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Coping with Water Scarcity in Private Irrigated Perimeters: Farmers' Adjustments in Southeastern Tunisia

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Abstract: Groundwater scarcity is a growing problem in Tunisia. Irrigation water is becoming an increasingly scarce resource for the agricultural sector in many regions. A common ground in past policy schemes was the development of adequate irrigation infrastructure to guarantee the supply of irrigation water as the demand for agricultural products was increasing. However, these expansionary policies have resulted in a massive use of irrigation water at a heavily subsidized cost and led to aquifer overexploitation. Groundwater scarcity has become an increasing social and economic concern for policy makers and private irrigated perimeters in south-eastern Tunisia. This research study analyzes the different methods adopted by farmers to cope with the groundwater crisis, social and economic factors that affect their choice of methods and the barriers to adaptation. For this research, a household survey and group discussions were undertaken. A total of 100 households were interviewed in Zeuss-Koutine region (South eastern Tunisia) and a logit model is used to analyse the determinants of farmers' choice of adaptation strategies. Two strategies were identified. First, strategies may be based on 'chasing' groundwater by deepening existing wells or by drilling other wells, so as to maintain a water-intensive farming system. Second, strategies that may be designated as adaptive, i.e., adapting the farming system to the water available on-farm given existing hydraulic infrastructures. Results from the discrete choice model employed indicate that the level of education, age, wealth of the head of household and social capital all influence farmers' choices. The major barriers include lack of information on adaptation methods and financial constraints.

Key words: Adaptation · Farm strategy · Groundwater · Scarcity · Tunisia

INTRODUCTION

Scarcity of natural resources and risks of climate change have made management of water resources a major concern worldwide, putting it at the forefront of policy-makers' agenda. In the Mediterranean area, Tunisia is a case in point, ranking in the category of countries least endowed with water resources. The latter are relatively low and their mobilization is quite advanced (90% in 2013) [1]. However, though these resources appeared sufficient not long time ago, or even abundant for agricultural development in arid areas, the current situation is not so reassuring. The profound changes occurred in the last forty years have resulted in marked and rapid developments, production systems and methods of operation and management of natural resources. Hence, we are witnessing the beginning of increased groundwater exploitation, development of irrigated crops and the rapid extension of arboriculture at the expense of pastoral areas, including the coastal zone related to transfers of land ownership. In this context, the spatial complementarity of agricultural systems has disappeared to make room for interconnected production systems whose dynamic is mainly expressed by a competition for access to natural resources, including groundwater resources in the southeast of Tunisia.

The rapid development of the use of groundwater for irrigation has enabled a significant agricultural growth. Nonetheless, such development has become unsustainable in many parts of the country, due to overexploitation of aquifers and inadequacy of instruments implemented and being considered to be used for unsustainable use of groundwater resources in irrigated areas.

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Despite the fact that several instruments appear promising, none of them has so far ensured a regain of balance between use and resource so as to achieve both objectives of an agricultural activity and use of sustainable groundwater resources. These instruments are not simple to design nor to implement and their effectiveness remain bound by the reproductive strategies that are sometimes complex and fragile for the irrigators [2; 3]. In the absence of specific policies, irrigators in several areas of southeast Tunisia are always obliged to invest in order to continue to have sufficient fresh water for their crops, or to change their cropping patterns to suit this water scarcity [4]. Farmers who have small family farms and who have limited financial capacity to dig ever deeper or leave to other regions to continue their agricultural activities are the most vulnerable to such unsustainable uses of water and soil. In the absence of a management of this unsustainable use, the differences between the farmers who have the means to invest ever so as to have enough water and those who need to adapt their activities to the shortage of water are on the rise. In this respect, few studies in Tunisia have focused on the study of adaptation strategies for the water shortage in the irrigation sector.

This study seeks to identify both the adaptations of strategies followed by irrigators and the most significant factors influencing the adoption of such strategies in private areas of the Governorate of Tataouine in the southeast of Tunisian through a statistical and econometric analysis.

This paper is organized in following way. Section two presents the methodological aspects, namely, clarifying the conceptual framework, presenting the study area, data collection used and the empirical and conceptual model. Section three is devoted to the descriptive analysis of the data and the results of the estimation of the logit model. The conclusion and directions are presented in section four.

MATERIAL AND METHODS

Conceptual Framework: A strategy is the sum of decisions made on the basis of hypotheses of behavior of people interested in a specific situation. With respect to agriculture, to have a strategy is to have the capacity to make coherent decisions in a context of uncertainty in terms of personal goals.

Therefore, a strategy is the set of decisions made by a farmer implementing the means and resources so as to achieve certain targeted objectives, while taking into account the external environment with its different constraints [2, 4].

Hence, adaptation appears to be more of a system state at any given time than of a continuous and dynamic process by which the system adapts [5]. With respect to the water sector, adaptation approaches implemented seek principally to anticipate and mitigate potential damage. In the agricultural sector, the adaptation will gradually adjust to the level of economic factors by changing both the agricultural practices (eg., by changing planting dates or by using more heat-tolerant varieties) and the production itself - with a probable move to other more favorable areas (freshwater). These individual actions of adaptation will, however, require public action, even if only to make them consistent with water management policies and land use [6].

The adoption of strategies of adaptations (new technologies) by farmers goes through four stages: awareness, interest, evaluation and, finally, adoption of Farmers is expected to compare the benefits and relevance of different strategies on the basis of the resources available and of their ability to profit [7] (Rogers and Shoemaker, 1971). The conceptual framework used in this work is the adoption of individual farm household model that focuses on identifying among farm managers the socio-personal, economic and institutional factors influencing their decision to adopt strategies for adaptations.

Study Area and Data Collection: Three private irrigated areas within the region of El Mouna, in the Delegation of Smar, in the region of El Ferch, in the Delegation of Ghomrassen and Bir Amir region, in the Delegation of Remada, constituted the fieldwork of our investigation (Figure 1). The total area of these irrigated perimeters is 1792 ha, with 68% of the total area is found in the Governorate of Tataouine. This is justified by the novelty of the irrigation activity[1] and by the profound changes experienced by the three delegations, which have resulted in an increased pressure on groundwater resources and overexploitation of aquifers and salinization of water and soil.

The agricultural activities practiced are mainly oriented toward fruit growing (olive trees) and market gardening [8-10]. The activity of livestock, being the main

[1] Within a few decades, the Governorate of Tataouine has grown from a small population agropastoral space to a space characterized notably by an arboreal grip and a very strong anthropic pressure increasingly strong marked by the creation and multiplication of irrigated perimeters (Jebahi, 2002).

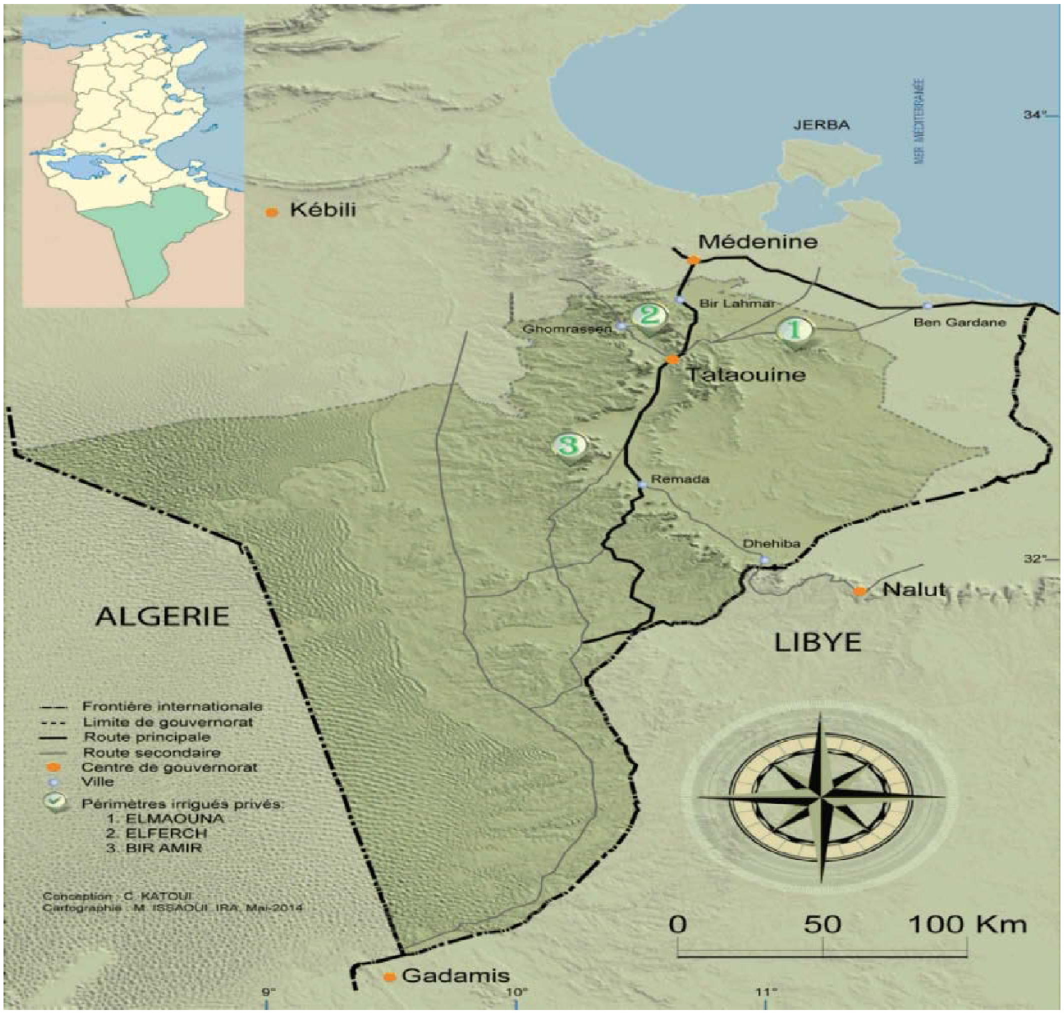

Fig. 1: Overview of the study area

source of income in the southeast region of Tunisian, is not sufficiently practiced in the irrigated areas. Generally, the irrigated perimeters of the studied area are still being operated with an operating rate of 49%. This reflects a lower increase rate of 60%.

Data collection was conducted through questionnaires and individual interviews. A total of 100 households were interviewed in Zeuss-Koutine region (South eastern Tunisia) under the three irrigation perimeters (Fig 1). The questionnaire is structured around three modules. The first module is primarily concerned with the socioeconomic identification of the operator and the household. The second module aims to identify all operating features and full technical details including agricultural labor, while the third module focuses on water component in the operation and the behavior of the operator (decision-making) in terms of adaptation strategies.

Empirical and Conceptual Model: In this study, we hypothesize that the socio-economic and technical variables influence the choice of an adaptation strategy to cope with the shortage of groundwater resources in southeast of Tunisia. One objective of our study has been to determine the behavior of farmers while dealing with water scarcity by identifying the factors that influence their uses or adaptations as a probability.

The choice of a strategy is a type of decision of "yes" or "no". It results in a dichotomous variable that takes two modes; "1" if the farmer chooses a strategy and zero if not.

The choice of a given strategy to cope with water scarcity is a type decision strategy of **yes** or **no**, which means that there should be a limited model of independent variable. Generally speaking then, it is to explain the occurrence or non-occurrence of an event. Given the qualitative and dichotomous nature of the explained variable in this study, namely the choice of an adaptation strategy, we have opted for a type of logit model, facilitating the manipulation of results [11], because, empirically speaking, analyzing the determinants of a farmer's use or adaptation of a strategy is based on a discrete choice model.

The dependent variable for the logit model is a binary variable that reflects the adoption of an adaptation strategy whether it is adaptive (defensive (S1)) or offensive ("chasing" of water (S2 and S3). Mathematically, it is presented by a random variable ***Y***: in our case ***Yi*** = 1 if there is adoption and ***Yi* = 0** if not.

For this dichotomous model, a logistic regression analysis using maximum likelihood was performed to test the effect of several explanatory factors on the probability of adoption of such a strategy by farmers. Mathematically, a logistic regression model is expressed as follows: Yi is a binary variable describing the adoption or non-adoption of such a strategy by a farmer i. We assume that Yi follows Bernouilli's law of pi probability, the value taken by the variable P for the farmer i [12]. We further assume that logit (P), that is, ln [P / (1-P)], is linearly related to the k variables X1, X2,..., Xki characterizing the farmers, using the following equation:

$$\log it\ (P) = \beta_0 + \beta_1 X_1 + ... + \beta_k X_k \quad (1)$$

where β0, β1,.. βk are unknown parameters to be estimated with data.

According to [12], the logit regression model characterizing the choice by an operator sample is specified as follows:

$$pi = E(yi) = F(\alpha + Xi\ \beta) = \frac{1}{\left[1 + e^{-(\alpha + x_i \beta_i)}\right]}$$

wherein the subscript "i" indicates the i^{th} observation in the sample, Pi is the probability that a given individual faces a given choice yi, e is the base of the natural logarithm, xi is a vector of exogenous variables, á is a constant and β i are coefficients associated with each explanatory variable Xi to estimate.

Explanatory Variables of the Adoption of Adaptation Strategies: The identification of explanatory variables of the adoption of innovations in the production processes is controversial. The choice of variables was based, along with the methodological requirements that meet the technical and economic characteristics of the study area, on a review of the economic literature dealing with similar issues [13-17] and on information obtained from the survey conducted in the study area. These variables that characterize the socio-economic situation of irrigators can be decisive in the choice of a coping strategy to the scarcity of groundwater resources in the Governorate of Tataouine. Table 1 shows all the main collected variables that explain the farmers' choices.

The adoption of an adaptation strategy whether it is adaptive (defensive) or offensive ("hunting"). This is the dependent variable that is influenced by socioeconomic factors. These strategies are followed by most farmers in order to adapt to water scarcity.

The Age of the Irrigator (AGE): This variable measured in years is also a proxy experience in irrigated crops. Less experienced producers are young. Young producers are willing to take more risk than older producers.

The Level of Education (LEV EDUC): This variable is a proxy of the managerial capacity of the irrigator. It also indicates the ability of the operator to dissect information on the economic environment and climate change. Educated producers have better abilities to apply and disseminate the instructions of vulgarization services. In addition, formal education positively determines farm income.

Table 1: Variables used in the model

Variable	Description of variables	Average	Standard deviation	Min	Max	N
ADOP	Adoption of a strategy (1 if one adopts and 0 if not)	0,64	0,48	0	1	65
AGE	Age of informant (years)	58,708	11,07	34	84	65
LEVEDUC	Level of education (1= secondary and more and 0 = other)	0,35	0,48	0	1	65
SIZFAM	Family size	6,63	2,69	1	15	65
IRRARE	Irrigable area	5,22	3,42	1	15	65
RG	Comprehensive income	18512	13900	3500	70000	65
PETITCOMM	Conducted off-farm activity is small business (1 = yes, 0 = no)	35,38	0,48	0	1	65
EXP	Years in Agriculture (the know-how)	23,55	14,88	2	78	65
PERCEPTION	(1= if the irrigator perceived well the risk of water shortage in their operations and 0 otherwise)	0,77	0,49	0	1	65

The Size of the Family (SIZ FAM): This variable is a proxy of the responsibility of the household head. Household head with extended responsibilities must develop more specific adaptive strategies for food and monetary needs of the household. This will promote increased production and thus revenue. Thus the predicted sign is positive.

The Irrigable Area (IRR ARE): This variable directs the possibility of increasing and reducing the irrigated area and, in addition, opens a field for diversification. It is also a proxy for the level of wealth of the farming operation.

The Expertise in Irrigated Crops (EXP): The number of years of experience in agriculture in the vulnerable areas allows farmers to have practical knowledge on agriculture and facilitates strategic direction. It is recognized that the number of years of experience positively influences the adoption of adaptation strategies.

The Perceived Risk of Water Scarcity (PERC): This variable is very crucial for the adoption of such a strategy, as the most knowledgeable farmers will tend to be innovative and adopt existing strategies. The more prone to water shortages farmers are, the more important the probability of adaptation is.

Off-farm Income (OFF INC): It is measured in Tunisian Dinar (DT). It is expected that this variable has a positive impact on the probability of adoption of adaptation strategies.

RESULTS AND DISCUSSION

Characteristics of Surveyed Farms: The demographic characteristics of heads of farms and their family groups greatly influence both the perception of scarcity of natural resources and the effects of the adoption of adaptation strategies and thereby determine its vulnerability or resilience. It is, therefore, useful to identify the farmers in the first place. In the private irrigated areas of the Delegation of Tataouine, the majority of the operators are aged. The average age is around 59 years old and the average household size is about 7 family members. The level of irrigators of instruction is low: nearly two thirds (64.6%) of them have a level below secondary education of whom 37% have no level.

Agriculture remains the main activity of the majority of populations. The average area cultivated by family farms is 5.22 ha, with a coefficient of variation of 65.65%, or deviations from 4.22 ha to 10.22 ha. Nearly three quarters (70%) of the surveyed informants have experience in the conduct of irrigated crops that does not exceed 30 years.

Irrigators who are aware of the problems of water scarcity (drawdown and salinity of water table) are numerous. They exceed an average of 60%. Therefore, the perception of water scarcity seems to have a positive influence on the adoption of adaptation strategies.

Throughout the study area, the bulk of farm income comes from agricultural activities (46.6%) and non-agricultural activities (53.4%). The contribution of livestock-related activities in generating income remains marginal (3%). At the delegation level, high emigration rates and income from non-agricultural activities dominate the others.

Diversified Adaptation Strategies to Cope with Water Scarcity: The results of the study show that farmers use several actions and management practices to adapt to water scarcity and saline water (Figure, Table 2). Among the developed actions, the annual cleaning and deepening of wells is the most cited by farmers, even if the utilization rate remains relatively average (33%). Secondly, bringing water from outside the farm (connection to the public water grid) is quoted for 23% of cases. Then resorting to saving water is cited by 17% of irrigators and ultimately, the reduction of the irrigated area is cited 7% against 13% who chose to do nothing for lack of financial means while waiting for the intervention of the public services in charge.

Three strategies were defined based on these types of action. Strategy S1 involves using only available water and existing pumping equipment and can be described as 'adaptive' vis-à-vis groundwater resources. Strategy S2 corresponds to actions only undertaken on the farm, either obtaining more water or reducing consumption. Strategy S3 consists in actively attempting to avoid changing the farming system by: (i) piping water in from other places; n (ii) renting or purchasing farmland in areas where water is still sufficient and not saline. This strategy may also involve increasing on-farm access and reducing water consumption in fields where fresh water could not be obtained in sufficient quantity. Farmers using strategy S2 may use actions related to strategy S1 and those using strategy S3 may also undertake actions related to the two latter strategies: in that sense, these strategies are 'nested' (Table 2). Strategies S2 and S3, which attempt to sustain groundwater use in order to limit changing cropping patterns, can be described as

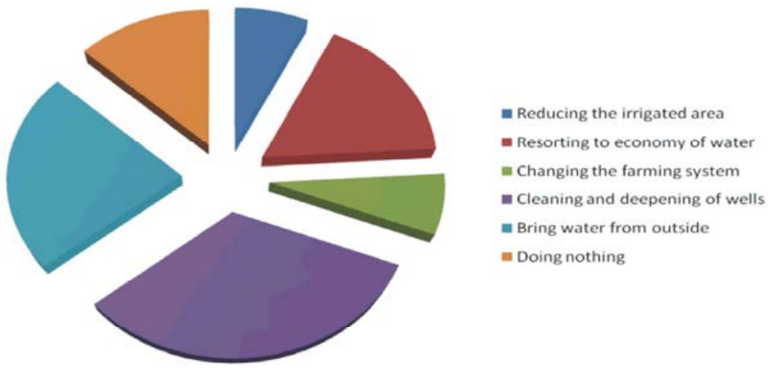

Fig. 2: Actions and practices addressing the challenge of water scarcity

Table 2: Main actions used by farmers

Action Type	Water scarcity problem	Water salinity problem	Adopted strategies
Draw water from outside the farm	-Connection to the public water grid. -Rental or purchase of agricultural land in areas where water is sufficient and unsalted.		**S3 :** strategy qualified as offensive or "hunting" of water.
Increase on -farm access	-Digging new wells or deepening of already existing ones. -Access to more than one resource of water (wells and public water grid)		**S2:** strategy qualified as offensive or "hunting" of water
Reduce on-farm water consumption	-Reduction of the irrigated area -Night irrigation. -Changing the farming system. -Economizing water.	-Changing the farming system. -Using more organic fertilizers.	**S1 :** strategy qualified as adaptive or defensive

'chasing' strategies vis-à-vis groundwater use (Bekkar *et al*., 2009). Farmers who adopt chasing strategies do not adapt their water use to the increasing groundwater stress, so such strategies may be considered as less sustainable, at resource level, than adaptive strategies where farmers adapt their water use to groundwater status (in terms of piezometric level or salinity rate).

Farmers who adopt strategy S2 can also make use of actions related to strategy S1 and those who use strategy S3 may also undertake actions related to strategies S1 and S2. These strategies are "nested"

In the El' Ferch area of the Delegation of Ghomrasen, offensive strategies have been adopted by farmers with areas that do not exceed 5 ha, with a considerable investment capacity (such as income emigrants, non-agricultural activities). Similar strategies have been observed in the region of El' Maouna of the Delegation of Smar; yet in this zone, offensive strategies have been implemented for most farmers who are interested in high-value added crops such as carrots and potatoes. The latter require large amounts of water and are irrigated by submersion.

Econometric Model: The *Logit* model was applied on a sample of 100 operating heads in the area of Tataouine. The estimating results are presented in Table 3 below. The dependent variable is the dichotomous variable reflecting whether an adaptive strategy in response to the lack of irrigation water is adopted or not. Generally, the results show that the estimated model is statistically valid. Indeed, the log-verisimilitude (64,69) is satisfactory and so is the chi-square model (X2 = 19.77), which is significant at 1%, showing thus a strong correlation between variables (R2 = 0.361 Pseudo).

Of all tested variables, there are generally three variables with significant influence on the probability of adoption of such a strategy of adaptation. These variables include: the irrigable area, experience and perception of scarcity.

In addition, the analysis of the sensitivity of the adoption probability with respect to the explanatory variables shows that certain variables have the highest marginal effects. Besides, certain variables affect the propensity for the adoption of the strategy in a positive way, while others affect it negatively.

Table 3: Determinants of adaptation strategies to water scarcity (Logit model).

Variable	Estimation	Odds Ratio	Standard deviation	Sig.
Constant	-1,165	1,002	2,184	0,594
AGE	0,002	0,845	0,029	0,954
IRRARE	-0,168	0,963	0,1	0,094**
EXP	0,038	1,000	0,022	0,080**
INCREV	0,00002189	1,199	0,0000239	0,06*
SIZFAM	0,182	1,002	0,130	0,161
PERC	2,631	13,886	0,788	0,001***
LEVEDUC	0,763	2,145	0,799	0,339
Number of observations			100	
Log-verisimilitude			64,69	
Pseudo R2			0,361	
Chi 2			19,77	
Prob			0,011	

Logit (y) = logit (0, 1). If y = 0: the farmer accepts no strategy; if y = 1: the farmer takes a coping strategy. *** *, ** represents the levels of significance of 1%, (5%) and 10% respectively.

The size of the irrigation area (IRRARE) has a significant effect on the probability of adoption of a strategy as much as 10%. However, the observed negative sign leads to the belief that the increase in irrigated area requires a set of heavy charges that drive the farmer to reduce his search for a greater supply of water and may have other possibilities of adaptation given by the orientation towards a rainfed agriculture (cereals and olives) to cope with the lack of irrigation water. In fact, the marginal change of an estimated coefficient unit is very intuitive. The exponential of these parameters, which is generally called side ratio (Odds Ratio), facilitates the interpretation of the influence of one variable on the probability of the dependent variable. To have the effect of the irrigable area, we proceed by the following formula: 1-**Odds ratio** = percentage of variation in the probability of adoption following the variation of 1% of the explanatory variable. The side ratio (odds ratio) shows that an increase in the irrigable area of 1 ha causes a decrease of 3.7% in the probability of adopting such a strategy.

The expertise of irrigators (EXP) significantly and positively influence as much as 10% the probability of adopting a given strategy to deal with water shortage. The more experienced farmers will tend to adopt more strategies than the less experienced. This shows that those who have more experience understand better the risks and challenges of water scarcity to their farm and are willing to take appropriate adaptation measures. They equally know better the importance of adopting a given strategy for the sustainability of their irrigated farm.

With as much as 5%, the extra agricultural income (INCREV) influences the probability to adopt offensive strategies to deal with water scarcity significantly and positively. Having other income generated by emigration is the main factor that has allowed these farmers to clean and dig new wells and drilling. Actually, migration is an important phenomenon in the region. Two thirds of farmers have family members abroad. Extra agricultural income can help farmers meet costs arising from the chosen strategy and cover the necessary capital costs.

The perception of water scarcity on the farming (PERC) has a highly significant influence, reaching as much as 1%, on the probability of adopting of a given strategy of adaptation. The perception reduces the risk of shortage and promotes the adoption of adaptation strategies

Finally, it should be noted that other a priori relevant variables in the model have no significant effect on the choice of strategies by farmers, although these variables are widely cited in the economic literature and influence significantly, whether positively or negatively, the choice of the adaptation strategy [18; 19; 11; 12] as determinants in the adoption process of adaptation strategies to water scarcity. These include the age of the irrigator (Age), educational level (LEVEDUC) and family size (SIZFAM).

CONCLUSION

In this article, we have studied and discussed the irrigators' behaviors and strategies while facing the scarcity of groundwater resources in southeast Tunisia. It analyzes how irrigators in irrigated perimeters in the Governorate of Tataouine have adapted to water shortage. It identifies the different types of adaptation observed and their socio-economic determinants. From a methodological point of view, the approach of a socioeconomic survey of 65 farms and the *Logit* model have allowed us, respectively, to identify the coping strategies adopted in response to water scarcity and highlight the significant variables that affect the strategy of farmers in the adoption of such a strategy.

The study of the farmers' behaviors while facing the scarcity of groundwater resources across private irrigated perimeters in the Governorate of Tataouine has helped to identify a set of strategies that can be qualified as adaptive or defensive (S1) and others which can be qualified as offensive or "hunting" of water (S2 and S3). Farmers who adopt such a strategy can also make use of actions related to another strategy.

The econometric estimation of the *Logit* model has allowed to identify the main factors for the adoption of such a strategy. In terms of estimated parameters, we generally find four (4) variables that have a significant influence on the probability of adoption. These variables include: the know-how of irrigation, the size of the farm, the off-farm income and the perceived risk of scarcity of water resources. Furthermore, the analysis of the sensitivity of the adoption probability relative to variables shows that some socioeconomic variables have the highest marginal effects. In addition, certain variables affect positively the propensity for the adoption of the strategy, while some others affect it negatively. Finally, it should be born in mind that other determinants related to the profitability of the investment, water pricing and technical training can encourage farmers to innovate or not in the irrigation systems. These aspects have not been addressed and may request additional studies.

This study is an important contribution to the issues of adaptation strategies of farmers to extreme climate indices. As such, the analysis and understanding of the irrigators' different adaptation strategies can help develop useful scientific analysis to different types of agents, so much for the awareness of the issues of adaptation to water scarcity than for the identification of adaptation options that are both realistic in terms of their implementation and ambitious in terms of their objectives. Similary, they can guide the adaptation strategies in the arid areas and effectively enhance the resilience of farmers to climate change.

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