear that contrasting the performance of an institutional setting currently in place with another desired structure, says nothing about how to put the alternative in place, (ii) gap between the best and the worst performing: comparing the same existing institutional structures that are applied in different contexts to each other (e.g. performant and non-performant associations). Here, the effect of some relevant environmental factors on the functioning of water institutions could be identified, and (iii) gap between actual and future options: comparing actual institutional options to some future options that are already planned for implementation as part of government strategy (e.g. current pricing system to a planned future pricing option).

9.2. Governance framework

At the macro level, the descriptive analysis of the water "governance framework" in Tunisia indicates the following:

- Despite the creation and implementation of many institutions oriented towards irrigation demand management, the demand for irrigation continued to increase for the past three decades. Benefits recorded following the creation of these institutions were mainly observed in the relative improvement in water use efficiency at plot level, in addition to increases in yield for irrigated crops. The potential for improvements in the intensification rate and development of new irrigated areas are some of the factors relevant to the growing demand for irrigation water.

- Theoretically, the downward arrow from "*institutional environment*" to "*governance structure*" (Fig 2.6, Williamson, 1996) indicates that shifts in the broad parameters of the institutional environment (e.g., changes to the constitutional rules and norms) result in alterations to relative prices and will induce changes in governance structures. According to this citation, and based on our literature review, we argue that water management transfer in Tunisia (set of transferred rights and responsibilities) was the main determinant of the currently observed water governance performance. In fact, many responsibilities with limited rights were transferred to the WUAs, - organisations created at a local level to manage irrigation and to collect water fees. The role of the WUAs was only a reallocation role, based on usage right for a given infrastructure. In many cases, the regional administration intervenes - even in the nomination of the WUAs' directors.

- Moreover, feedback from governance to the institutional environment could be considered as a lobbying operation executed by the governance structure on the governance framework (Fig 2.5). This pressure is executed in order to achieve some adjustments at the constitutional level that favour the organizations operating at the governance level (e.g. WUAs in our case study). According to our research, this strategic behaviour was not recorded in the institutional scheme for the water sector in Tunisia.

- More studies based on deep census are needed in order to qualify the role of the water users' associations (WUA) in Tunisia. In fact, these can be considered as micro-institutions working in the interests of government to implement policy, or as organizations of farmers regrouped for a common interest. According to our own interpretation, WUAs look to be more a governmental tool than a farmers' association.

9.3. Governance structure

Two decades after the creation of WUAs in Tunisia, some of them do not yet cover their O&M costs. Their analysis reveals social, technical and organizational problems with regard to their functional performance (cost recovery, rate of adherents, investments, etc.). Also, a statistical overview identifies a number of differences between them, in terms of performance, despite the fact that they operate under the same basic judicial and functional form.

In this dissertation, we considered that "governance can be defined as the body of rules, enforcement mechanisms and corresponding interactive processes that coordinate and bring into line the activities of the involved persons with regard to a common outcome" (Huppert *et al*., 2003). In other words, governance structure is a set of systems that controls decision making with regard to water management and water service delivery (Moriarty *et al.*, 2007). It comprises the technical, economic, administrative, financial and social aspects of local irrigation water management (Brooks, 2004). Thus, we assumed that this governance level can be analyzed through the performance of water users' associations, as these organisations are supposed to apply "the rules settled at an institutional environment", at a local level. WUAs are, in fact, considered in lieu of interaction between government choices and individual preferences.

By comparing the overall, management, and engineering efficiencies for a set of WUAs representing all associations involved in the management of irrigation water for the Cap Bon region in Tunisia, we obtained some relevant indicators as to the levels and determinants of their performance:

- Average overall efficiency of the WUAs operating in our study area was found to be relatively high. However, low efficiency levels concerning the organizational, managerial, technical, and scale attributes of WUAs were observed. We also identified a high level of variability in performance between WUAs in the study area. Thus, improvements in

WUA functioning and performance are still possible and could be of significant benefit for the irrigation sector for two main reasons:

- Additional savings in financial resources are possible and can be used for development purposes. These savings could, for instance, be reflected in the irrigation water price;
- Low WUA performance could have a negative effect on farmers' perceptions, attitudes, and decision making. This effect was the purpose of the investigation into further applications, as undertaken in this dissertation.

- Overall WUA efficiency was found to be significantly correlated to the engineering and managerial efficiency levels of the association. Also, engineering and managerial efficiency levels of WUAs were found to be significantly correlated.

Further research could be proposed at this governance level, concerning the functioning and performance of WUAs: suggestions are as follows -

- A negative correlation between the number of years in operation and the calculated WUA efficiency was observed in this dissertation. However, we were not able to provide an explanation as to the causes of this negative relationship. More studies using dynamic methodologies for the evaluation of WUA performance are needed in order to further investigate the financial and social sustainability of these associations.
- In the case of irrigation resources, the productivity and durability of the irrigated systems, in addition to their observed governance structure, could be related to the social norms of the group holding and managing the water property rights. Through further research using various quantitative and qualitative methodologies, this assumption could be verified in order to improve our understanding as to the influence of social capital on WUA performance.
- Results found in this dissertation regarding WUA performance only concern the region of Nabeul, which is one of the main consumers of irrigation water in Tunisia. However,

similar efficiency evaluations for other regions in the country would also be useful. Specific regional determinants of WUA efficiency/inefficiency could then be drawn by comparing regional results.

- From our study, it was also clear that the number of members in the administrative council negatively affects the scale efficiency of the WUA, in addition to its management performance. This could be due to a coordination problem between the WUA's council members. A deeper analysis of the social and organizational interactions inside WUAs is necessary. Elucidation of these points could provide guidance to policy makers as to potential reforms that might be more appropriate for improving the functioning of these associations (e.g. adjustment of the council members' number according to the size of WUA, better accountability systems, set of incentives for these members, etc.)

From results found at the governance level concerning technical and organizational attributes of WUAs, we draw the following conclusions that have been tested using individual quantitative and perceptional data.

- We believe that insecurity in the water supply, due to low WUA engineering efficiency, stimulates farmers to overuse water when they gain access to it. Thus, improvements to the technical attributes of the WUA in order to enhance its water delivery performance should have a direct effect on water use efficiency at farm level. In addition, WUAs in Tunisia now have a new legal statute calling upon them to contribute to the technical extension of farmers in their regions. Accordingly, WUAs can play a crucial role in enhancing the efficient use of water at plot level by providing more practical advice to farmers in their area, regarding optimal timings and doses for irrigation.

- Given that water fees are calculated on the basis of WUA expenses, a reduction in these expenses (through an improvement in WUA performance) will then result either in lower water prices (affecting the water demand functions of farmers) or higher irrigation cost recovery rates.

- Farmers realizing that their managers are wasting WUA resources will not be motivated to contribute to various collective actions. Thus, improving WUA efficiency can make farmers more willing to pay higher water rates in order to contribute to the recovery cost.

9.4. Effect of the local governance structure on irrigation water use efficiency at farm level

Our calculation of the level of irrigation water use efficiency (IWUE) in the two regions studied in Tunisia, confirms the results found in other research, that IWUE is still very low compared to the efforts to improve it (i.e. subsidies for the adoption of water saving technology, charging higher water prices, development of infrastructure, etc.). According to Al Atiri, 2004, the “National Irrigation Water Saving Programme”, introduced in 1995 to encourage irrigators to invest in water saving technology, generated higher IWUE and improved farmers’ incomes in Tunisia. This encouragement strategy resulted in high benefits at the national level, as a result of an increased irrigation rate , as well as at the farm level, where yield and revenue levels for some crops increased remarkably. However, more studies are needed in order to investigate the determinants of adoption and constraints limiting the access to water saving technologies. For instance, Fouzai, (2007) point out that the adoption of more recent water saving technology is still limited to certain high-value crops that are mainly produced by large farms who are well integrated into the food market chain. Also, national statistics stress the high percentage (28.7 %) of areas equipped with “improved gravity techniques” at the national level. Using this technique, water is not pumped in pipes but distributed through gravity flows, which do not completely eliminate water losses. This result also raises the hope that significant quantities of water could be saved by the agricultural sector if the calculated IWUE can be improved.

As revealed in chapter 5, IWUE is, on the other hand, highly correlated with the overall farming performance of individual farmers. Consequently, improvements in IWUE will have a positive effect, not only on water conservation but also on the overall competitiveness of Tunisian agriculture.

Measures other than technological ones can also enhance the IWUE. In this dissertation, we elucidated the relationship between local irrigation governance and IWUE. Distinct from other studies regarding the levels and determinants of IWUE at farm level, our work shows that IWUE is partially dependent on the local governance context. IWUE was found to be significantly variable between groups of farmers who differ in terms of the governance context in which they operate.

Perception-based information used in our statistical tests reveal main local irrigation governance attributes which explain the variability of farming and IWU efficiency between farmers (in our sample). In fact, considering our sample, we found that the average IWUE is highly and significantly different between the satisfied and the non-satisfied farmers concerning the technical functioning of the irrigation network managed by their WUA. Also, when considering the group of farmers belonging to the WUA with weak level of management efficiency, our tests reveal that the average IWUE for farmers belonging to this WUA significantly differ according to the farmers' satisfaction as to the internal functioning and organization of the WUA. These results are highly interesting since they prove the importance of "good governance" on irrigation water management performance.

Also, in chapter 4, we found that the technical and managerial performance of WUAs is correlated. Thus, both types of managerial and technical skills in WUAs have to be framed and improved by policy makers due to their significant implications for farmers. This will surely have a positive impact on resource conservation and on the improvement of IWUE at farm level.

However, the relationship between IWUE and WUA performance need further to be investigated. It would be interesting to further explain the causality effect between farmers' perceptions and their performance on the one hand, and the WUA performance on the other.

9.5. Pricing policy and cost recovery strategy

Irrigation water pricing is one of the main institutional aspects used by the Tunisian government since the 1970's, for developing irrigated areas and managing the demand for water resources. Tunisia has succeeded in recovering the O&M costs at a national level in a relatively short time and is planning to recover the full cost of irrigation water in the next few years. Water meters, necessary for the implementation of volumetric pricing (the main pricing method used in the country) are also being installed in all remaining areas. Generalization of the pricing tool across all irrigated areas in the country was accompanied by a strategy for subsidizing the adoption of water saving technology at farm level. The principal aim was to enhance the productivity of farmers in order to enable them to pay higher irrigation rates.

However, despite the increases in water prices observed during past decades, total irrigation water demand in Tunisia is still increasing. In this dissertation, we estimated irrigation water demand functions for our study area in order to test whether the current pricing policy, based on improvements in farmers' technical capacity in parallel to increases in irrigation prices, can simultaneously lead to full cost recovery, financial sustainability of irrigation activity, and water conservation at the national level. These three objectives are the main guidelines for government policy on pricing for irrigation water.

It has been empirically verified in this dissertation that the current policy for increasing prices will not permit the three above mentioned objectives to be achieved together. In fact, cost recovery strategy, water conservation, and sustainability of irrigation activity are not likely to happen simultaneously in Tunisia for the following reasons:

- Small farmers were found to be the least efficient but most elastic regarding water prices. According to our results, when the price of water increases, these farmers will shift towards a cropping pattern for which less water, variable inputs and more land is necessary. Small-size farmers are generally more constrained in terms of improving their technical efficiency. Thus, the full cost recovery objective will threaten the financial sustainability of small irrigated schemes if their technical efficiency cannot be improved. More facilities such as credit access, training programmes, market integration, etc. are needed to support them

- In the same sense, if technical efficiency for these small-size farmers can be improved, then, the water saving objective will be difficult to achieve since farmers' demand become then highly inelastic, as found in this dissertation. Efficient farmers will only reduce the scale of their operation as a reaction to increases in the irrigation prices. However, if the farmers who are currently most efficient have access to advanced technology, then the efficient frontier can be drawn by other more efficient patterns which would ensure both water conservation and irrigation intensification.

The governance structure, which was found to be significantly correlated to the IWUE, has also an indirect effect on the effectiveness of pricing policy and water demand functions. In fact, improvements to the governance structure (i.e., WUA performance) could help farmers to use water more efficiently and thus make their water demand functions more inelastic and increase their ability to pay higher water rates. From another viewpoint, the waste of financial resources, due to low WUA efficiency, could be reflected in the unitary water price, since irrigation rates are based on the financial balance of the WUA. Thus, by adjusting these inefficiencies, full water cost recovery can be achieved with lower pressure on farmers' budgets.

9.6. Changes to water property rights and farmers' willingness to pay (WTP) for water

Finally, the efficiency of "water access" and "water delivery" rights considered as two aspects of the water laws' institutional component have been also assessed in this dissertation. It was hypothesized that "by improving WUA efficiency farmers will be more willing to pay higher water rates. Farmers realizing that their managers are wasting the WUA resources will be less motivated to contribute". It was also assumed that "constitutional laws concerning the qualification of water access rights can be a source of inefficiency. A change towards more flexible and tradable access rights can generate higher economic value for the resource". Accordingly, changes in attributes relating to the "water access right" and "water delivery right" were integrated into three scenarios in order to evaluate farmers' willingness to pay for them. The three selected scenarios are as follows: better "allocation reliability", "quantification of the right" (quotas system), and "transferability of the right" (market system).

Our results show positive willingness to pay values for all scenarios. However, farmers in the studied region were found to be more willing to pay for changes in the "water access right", and more specifically for the transferability option. Furthermore, their perceptions concerning the organization and functioning of the WUA, to which they belong, in addition to their productivity, significantly affected their willingness to pay. The probability of accepting higher water prices in areas, where water reliability performance is low, was found to be high.

These results stress the following main points that need special attention from policy makers in

Tunisia:

- Improvements in the technical capacity of WUAs enabling them to provide a more reliable water supply, can have a positive effect on the cost recovery strategy and the acceptance of farmers to paying higher water rates. In the same sense, improvements in the internal organization and functioning of WUAs can also increase the probability of acceptance of higher water charges by farmers.

- Adjustments to the constitutional attributes concerning the “water access right” can also have some positive repercussions on the economic valuation of water by farmers. However, more studies are needed to identify the relevant characteristics of access rights that can be implemented in Tunisia. Furthermore, cost benefit valuation of institutional changes, taking into account the implementation cost of any institutional alternative, has to be undertaken before any decision can be made to change the current water right system.

- Pricing policies and cost recovery, willingness to pay for higher irrigation water, and the IWUE at farm level are all highly dependent on the functioning and performance of WUAs in a given irrigated area. Local irrigation governance resulting from the performance of WUAs at the local level is also partially dependent on institutional aspects agreed at the macro level: “governance framework”.

9.7. Concluding remarks

Despite the arid climate and the scarcity of water resources in Tunisia, policy makers succeeded at an early stage in establishing a rational strategy for the mobilization of resources and efficiency improvements in water use. This strategy was based on fundamental reforms to water institutions starting from the early 1970’s, with the aim of decentralizing water demand management to a local level. Currently, much progress has been made in Tunisia with regard to the transfer of irrigation management, private participation; O&M cost recovery, and water use efficiency at farm level. However, in this dissertation, we showed that significant benefits could still be achieved by improving the coordination and functioning of the implemented irrigation institutions.

Technical and managerial capacities of WUAs are often low, and insufficient training is offered during their establishment process. However, these capacities will generate a local irrigation governance context which could strongly affect farmers' behaviour and decision making. Thus, promotion of good local governance has to be undertaken prior to efforts made at the individual level.

Finally, much more attention has to be given to the irrigation water demand management in Tunisia in order to reduce the volume of water used in this sector. Potential savings are possible since there is wide scope to improve the irrigation water use efficiency, as shown in this dissertation. However, the orientation of the Tunisian society toward a consumption society and the free trade agreements signed by the Tunisian government can be breaks for irrigation water use reduction in the near future.

SUMMARY

This PhD dissertation is studying the efficiency of irrigation water management institutions in Tunisia. Our general objective is to show that, not only do the existence and functioning of institutions for water demand management matter, but also their performance and effectiveness. According to this, we sought to prove that by designing and implementing high performing institutions, and by improving the functioning of existing ones, Tunisia can greatly improve the efficiency of agricultural water use. We assumed that the performance of irrigation institutions can be assessed using the "institutional decomposition" and "comparative institutional analysis" frameworks developed among others by Saleth and Dinar (1999, 2004).

Our approach for decomposing irrigation water institutions in Tunisia was based on the Institutional Decomposition and Analysis framework which distinguish three main components of water institutions: components relating to constitutional choice rules: water laws; components relating to collective-choice rules: water policies; and components relating to operational rules: water administrations. In addition to this decomposition, in our analysis we also distinguished between the three layers of institutions according to the scheme proposed by Williamson (1996) who differentiated between the "*governance framework*", "*governance structure*", and "*individual level*". In this dissertation, we mainly focused on the individual level, as we believed that the final outcomes of irrigation institutions could be assessed.

First part of this dissertation, which is designated to the description of the water sector' institutional environment, shows that serious shortage problems can occur in the near future if water demand continues to grow like it is currently. In fact, despite the creation and implementation of many institutions oriented towards irrigation demand management, the demand for irrigation has continued to increase for the past three decades. This was mainly due to the creation of new irrigated areas and to the intensification of the existed ones. Also, at this institutional level, feedbacks from governance structures (Water Users' Associations: WUA) on the institutional environment was not recorded in the institutional scheme of Tunisian water sector. These feedbacks are considered as pressure executed in order to achieve some adjustments

at the constitutional level that favour the organizations operating at the governance level. This gives the impression that WUA in Tunisia can be defined as micro-institutions rather than users' associations.

At the governance level, a comparative efficiency analysis of WUAs sample shows that still some inefficiency related to their functioning occur. Additional savings in financial resources (spent by these associations) are possible and can be used for other local irrigation development purposes. These savings could for instance be reflected in the irrigation water price and cost recovery levels. Also, low WUA performance could have a negative effect on farmers' perceptions, attitudes, and decision making. This effect was the purpose of the investigation into further applications undertaken at the individual level.

At the individual level, we confirm that significant relationship exists between the quality of the local irrigation governance and the irrigation water use efficiency (IWUE) at the farm level. We also found that current irrigation pricing policies can have different impacts on farmers according to their farming efficiency levels. More efficient farmers have a more inelastic water demand functions. Thus, the Tunisian pricing policy aiming to enhance the technical efficiency of farmers in addition to charging higher irrigation rates could fail in generating additional water saving at the national level. Moreover, the study of the efficiency of current irrigation usage right in Tunisia shows that additional economic gains could be collected from farmers if various attributes of the right could be improved. More precisely, we found that farmers are willing to pay higher water prices for more reliable and for transferable irrigation rights.

It is then clear according to this dissertation that water institutions are important elements affecting the performances of water sector at national level. Improvements of their functioning and performances have deep effect on social as well as individual welfare. A performing irrigation institution will be the one which generates a "good governance" context providing more motivation and incitation for individual irrigators.

SAMENVATTING

Deze doctoraatsthesis onderzoekt de efficiëntie van de instituties voor beheer van irrigatiewater Tunesië. De algemene doelstelling is om aan te tonen dat naast het bestaan en het functioneren van deze instituties ook hun efficiëntie en doeltreffendheid een rol spelen. Daarom werd getracht aan te tonen dat door het opstellen en invoeren van sterk prestatiegerichte instituties en door het verbeteren van het functioneren van de reeds bestaande instituties, Tunesië de efficiëntie van het watergebruik voor landbouwkundige doeleinden sterk kan verhogen.

De aanpak van het ontleden van de Tunesische instituties voor beheer van irrigatiewater is gebaseerd op het kader voor institutionele decompositie en analyse waarbij onderscheid wordt gemaakt tussen drie belangrijke karakteristieken van deze instituties: i) karakteristieken gerelateerd aan het constitutionele niveau zoals de water wetgeving, ii) karakteristieken gerelateerd aan het gemeenschapsniveau zoals waterbeleid en iii) karakteristieken gerelateerd aan het operationele niveau zoals water administratie. Bovenop deze indeling is in de gebruikte analyse tevens onderscheid gemaakt tussen de drie institutionele lagen volgens het schema van Williamson (1996). Hierbij wordt onderscheid gemaakt is tussen het bestuurskader, de bestuurstructuur en de individuele beslissingsmaker. In deze verhandeling wordt hoofdzakelijk gefocust op de individuele beslissingsmaker, omdat we denken dat deze het meest invloed kan hebben op het eindresultaat.

Het eerste deel van deze verhandeling beschrijft de institutionele omgeving waarin de Tunesische watersector zich bevindt. Hierbij wordt aangetoond dat bij een gelijkblijvende groei in de vraag naar water, ernstige tekorten aan water kunnen optreden in de nabije toekomst. Ondanks het ontstaan van vele nieuwe instellingen omtrent irrigatiebeheer bleef de vraag naar irrigatiewater toenemen gedurende de laatste 30 jaar. Dit is hoofdzakelijk te wijten aan het ontstaan van nieuwe irrigatiegebieden en een intensifiëring van de reeds bestaande. Bovendien werden in het institutioneel kader van de Tunesische water sector geen terugkoppelingen geconstateerd van de bestuurstructuur (Water gebruikers associaties: WGAs) naar de institutionele omgeving. Deze terugkoppelingen vormen een druk om aanpassingen te bekomen op institutioneel niveau die positief kunnen zijn voor organisaties op operationeel niveau. Dit geeft de indruk dat WGAs in Tunesië eerder micro-instituties zijn dan gebruiksassociaties.

Op het operationeel niveau toont een vergelijkende efficiëntie analyse van WGAs een inefficiëntie in de functionering aan. Bijkomende besparingen in de financiële middelen (gebruikt door deze associaties) zijn mogelijk en kunnen gebruikt worden voor andere lokale irrigatie ontwikkelingsdoeleinden. De besparingen kunnen dan voor een verlaging van de irrigatieprijs of voor een betere kostendekking zorgen. De lage efficiëntie van WGAs kunnen een negatief effect uitoefenen op de perceptie van de landbouwers, hun gedrag en de uiteindelijke beslissingen. Dit effect leidde tot het verder onderzoeken van deze toepassingen op landbouwersniveau.

Op dit landbouwersniveau zien we dat er een significante relatie bestaat tussen de kwaliteit van het lokale irrigatiebeleid en de gebruiksefficiëntie van het irrigatiewater op bedrijfsniveau. Bovendien blijkt dat het huidig prijsbeleid omtrent irrigatie een andere impact kan hebben naargelang de efficiëntie van het bedrijf. Meer efficiëntie bedrijven hebben een meer inelastische vraag naar water. Bijgevolg blijkt dat het Tunesische prijsbeleid waarbij getracht wordt de technische efficiëntie op bedrijfsniveau te verhogen d.m.v. prijsverhogingen niet gegarandeerd zal leiden tot extra water besparingen. Bovendien toont de efficiëntiestudie naar watergebruiksrechten aan dat er economische winsten kunnen gehaald worden bij de landbouwers indien verschillende attributen van de waterrechten kunnen verbeterd worden. Meer precies is aangetoond dat landbouwers bereid zijn een hogere prijs te betalen voor meer betrouwbare en verhandelbare irrigatierechten.

Deze doctoraatstheses toont aan dat de waterinstituties een belangrijke invloed uitoefenen op de efficiëntie van de water sector op nationaal niveau. Verbeteringen in het functioneren van deze instellingen hebben een groot effect op zowel de maatschappelijke als op de individuele welvaart. Een goed functionerende instellingen voor beheer van irrigatiewater zal door een goed eigen beleid zorgen voor motivatie en impulsen voor de individuele gebruikers van irrigatiewater.

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