Efficiency of the irrigation water user association in the Zeuss-Koutine region, south-eastern Tunisia

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Jel Classification: Q12, Q15, C61

Abstract

This paper analyzes the efficiency of Water User Associations (WUA) in the Zeuss-Koutine region (Tunisia) and studies its main determinants. First, Data Envelopment Analysis (DEA) is used to assess the overall WUA efficiency and to evaluate the management and engineering sub-vector efficiencies separately through a mathematical modification of the initial DEA model. In a second step critical determinants of sub-vector efficiency are determined using a Tobit model. A major finding of the study is that WUAs are clearly inefficient. Under variable returns to scale (VRS) specification, the average technical efficiency of WUA was 84.4%. This implies that output level could be produced by saving 15.6% of (all) used inputs. The average scale efficiency was around 96.5%, indicating that many WUAs are not operating at an efficient scale. Results show also that inefficiencies of the management and maintenance are higher than the overall inefficiency. The average management efficiency is around 80.6% while the average engineering efficiency is 82.3% indicating that about 19% of management and maintenance expenditures could be saved if WUAs were operated in a sound manner. The inefficiency found can be mainly attributed to the number of water pumping stations managed and the number of years of experience operating a WUA (age).

Keywords: *WUA, irrigation, technical efficiency, sub-vector efficiency, DEA method, Tunisia.*

Résumé

L'objectif de cet article est d'évaluer l'efficience technique des Groupements de Développements Agricoles (GDAs d'irrigation) et de ses déterminants dans le sud-est tunisien. A ce propos, nous proposons d'étudier en premier lieu l'efficacité technique de ses structures et de proposer une mesure de l'efficacité de gestion et de maintenance moyennant l'application de l'approche DEA (Data Envelopment Analysis). Dans la deuxième étape, les déterminants techniques et organisationnels des efficacités calculées sont recensés à l'aide d'un modèle Tobit. Il ressort de cette analyse que ses structures sont inefficaces. Les résultats montrent qu'en moyenne 15,6% des dépenses totales des GDAs pourrait être économisé si toutes les associations étaient gérées à l'optimum. Les inefficacités sont liées principalement au nombre d'années d'expérience des GDAs. L'efficacité d'échelle moyenne de l'échantillon étudié est de 96.5%, indiquant que plusieurs GDAs ne sont pas gérés à une échelle pertinente. Les inefficacités d'échelle sont principalement liées à des variables administratives et organisationnelles. Les résultats montrent aussi, qu'en moyenne, l'efficacité des GDAs est plus affectée par leurs dépenses de gestion et de fonctionnement interne que par leurs activités de maintenance et d'entretien.

Mots-clés: GDAs, irrigation, efficacité technique, efficacité technique des sous-vecteurs, méthode DEA, Tunisie.

1. Introduction

Irrigation water is becoming an increasingly scarce resource for agriculture in many regions of the world. A common ground in past policy schemes was the development of appropriate irrigation infrastructure.

The irrigation water supply as the demand for agricultural products was increasing. However, these expansionary policies have led to a massive use of irrigation water at a heavily subsidized cost, and a scarcity of the resource. Water shortage has become a socially increasing and economic concern for policy makers and for those who must compete for the resources. In particular, policy makers are beginning to point to agriculture as the sector at the core of the water problem. Tunisian water reserves are estimated at 4.7 billion m^3/year, of which 2.7 billion m^3 come from annual rivers in the north, 0.7 billion m^3 from groundwater in the centre, the plains and the coastal area, and approximately 1.3 billion m^3 from the deep groundwater table mainly in the south (Al Atiri, 2005). Water resources are unevenly distributed across the country, with around 60% located in the north, 18% in the centre and 22% in the south. Water resources that have a salinity below 1.5g/liter are distributed as follows: 72% of surface water resources, 8% of shallow groundwater and 20% of deep groundwater (Hamza, 2008).

Taking into account the limited water resources and the frequent disparity between supply and demand during dry seasons, Tunisia has engaged, over the last three decades, in a dynamic program of water mobilization. Several investment projects have been granted, reaching 9% of total investments in the government's Development Plan XI (2007-2011), 19% in water programs.

Agriculture, which accounts for approximately 12% of the GDP, is the sector that consumes the highest amount of water (80%) from the available water resources. Today, about 450 thousand hectares (9% of useful agricultural land) are irrigated in Tunisia (MA, 2010). Irrigated agriculture consumes 80% of the available water resources and represents 35% of the output value derived from the agricultural sector, 22% of exports, and 26% of agricultural employment. Irrigated areas provide 95% of horticultural crops and 30% of dairy production (Frija *et al.*, 2009). Moreover, the efficiency of the irrigation networks is relatively weak, estimated at approximately 50% (Bachta and Ghersi, 2004). Therefore, during the recent decades concerns regarding the efficient use of water resources in the country have increased. These concerns have been addressed particularly to the transfer of government water management systems to water user associations (hereafter WUAs).

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WUAs have been created by government financing but they are responsible to ensure the collection of the water fees as well as service-related fees (infrastructure maintenance, etc.). The number of WUAs has risen strongly from about 100 in 1993 to 1250 in 2009 managing around 188 000 hectares of irrigated lands (MA, 2010b). In 2009, they were responsible for the management of 42.4% of the irrigated land in Tunisia. On the other hand, 47% of irrigated land was managed by private farmers, who mainly use private wells, and the rest (10.6%) is publicly managed by Regional Agricultural Development Commissions (Commisariat Régional de Développement Agricole: CRDA), which are regional public administrations with financial independence.

Each year, WUA is responsible for the elaboration of its own budget. WUAs also have the right to determine the water price and to decide whether the payment is on the basis of water volumes to be produced or distributed. Furthermore, they establish the amount of projected investments, and the operation and maintenance charges. Financially, WUAs perform the following tasks: operation and maintenance of canals, repairing of various infrastructures, functioning of the association and investments. The water charge established by the WUAs comprises water-purchase charges, energy fees, labour force charges and maintenance and management fees.

Already 30 years have passed after the transfer of water authority from the government to WUAs; only 25% of WUAs[1] succeeded to cover their entire operation and maintenance costs while 25% of them covered even less than 50% of those costs and were still subsidized by the government (Louati, 2008). It is also clear that WUAs in Tunisia still face a lot of challenges related to technical, financial and social aspects (Bachta and Zaïbet, 2007; Romagny and Riaux, 2007). Problems are however different from one WUA to another, with only some associations that can be considered efficient. In response to this observation, and taking into account 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 (Frija *et al*., 2008). In our case, the relative efficiency of a sample of WUAs in Zeuss-Koutine region (south-eastern Tunisia) is analyzed using data envelopment analysis (DEA). In fact, many studies have used DEA methodology to analyze organizations' efficiency. The applications range from banks, health and educational institutions and forest organizations to airlines and railway companies (Frija *et al.,* 2008). To our knowledge, the application undertaken in this paper to assess the efficiency of organizations specializing in water management is still limited. Only Frija *et al*. (2009) have applied a similar DEA analysis in Cap Bon WUAs (north-eastern Tunisia) and Umetsu *et al*. (2005) in Turkish WUAs. In the irrigation and drainage sectors, DEA has often been applied to estimate the production efficiency of large irrigated systems and districts at regional level (Malana and Malano, 2006; Diaz Rodriguez *et al*., 2004, 2005; Malano *et al*., 2004). In our study, we assume that DEA is not only suitable to apply in the case of water management associations, but moreover the methodology used allows calculation not only of overall, but also of sub-vector efficiencies (for alternatives see Oude Lansink *et al*., 2002; Lilienfeld and Asmild, 2007; Speelman *et al*., 2007). Management and engineering efficiencies were assessed using this concept of sub-vector efficiencies. In fact, by management efficiency we try to express how well a given WUA allocates expenditure to manage the organization and the functioning of the WUA, compared to 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 the WUAs in the sample studied.

Maintenance expenditure includes expenses related mainly to the maintenance and repair of the irrigation network and the pumping stations. Energy costs (for WUAs that pump water from boreholes) and the labour cost of performing the above-mentioned tasks are also included in the maintenance expenditure vector. In a second step, a Tobit model was estimated to provide ideas about local inefficiencies and to determine potential factors affecting the functioning of WUAs. To achieve these objectives, the paper is divided into five separate sections. After the introduction, in section 2, we describe the DEA technique as well as the Tobit model used in this study. Section 3 describes the empirical application. Results and discussions are presented in the last two sections after which the most important conclusions are drawn.

2. Methodology

2.1. Efficiency measures

Technical efficiency is defined as the ability of a farm to either produce the maximum possible output from a given bundle of inputs and a given technology, or to produce the given level of output from the minimum amount of inputs for a given technology (Basanta *et al*., 2004). The absolute efficiency position of farmers is usually not known. Therefore, the problem is to measure the efficiency of one farm relative to others **(**A. Chebil *et al*., 2013)**.**The evaluation of farm specific technical efficiency is usually based upon deviations of observed output or input vectors from the best production or efficient production frontier. Farrell (1957) was the first to use frontier production functions to measure technical efficiency. Firms that are technically efficient will be located at the frontier, while those that are not will appear below the frontier, with the ratio of the actual to potential production defining the level of efficiency of the in-

[1] Total WUAs number in Tunisia is currently around 1250.

dividual firm. In empirical work, frontier production functions are obtained from available data, and technical efficiency estimates are based on empirical relations from sampled data, where the estimated efficiency scores in the current study indicate how much a farm should be able to minimize the use of all inputs in the production process, while continuing to produce the same level of output.

There are two main competing paradigms for estimating the relative efficiency of farms: parametric and non-parametric. The parametric stochastic frontier production function approach (Aigner *et al*., 1977; Meeusen and van den Broeck, 1977) and the non-parametric approach, commonly referred to as data envelopment analysis (DEA) (Charnes *et al*., 1978) are the two most popular techniques used in efficiency analysis. Among many authors, Coelli (1995) presents the most recent review of various techniques used in efficiency measurement, including their limitations, strengths and applications in agricultural production. The main advantages of the DEA approach are the higher flexibility in that they avoid a parametric specification of technology as well as the distributional assumptions of the efficiency, although allowing curvature conditions to be imposed easily (Sharma *et al*., 1999; Speelman *et al*., 2007). Consequently, DEA is used in this study to compute input-based measures of overall technical efficiency (TE) and sub-vector technical efficiency (in terms of input use) for irrigated agriculture in south-eastern Tunisia (IE).

2.1. Data Envelopment Analysis

Data envelopment analysis (DEA) was developed by Charnes *et al.* (1978) based on Farrel's contribution to productive efficiency. The data envelopment analysis technique uses linear programming methods to construct a non-parametric frontier. The technique also identifies efficient production units, which belong to the frontier, and inefficient ones, which remain below it. The evaluation of farm (the decision-making unit) performance is usually based on economic efficiency, which is generally made of two major components: technical efficiency and price or allocative efficiency (Farrell, 1957). Technical efficiency is defined as the ability of a farm to either produce the maximum possible output from a given bundle of inputs and a given technology, or to produce the given level of output from the minimum amount of inputs for a given technology. Technical efficiency can be decomposed into two components: pure technical efficiency and scale efficiency (Sharma *et al*., 1999). When one separates the scale effect from the technical efficiency, the pure technical efficiency is obtained. Scale efficiency relates to the most efficient scale of operation in the sense of maximizing average productivity. A scale efficient farm has the same level of technical and pure technical efficiency.

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 the efficiency and the scale of operation, thus assuming that large WUAs are just as efficient as the small ones in converting inputs to outputs. Furthermore, we assume that changes in the organization's inputs can lead to disproportionate changes in its outputs. Therefore the option of VRS will be chosen in 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 is input-oriented (Diaz Rodriguez *et al*., 2004). In our case, as a national objective of the decentralization process, it is necessary that WUAs reach a cover rate of their expenditures ensuring their sustainability (Mihci *et al*., 2011). 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 for the determination of water rates in the WUA. Therefore, during the agricultural year, WUAs will focus mainly on the minimization of their expenditure. For those reasons, it is estimated that an input-oriented model will be more suitable for our problem. To recap, we chose to estimate Variable Return to Scale (VRS) efficiencies through BCC (Banker *et al*., 1984) and input-oriented model.

Following Banker et al. (1984), the BCC-DEA model is presented here for the situation with J farms (j=1,……n), each producing M outputs y_{mn} (m=1,…M) by using K different inputs x_{kn}(k=1,…..K), each farm becoming the reference unit. For the i-th firm we have vectors x_i (kx1) and y_i(Mx1). For the entire data set, therefore, we have a KxN input matrix X and MxN output matrix Y.

The technical efficiency (TE) measure is obtained by solving the following DEA model (equation 1):

$$Min_{\theta,\lambda}\ \theta \quad (1.1)$$

$$s.t\ \sum_{k=1}^{K} \lambda_k y_{m,k} \geq y_{m,0} \quad (1.2)$$

$$\sum_{k=1}^{K} \lambda_k x_{n,k} \leq \theta . x_{n,0} \quad (1.3) \qquad \text{(Model 1)}$$

$$\sum_{k=1}^{K} \lambda_k = 1 \quad (1.4)$$

$$\lambda_k \geq 0 \quad (1.5)$$

Where θ is a variable representing the efficiency of the reference DMU_0, and hence the percentage of reduction to which each input must be subjected 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 DMU0. 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. The estimate will satisfy restriction $\theta \leq 1$ with a value θ=1 indicating a technically efficient farm. Equation 4 consists of the convexity constraint which specifies a variable returns to scale option. The DMUs whose λ values are positive will be the reference set for D-MU_0 under study. In fact, it is the linear combination of those units which will formulate the situation objective needed to become efficient.

It should also be noted that equation 1 has a variable return to scale (VRS) specification which includes a convexity constraint $\sum_{k=1}^{K} \lambda_k = 1$. Without that constraint, equation (1) would have constant returns to scale specification (CRS). Using that specification, it is assumed that farms are operating at their optimal scale (Oude Lansink and Silva, 2004). In the case of agriculture, increased amounts of inputs do not proportionally increase the amount of outputs. For instance, when the amount of water to crops is increased, a linearly proportional increase in crop volume is not necessarily obtained, one reason why the variable return to scale option might be more suitable for our problem (Diaz Rodriguez *et al*., 2004).

To calculate the efficiency of use of an individual input or subset of inputs, the "sub-vector efficiency" concept can be introduced (Speelman *et al*., 2007; Chebil *et al*., 2013). The sub-vector efficiency measure looks at the possible reduction in the selected subset of inputs holding all other inputs and outputs constant (Oude Lansink *et al*., 2002; Oude Lansink and Silva, 2004). Using the notion of sub-vector efficiency proposed by Färe *et al*. (1994) in (Oude Lansink *et al*., 2002) technical sub-vector efficiency for variable input t is calculated for each firm i by solving the following linear programming (LP) problem (2):

$$
\begin{aligned}
& Min_{\theta^t,\lambda}\, \theta^t && (2.1) \\
& \text{s.t.} \\
& \sum_{k=1}^{K} \lambda_k y_{m,k} \geq y_{m,0} && (2.2) \\
& \sum_{k=1}^{K} \lambda_k x_{n-t,k} \leq x_{n,0} && (2.3) \qquad \text{(Model 2)} \\
& \sum_{k=1}^{K} \lambda_k x_{t,k} \leq \theta^t x_{t,0} && (2.4) \\
& \sum_{k=1}^{K} \lambda_k = 1 && (2.5) \\
& \lambda_k \geq 0 && (2.6)
\end{aligned}
$$

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 program (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).

2.2. Identifying determinants of efficiency using Tobit analysis

After calculating the efficiency measures, the next step is to identify the determinants of inefficiency, something commonly done by estimating a second-stage relationship between the efficiency measures and suspected correlates of efficiency (Binam *et al*., 2003). Since the efficiency parameters vary between 0 and 1, they are censored variables and thus a Tobit model needs to be used (model 3):

$$
\theta^{t*} = \sum_{i=1}^{N} \beta_i Z_i + \varepsilon_i
$$

$$
\theta^t = \begin{cases} \theta^{t*} \, if \, 0 \prec \theta^{t*} \prec 1 \\ = 0 \; if \, \theta^{t*} \prec 0 \\ = 1 \; if \, \theta^{t*} \succ 1 \end{cases} \qquad \text{(Model 3)}
$$

Where θ^t are the DEA overall, scale, management, and engineering efficiencies used as a dependent variable and Z is a (*N*1*) vector of independent variables related to attributes and characteristics of WUAs in the sample. The variables included in the Tobit model are discussed in the following section. The estimation of the Tobit model is based on maximum likelihood procedures. For Tobit estimates to be consistent, it is necessary that residuals (ε_i) are normally distributed (Holden, 2004).

3. Empirical Application

3.1. Case study and data sample characteristics

The database used for this analysis was collected by the CRDA Médenine. This regional data concerns 9 WUAs which represents all the WUAs operating in the Zeuss-Koutine (governorate of Médenine). The Zeuss-Koutine is located in the south-eastern area of Tunisia. In this region, irrigation activity is recently introduced and water scarcity is an important issue (Mahdhi *et al*., 2011). The groundwater resources are scarce and over exploited. This exploitation reaches 183% with annual renewable resources of 1.39 Mm^3. Total irrigated agricultural area of the region is 2727 ha. Two subsystems can be distinguished: the subsystem of private irrigated farms is based on surface wells (1423 farms with 2300 ha). The subsystem of public irrigation schemes is based on collective tube-wells (170 farms with 427 ha), usually established by the state. The water management is ensured by a water user association known as the 'GDA'. The agricultural production is based on crop production and the irrigation system is characterized by surface irrigation methods. According to the CRDA Médenine (2009), the main crops produced in the region are fruits (46%), vegetables (36%), and cereals (8%). Total agricultural production of this region contributes with nearly 8% to the total regional agricultural production and provides 26% of labour recruitment in agriculture.

3.2. Overall management and engineering efficiencies

Concerning the selection of outputs and inputs, according to the database, the WUA expenditures can mainly be divided into management expenditures, maintenance costs, water purchasing costs, labor costs, investments, reimbursements of debts and other expenditures. Given that in our empirical application, we try to focus on the relationship between inputs-outputs of the WUAs within a general framework of minimization of irrigation water prices, we choose to aggregate the main financial inputs of the water users associations into management expenditure, maintenance expenditure, and purchasing water expenditure. The maintenance expenditure vector integrates the labor and energy fees in addition to the classic maintenance costs.

The chosen outputs considered are the annual irrigated area (ha), and the total annual irrigation water delivery per unit irrigated area (m^3 $ha^{-1}yr^{-1}$). According to this input-output choice, an efficient WUA will be the one that had a lower Input/Output ratio (Expenditures/m^3 and Expenditure/ha) and consequently which reflects more performance in minimizing water rates for farmers.

In the management sub-vector efficiency, only the efficiency of the individual management expenditure input is considered, while holding the rest of inputs and outputs constant. Generally, the management expenditures are stable over the time (Terraux *et al*., 2002). The engineering sub-vector efficiency considers the inputs related to the total expenditure in maintenance (labor, energy and other maintenance expenditures). In the short term, this input gives an idea on the efficiency of the maintenance tasks and on the technical network situation of the WUA. Only the efficiency of this latter individual input will be considered in the calculation of the engineering sub-vector, while holding the rest of input vectors constant.

The 9 WUAs in Zeuss-Koutine are managing around 282 ha of lands (18 % of total irrigated land in the governorate) owned by 177 adherent farmers. The total volume of water distributed by those associations is around 642,200 cubic meters and the average irrigated surface per WUA is nearly 21 ha. Basic statistics regarding the selected WUAs are shown in Table 1.

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

	Outputs		Inputs		
	N of irrigated ha/year	Vol of water distributed/ha	Management expenditure (TDN)	Maintenance expenditure (TDN)	Purchasing water cost (TDN)
Average	21	3912	132	2776	3609
Standard deviation	9	2377	50	1038	2407
Minimum	5	1067	51	445	435
Maximum	35	7400	205	4000	7693

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 the WUAs made by the Tunisian Ministry of Agriculture and Hydraulic Resources.

Technical characteristics can include the number of years of experience operating a WUA (age of the association), the number of pumping stations managed by the WUA, the ratio of irrigated area under control of WUA and that equipped with water saving technologies, the ratio of exploited area, and the ratio of water losses in water distribution operation. In the study, we considered just two variables, the number of pumping stations managed by the WUA and the age of the association.

Organizational and administrative characteristics are also assumed to have an important effect on resources management inside a given WUA. In fact, the most organized WUAs are expected to be more efficient. Used variables can be: 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. In the study, we limited the number of members in the administrative council at one variable.

4. Results

4.1. Efficiencies analysis

Using the General Algebraic Modelling System (GAMS) to solve the linear programming problems outlined above, the efficiency measures of the WUAs were estimated. Model (1) was solved 9 times to provide efficiencies for each farm under VRS specification. Management and engineering sub-vectors efficiencies were also calculated for each farm solving the second model (2). Results for estimates of technical efficiency (TE) and sub-vectors efficiencies are presented in Table 2.

Under the VRS specification, the estimated input-oriented technical efficiency ranges from a minimum of 48.4% to 100% with an average estimate of 84.4%. The average efficiency provides information about the potential resource saving that could be achieved while maintaining the same output level.The results mean that a 15.6% decrease in all inputs is possible with the present state of technology and unchanged outputs, or the same level of output can be reached by only using 84.4% of the used inputs, if technical inefficiency is completely removed. Average scale efficiency, which can be calculated as the ratio between CRS and VRS efficiencies, is around 96.5%. This measure indicates that many WUAs are not operating at an efficient scale.

Table 2 - *Frequency distribution of overall efficiency for the studied sample.*

Efficiency level (%)	Overall VRS efficiency	
	N°. of WUAs	%
0<Eff<=25	0	0
25<Eff<=50	2	22.22
50<Eff<=75	3	33.33
75<Eff<=100	4	44.44
Average efficiency	84.4	
Scale efficiency	96.5	

On the other hand, results also show that inefficiencies of management and maintenance are larger than the overall inefficiency. The average management efficiency is around 80.6%, while the average engineering efficiency is 82.3%. Scale efficiencies of both sub-vectors are very low, indicating that nearly 25% of management and maintenance expenditure can be saved if WUAs operated at an efficient scale. The frequency distribution of the two efficiencies is reported in Figure 1.

Figure 1 - *The frequency distribution of efficiencies scores.*

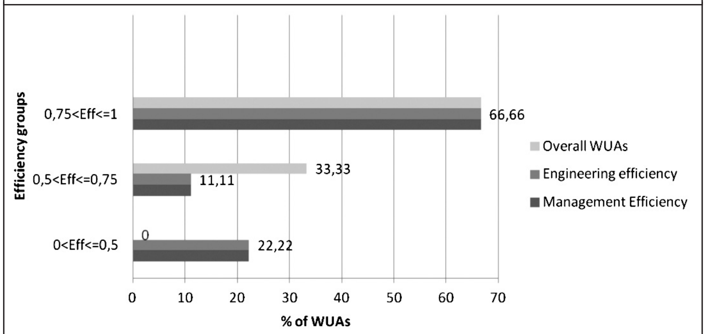

Figure 1 shows that nearly 22.22% of WUAs belong to the group of weak management efficiency (between [0; 50%]) while 33.3% of them belong to the second group (between [50%; 75%]) regarding the same criterion. In both groups we remark that inefficient WUAs in management are the same as inefficient WUAs in engineering tasks. 11.11% of WUAs are inefficient (between [0.5; 0.75%]) in management and maintenance. In the same perspective, 66.66% of WUAs belong to the groups of good efficiency [50%; 100%] regarding maintenance and engineering efficiency.

4.2. Factors affecting efficiency of WUAs

Regressions in Table 3 present the estimation results of factors affecting scale, overall WUAs, management efficiency and engineering efficiency scores, respectively.

As shown in Table 3, the regressions explain little of the variations in the calculated efficiency scores with the pseudo R-square value ranging from 0.334 to 0.545. Most of the independent variables have significant effect on efficiencies. Of the three "technical" characteristics used in this study, one has a significant effect on the scale efficiency. The number of the managed pumping stations has a significant negative effect on the efficiency of the Zeuss-Koutine. In addition, the number of years in function and the number of members in the governing board have a negative but not significant effect.

For the overall WUAs efficiency scores, only the number of years in function has a significant effect (1% level) on this efficiency. The other administrative characteristics (the number of water pumping stations and the number of members in the governing board) have a negative but not significant effect on the overall WUAs efficiencies.

Table 3 presents also 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 WUAs has a negative and statistically significant (1% level) effect on the regressed scores. In addition, management efficiency was found to be also negatively affected by the number of members in the governing board. Remaining independent variables had no significant effect on both dependent vectors.

Table3 - *Factors associated with efficiency scores: results of Tobit models.*

Explanatory variable	**Explained variable**							
	Scale Efficiency		Overall WUAs efficiency		Management efficiency		Engineering efficiency	
	Estimate	*P*-Value	Estimate	*P*-Value	Estimate	*P*-Value	Estimate	*P*-Value
Technical characteristics								
-N of water pumping stations	-0.003**	0.003	-0.004	0.647	-0.006	0.624	-0.011	0.356
- N of years in function	- 0.070	0.56	-0.068***	0.000	-0.073***	0.003	-0.074**	0.003
Administrative and organizational characteristics								
-N of members in the governing board	-0.011	0.297	-0.051	0.530	-0.121	0.290	-0.054	0.639
σ	0.022	0.040[1]	0.161	0.057	0.225	0.042	0.229	0.003
Pseudo R2	0.545		0.334		0.456		0.475	
Log-Likelihood	21.356		3.641		23.641		19.463	
N of observations	9		9		9		9	

***= significant at 1%.
[1] For σ the standard error is reported instead of the P-value.

5. Discussion and Concluding Remarks

The study used a DEA approach to measure the technical, management and engineering efficiencies for WUAs in Zeuss-Koutine region, south-eastern Tunisia. The Sub-vector Data Envelopment Analysis has been used for the first time to measure management and engineering efficiencies that express the performance of a given WUA in terms of allocating expenses for internal management and functioning activities and for maintenance tasks. The results for estimates of technical efficiency (TE) indicate that the estimated mean input-oriented technical efficiency under VRS specification ranges from a minimum of 48.4% to a maximum of 100% with the average estimate of 84.4%. The result means that a 14.6% decrease in all inputs is possible with present state technology and unchanged output, if technical inefficiency is completely removed.

The average scale efficiency obtained shows that WUAs are not operating at an optimal scale. This finding confirms inefficiencies due to the WUAs' size reported by Umetsu et al. (2005). However, Fujiie *et al.* (2005) in Frija *et al.* (2009) 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 just conclude that an adjustment of the scale could improve the global efficiency and the use of financial resources in Tunisian WUAs.

Thirdly, the calculated management and engineering sub-vector efficiency shows poor performance in terms of allocating expenses for internal management and functioning activities, but also in terms of allocating expenses for maintenance tasks. In fact, operation and maintenance are among the main WUA expenditures. However, despite the objective fixed by the government of fully covering rates of maintenance and operation costs, important losses in those financial tasks were assessed in the present study. This finding confirms sub-vector inefficiencies reported by Frija *et al.* (2008) in Cap Bon WUAs[2].

The Tobit regression analyses give some interesting findings. From the factors included in the scale efficiency regression that are significant, only the number of pumping stations managed in a given WUA has a negative impact. In fact, each pump is used by a group of farmers. According to our first field inspections, the timing of the pump use is always a source of conflict between farmers who want to irrigate at the same time. An increase in the pumps' number and the creation of sub-councils from farmers which are managing the same pump could be good factors of improving the global WUAs efficiency. Another important factor, which had a negative and statistically significant impact on overall and sub-vector efficiencies is the number of years in function for a given WUA. In contrast, older associations are expected to be more stable (Frija *et al.*, 2009). Nevertheless, this result can be interpreted in two ways. With time, the irrigation networks managed by the association will be older; therefore, their maintenance or renewal will be more expensive. For this reason, older WUAs spend more money especially for maintenance and management tasks. This can influence their global efficiency and lead to resource losses. Good network management and renewal strategies could be a solution for this kind of problems. However, in most cases the WUAs administration members or even the technical director are not well instructed persons. For them, elaborating a global optimal management plan is a difficult task. The help and guidance of the government will be needed in such cases. The second explanation of the negative impact of WUAs' "age" can be reported as a non-social sustainability between the members of the association. According to Meinzen-Dick *et al*. (1994) in Frija *et al*. (2009), 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 be unstable over time. For the Tunisian case, some specific studies (Makkaoui, 2006; Ben Salem *et al*., 2005; Chraga and Chemakh, 2003) report the existence of such conflicts and the weak social relationships between farmers and members in the Tunisian WUAs.

Finally, the number of members in the governing board of the WUAs had a negative and statistically significant impact on the scale efficiency. This suggests that a reduction of this number would improve the scale efficiency. This is opposite to the logical expectation that a higher number of administrative staff could improve the accountability and the governance of the WUA. We remark 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 WUAs 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.

This paper contributes to the rare studies on firm (organizations specialized in water management) level efficiency measurement and explanation using a DEA approach. The organizations studied were particularly complex for many reasons. In fact, objectives are multiple and different targets can be pursued, leading to bias in some annual stated inputs, which can be used in the DEA models.

Deeper analysis of the Tunisian WUAs should be undertaken in order to clarify some additional aspects of the structure and the functioning of WUA. Tests focusing on the scale efficiency are among the advances that can be done in order to see if it concerns increasing or decreasing returns to scale. Social qualities of the members of governing board are also important factors that should be more investigated in order to understand the negative effect of this variable on efficiencies. It will be necessary also to test the effect of the age of the irrigation network on the efficiency of the WUA. In fact, in some cases, the irrigation network exists before the creation of the WUA. A WUA charged to manage an old network will not be so efficient as another one which is charged to manage a new irrigation network.

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[2] The average management efficiency is around 65.7%, while average engineering efficiency is 74.5%.

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