IMPACT OF AGRICULTURE ON A TUNISIAN COASTAL AQUIFER AND POSSIBLE APPROACHES FOR A BETTER WATER MANAGEMENT

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ABSTRACT

The purpose of this study is to provide a better understanding of the impact of agricultural activities on groundwater quality in a semi-arid coastal environment, Korba, in Northern Tunisia which has significant agricultural activities, dependent on irrigation. Impacts have been assessed through the systematic collection of Groundwater samples were collected in this region and analysed for a range of physical and chemical parameters in order to describe the aquifer status. The results indicate that intensive irrigation, groundwater overexploitation, a high fertilizers use and wastewater treatment plant proximity have affected both the quantity and the quality of the groundwater as demonstrated by very high nitrate and salinity levels as well as a significant decrease in piezometric levels.

The effective mitigation of these nuisances requires the implementation of appropriate regulatory and economic instruments to foster sustainable practices in the agricultural sector. Through stakeholder involvement processes, issues related to the regulation and control of groundwater abstractions were analysed with the promotion of wastewater reuse, efficiency improvements in irrigation water use, as well as instruments to strengthen the socio-economic and institutional environment towards better managing and conserving available groundwater resources.

Keywords: Groundwater pollution; overexploitation; agricultural activity; economic instruments; Korba (Tunisia).

INTRODUCTION

Groundwater resources are threatened by pollution from industrial and urban waste, livestock breeding and crop cultivation activities. Agriculture contributes to

groundwater exploitation and increases the risk of quality degradation in shallow aquifers (Trabelsi et al [15]., 2004), particularly in coastal areas (Kouzana et al[7]., 2009). It also leads to a decrease in piezometric levels, sea water intrusion (Richer et al[13]., 1993), salinization of soils (Bear et al[2]., 1999), and seepage of nitrates, pesticides and fecaliae (Hudak [5], 2000; Nolan[10], 2001). The higher salinity levels of water used for irrigation increase the soils salinity and reduce land productivity, often resulting in the complete loss of agricultural land (Gaaloul et al[3]., 2003), whereas the high concentration of nitrates, which in some case exceeds 300 mg NO3/l, and the high levels of faecal contaminants render the water unsuitable for potable use and exacerbate health hazards.
The aim of this study is to assess the impact of agricultural activities in a coastal aquifer, the Korba region (Tunisia). Impacts are assessed through the monitoring of the levels of salinity, chlorides, sodium, potassium, calcium, magnesium, nitrate and heavy metals and also of the bacteriological parameters in 18 shallow wells and piezometers through the studied area. Furthermore, this study presents the results of a participatory exercise undertaken within the framework of the EC-funded INECO project ("Institutional and Economic Instruments for Sustainable Water Management in the Mediterranean Region", Contract No: INCO-CT-2006-517673), aimed at identifying, jointly with local stakeholders, policy instruments and pathways for mitigating groundwater overexploitation.

2. THE STUDY AREA

This study is carried out in the Korba coastal aquifer, located in the Cap-Bon peninsula at the north-eastern part of Tunisia, the climate of the region is characterised as semi-arid, with a mean annual precipitation of 400 mm. The aquifer system of the eastern coast is formed by two directly superimposed aquifers, a phreatic groundwater table whose rate of replenishment is estimated at 50 MCM/yr and a deep aquifer, with a replenishment rate of about 11.1 MCM/yr, formed by the detrital deposits of the oligo-mio-plio quaternary with a total surface of 1400 km2. The groundwater contained in these quaternary formations is the most important of the region of Cap-Bon (north-eastern Tunisia), corresponding to more than 90% of the available groundwater resources.

The main economic activities comprise tourism and irrigated agriculture with some agro-industries. The total population is 100,000 inhabitants (Paniconi et al[12]., 2000). Agriculture dominates the economic life of the Korba region, defining its unique character. Field crops are the most important cultivations, particularly tomatoes and peppers. Furthermore, the area is one of the most important winter suppliers of fresh vegetables and fruits to the Tunis metropolitan area.

The type of fertilizers and pesticides used in the study area were determined through interviews with local farmers. Overall, three types of fertilizers are used: organic, mineral and mixed (both organic and mineral). Nitrogen fertilizers affect both the volume of production in the harvest season and the length of the cultivation period, through their effect on plant growth.

Pesticides are used as preventive or curative means of pest infestation control, in order to protect crops from damage. Their massive use in the Korba area has disturbed the local ecosystem, and increased pest resistance, which results to even more extensive pesticide use.

3. SAMPLING, PREPARATION AND ANALYSIS METHODS

Groundwater samples were obtained from the shallow aquifer on August 2008 from 12 piezometers (P and PZ) and 5 shallow (SW) , the location of these points were chosen by the local "Regional Centrer for Agricultural Development (CRDA)" prior to this study, in order to allow the control of groundwater quality in this region, that is the purpose of this study. The average sampling depth was 15m, and a GPS was used to determine the exact location of each sampling point (Figure 1).

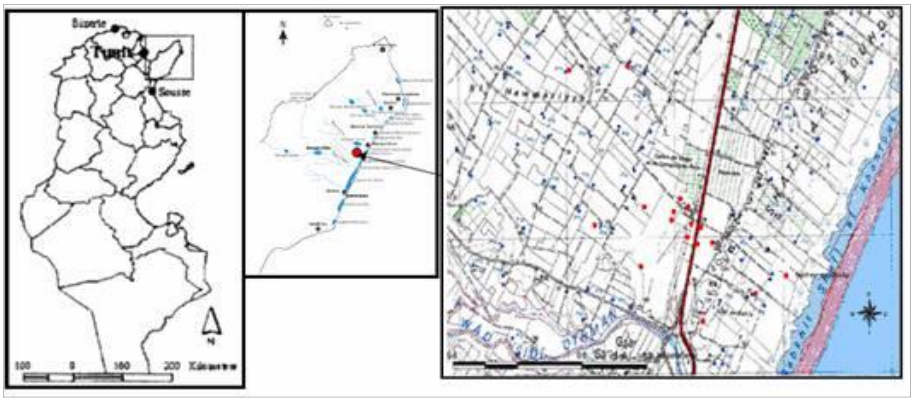

Figure 1. Location of the study area and sampling points (red dots)

Chemical, physico-chemical and microbiological analyses were performed at the laboratories of the International Center for Environmental Technologies of Tunis (CITET), according to ISO and NF standards (El Ayni et al [4]., 2011). Cations and heavy metals were analyzed by Perkin Elmer Inductively Coupled Plasma spectrometer optima 3300 ICP AES. Nitrates, chlorides, sulphates and bromides were analyzed using Dionex ionic chromatograph.

4. RESULTS

Piezometric level decline

The plio-quaternary aquifer of the Eastern coast experienced a piezometric decline as its exploitation was intensified. This aggravation is linked to the development and the deepening of the wells, as well as to the increase of extracted volumes due to their connection to the electricity network. The piezometric surface of the plio-quaternary aquifer in 2006 has particularly decreased when compared to that of 1993 as the piezometric level was between - 5m NGT and reached -10 m NGT between the cities of Korba and Tafelloune (Figure 2 and 3). This leaded to seawater intrusion also depriving the plio-quaternary aquifer of potential recharge with sub-soil water.

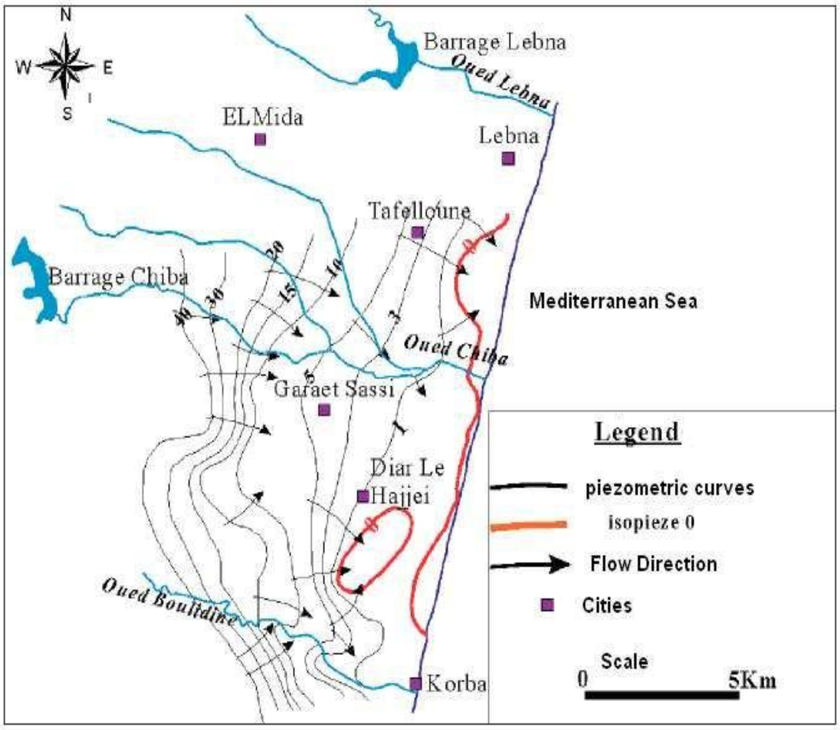

Figure 2. Piezometric map of Korba region in 1993 (Kouzana et al[6], 2007)

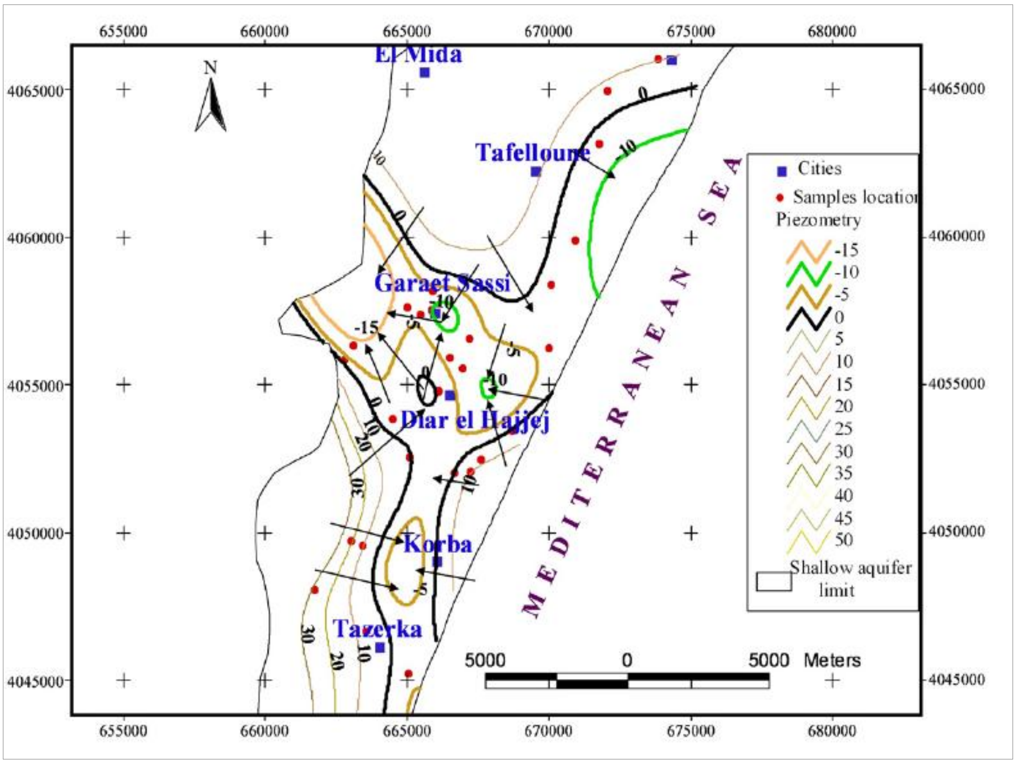

Figure 3. Piezometric map of Korba region in 2006 (Kouzana et al[7] 2009).

Analysis of groundwater samples

Salinity varies significantly, between 0.1 and 10.4 g/L, and is considered high for the majority of samples. The pH is around 7.00 for 65% of samples, whereas 35% of samples are alkaline. A comparison between the Electrical Conductivity results (Table 1) and thresholds (Table 2) leads to the conclusion that almost 50% of samples are saline, with 18% classified as strongly saline and 6% as extremely saline. The use of these saline waters for irrigation purposes would result in a reduction of crop yield for many crops. The 24% of samples that are classified as slightly saline are unsuitable for irrigation of sensitive crops.

Table 1. Physicochemical parameters of analysed groundwater samples. Piezometers (P and PZ), Shallow Water (SW)

Sample	Salinity ($g\ L^{-1}$)	Electrical Conductivity ($dS\ m^{-1}$)	pH
P 1	5.9	10.6	7.43 at 17.4 ºC
P 2	2.1	4.17	7.81 at 17.3 ºC
P 3	10.4	17.4	7.70 at 17.3 ºC
P 4	6.6	11.4	7.11 at 20.2ºC
P 5	<0.10	0.44	8.07 at 20.5ºC
P 7	0.10	0.69	8.85 at 18.3ºC
P 8	1.2	2.50	8.00 at 17.5ºC
P 9	<0.10	0.36	10.0 at 16.9ºC
PZ 15	0.2	0.92	8.72 at 18.1ºC
P 1186	1.9	3.78	8.41 at 19.3ºC
P 207	2.9	5.37	7.15 at 16.8ºC
P IRH	1.9	3.71	7.26 at 19.2ºC
SW 52	0.6	1.56	7.59 at 20.2ºC
SW 62	1.2	2.51	7.51 at 18.7ºC
SW 35	6.0	10.5	7.05 at 19.2ºC
SW 9	3.7	6.82	6.98 at 16.9ºC
SW SS4	3.2	5.98	6.94 at 17.2ºC

Table 2. Impact of irrigation water salinity on crop yields (Mulla [9]**, 2008). Electrical Conductivity (EC)**

EC(dS /m)	Classification	Reduction in crop yields
0-2	Non-saline	None
2-4	Slightly saline	For sensitive crops
4-8	Saline	For many crops
8-16	Strongly saline	None in tolerant crops
>16	Extremely saline	For most crops

The measured concentrations of nutrients (Table 3) demonstrate that nitrate levels are very high in the majority of samples, varying between 13.6 mg NO3/L to 332 mg NO3/L. Such results are attributed to the excessive use of fertilisers. Potassium concentrations are also high, reaching levels as high as 77.8 mg/L. The low concentrations measured for phosphorus are attributed to soil and sediment absorption.

Table 3. Nutrient concentrations

Sample	Nitrates (mg L^{-1})	Phosphorus (mg L^{-1})	Potassium (mg L^{-1})
P 1	114	0.06	48.8
P 2	185	<0.05	27.4
P 3	66.8	0.10	77.8
P 4	306	0.38	15.5
P 5	13.6	0.12	18.2
P 7	21.6	0.26	12.8
P 8	132	0.10	10.6
P 9	7.45	0.09	18.8
PZ 15	24.6	<0.05	20.1
P 1186	36.0	0.15	54.0
P 207	112	0.29	48.8
P IRH	70.5	0.09	19.7
SW 52	52.8	0.09	6.10
SW 62	42.6	0.14	7.49
SW 35	192	0.08	14.6
SW 9	225	<0.05	9.10
SW SS4	332	0.15	10.2

The results of heavy metals concentrations measurements indicate that water samples from the piezometers and shallow wells do not contain significant amounts of them. All values are below the ICP detection limits, except in the one sample (P1) where aluminium and iron concentrations are respectively 3.45 and 0.279 mg L-1, at these levels there is no toxicity risk.

Irrigation water quality is determined by the concentration of Na+ in relation to other cations, quantified through the Sodium Adsorption Ratio (SAR). When present in high levels, sodium can induce alterations in soil characteristics, enhancing the risk of soil structure degradation, and restrict the choice of crops (Leal et al [8]., 2009). Indeed, high sodium concentrations affect the permeability of soils and cause infiltration problems. This is because sodium, when present in the soil in an exchangeable form, replaces calcium and magnesium adsorbed on the soil clays and causes dispersion of soil particles. When calcium and magnesium are the predominant cations adsorbed on the soil exchange complex, the soil tends to be easily cultivated and has a permeable and granular structure. This dispersion results in the breakdown of soil aggregates. The soil becomes hard and compact when dry, and infiltration rates of water and air into the soil are reduced, affecting its structure. The problem is also related to several other factors, such as salinity and soil type. For example, sandy soils may not be damaged as easily as other heavier soils when irrigated with high SAR water. High sodium concentrations become a problem when infiltration is reduced to such a rate that the crop does not have enough water available or when the hydraulic conductivity of the soil profile is too low to provide adequate drainage.

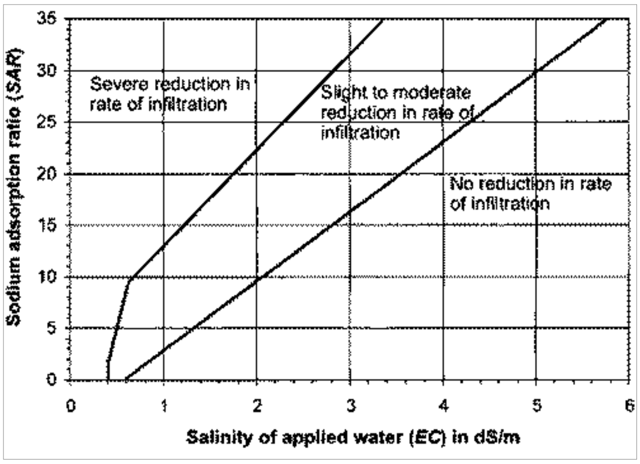

Figure 4. Relative rate of water infiltration as affected by salinity and sodium adsorption ratio (adapted from Rhoades [14] **1977; Oster and Schroer**[11]**, 1979)**

As depicted in Figure 4, for extremely low salinity irrigation water, even low SAR water should be avoided, whereas high salinity water with SAR above 4 needs to be carefully managed. The higher the salinity, the higher the SAR index which can cause infiltration problems. On the other hand, the lower the salinity, the greater the risk of infiltration problems, independently of the SAR value.

Relevant results for the analysed samples are presented in Table 4: 47% of samples present a SAR value higher than 9, which can have a significant impact on soils, whereas results for the remaining 53% (SAR values between 3 and 9) call for increased attention with regard to the use of irrigation water for sensitive crops and possibly indicate the use of gypsum to improve quality. Comparing results to the thresholds presented in Figure 4 and the relevant analyses by (Ayers and Westcot [1]; 1989), it can be further concluded that for most cases a none- to-moderate reduction of infiltration can be expected. An exception is recorded for water from one piezometer (P 5), where a severe reduction of infiltration can be expected, should the water be used for irrigation purposes.

Table 4. Anions and cations concentrations. Sodium Adsorption Ratio (SAR), Calcium (Ca), Magnesium (Mg), Sodium (Na), Electrical Conductivity (EC), * according to Ayers and Westcot [1]; (1989).

	Ca (mg L-1)	**Mg (mg L-1)**	**Na (mg L-1)**	**SAR**	***EC (dS m^{-1})***	**Reduction in Infiltration rate***
P 1	331	123	1400	14.9	10.6	**None**
P 2	160	57.8	578	10.0	4.17	**None**
P 3	395	319	2980	27.0	17.4	**None**
P 4	578	199	1850	16.9	11.4	**None**
P 5	17.5	1.69	95.2	5.8	0.44	**Severe**
P 7	16.5	9.92	96.1	4.6	0.69	**Moderate**
P 8	152	8.4	318	6.8	2.50	**None**
P 9	5.23	1.72	50.1	4.9	0.36	**Severe**
PZ 15	54.6	1.74	43.5	5.7	0.92	**Moderate**
P 1186	59.9	30.5	520	13.6	3.78	**None**
P 207	83	75.4	1024	19.6	5.37	**None**
P IRH	221	5.84	524	9.50	3.71	**None**
SW 52	117	24.6	167	3.70	1.56	**None**
SW 62	173	251	363	6.20	2.51	**None**
SW 35	769	301	1700	14.8	10.5	**None**
SW 9	460	124	700	7.50	6.82	**None**
SW SS4	463	118	682	7.30	5.98	**None**

Microbiological parameters were monitored in three locations and relevant results are presented in Table 5. In all three waters there is a substantial contamination with streptococci and coliforms (faecal coliforms, total coliforms, Escherichia Coli) but not with salmonella. Such contamination can be attributed to different pollution sources, such as animal breeding, which is an important activity in the area, as well as to sludge drying processes in the local wastewater treatment plant. As a result of this analysis, some concerns arise with regard to health risks from the use of these waters for irrigation purposes, and from its accidental use as drinking water.

Table 5. Microbiological parameters

	Streptococcus (/100 mL)	**Faecal Coliforms (/100 mL)**	**Total Coliforms (/100 mL)**	**E Coli (/100 mL)**	**Salmonella (/100 mL)**
P 3	$0.92\ 10^{2}$	$1.1\ 10^{4}$	$1.1\ 10^{4}$	$1.1\ 10^{4}$	absence
P 4	$1.1\ 10^{4}$	$0.1\ 10^{4}$	$1.1\ 10^{4}$	$1.5\ 10^{3}$	absence
P 207	$9.3\ 10^{2}$	$1.1\ 10^{4}$	$>1.1\ 10^{4}$	$3.5\ 10^{2}$	absence

5. DEFINING INSTITUTIONAL AND ECONOMIC INSTRUMENTS FOR MITIGATING GROUNDWATER OVEREXPLOITATION ISSUES

Within INECO in framework of the EC-FP6 INECO Project ("Institutional and Economic Instruments for Sustainable Water Management in the Mediterranean Region", Contract No: INCO-CT-2006-517673), which focused on issues relating to groundwater overexploitation at the national level and in the Nabeul Governorate (Tunisia), stakeholder engagement was promoted through the application of the Objective Oriented Project Planning (OOPP) methodology. The methodology, which is based on the Logical Framework Approach, is broadly divided into three stages:

1. **Problem Analysis,** which involved the mapping of main water management issues, constraints and opportunities, as identified by key stakeholders, and the definition of a key (focal) water management issue in the Cap-Bon area which, in this case, concerned groundwater overexploitation. In addition, this stage included the identification and analysis of cause and effect relationships between threats and root causes of the selected focal water management problem;
2. **Objective Definition,** including the identification of policy objectives, on the basis of the agreed root causes, the evaluation of their feasibility and the analysis of the relevant means-to-end relationships;
3. **Option analysis,** which concerns the identification of different options that can contribute to the achievement of the agreed objectives. Options are subsequently evaluated to identify appropriate pathways for problem mitigation.

Stage 1: Analysis of the focal problem of "Groundwater overexploitation"

Its primary aim was to further discuss the problem with the local stakeholders, through the development of a "Problem Tree", qualitatively describing the causes and effects of the problem (Figure 5).

According to the qualitative "Problem Tree" analysis, groundwater depletion is on the one hand caused by limited recharge and on the other by the overexploitation (abstractions exceeding natural replenishment) of aquifers. Overexploitation can be attributed to the operation of illegal boreholes, mostly drilled by farmers for irrigation purposes and to the lack of control over the operation of private boreholes. Abstractions are not metered, mostly due to social and political pressures by the affected user groups. Furthermore, the low efficiency in irrigation water use, resulting from the limited application of water saving techniques, the adoption of water intensive cropping patterns and the limited technical capacity of farmers exacerbates the problem. Incentives in using alternative non-conventional resources (treated wastewater) are considered inadequate, and the application of water reuse remains limited. Main reasons include the low quality of treated effluents, adopted standards, climate, soil types, choice of crops, land-use patterns, and especially farmers' unwillingness to accept and pay for treated wastewater and public perception issues. Aquifer recharge is still at the experimental stage, and results are encouraging. However, outside the public irrigation schemes, awareness campaigns to promote water reuse and water conservation have not yet managed to adequately address the concerns of end-users, and application remains limited in spite of the governmental subsidies offered. In the long run, it is expected that aquifer overexploitation will have negative impacts on the environment, on agricultural income and on the development of rural areas.

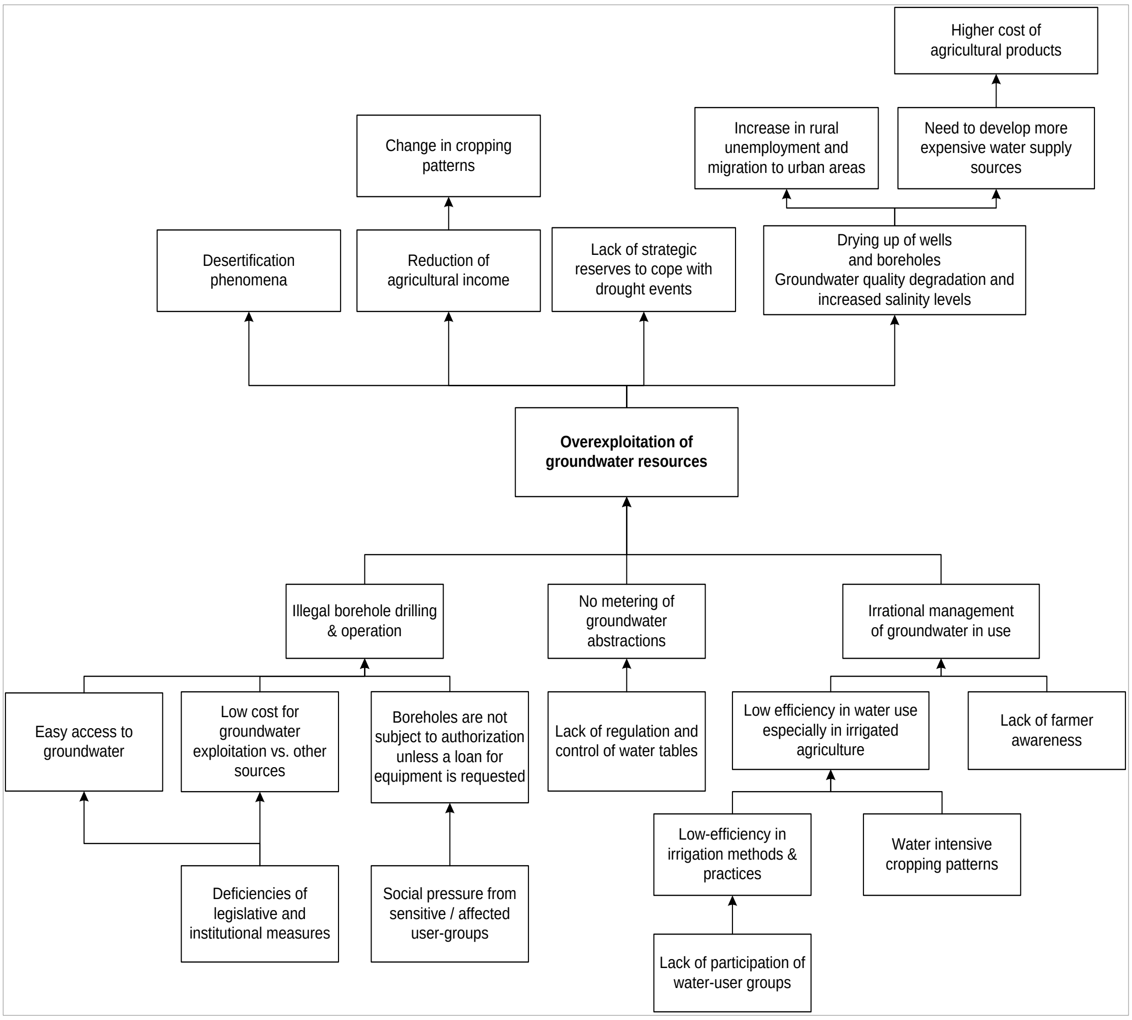

Figure 5. Problem tree analysis of the causes and effects of groundwater overexploitation in the Cap-Bon area

Stage 2: Definition of objectives for problem mitigation

The main goal of "Achieving regulated and rational use of groundwater resources", incorporating the views and goals of all stakeholders. Through this process, the following key objectives are identified:

- Control and regulation of borehole drilling and of groundwater abstractions, particularly outside public irrigation schemes, encompassing also enhancement of the use of alternative water supply sources to substitute groundwater in sensitive areas;
- Promotion of efficient groundwater use, linked to enhanced efficiency in irrigation water use and change of cropping patterns.
- Furthermore, and as all the consulted parties supported (a) the introduction of treated wastewater, as means for substituting freshwater use for crop irrigation,

(b) the participative management of water tables, suggested options were also oriented towards the promotion of reuse in irrigated agriculture and the reinforcement of end-user participation in decision-making.

Stage 3: Identification and evaluation of options for mitigating groundwater overexploitation

The first step towards the evaluation of potential instruments responses was their prioritization by local stakeholders. This was implemented through a first survey, aimed at evaluating the feasibility and applicability of suggested options, taking into account the local and the national water management context, current conditions and priorities, and future challenges facing the water sector. The step was implemented from February to June 2008, and involved the ranking of ten (10) broad categories of instruments. In total, 64 stakeholders participated responded to the questionnaire. The outcomes are summarized in the spider chart of Figure 6.

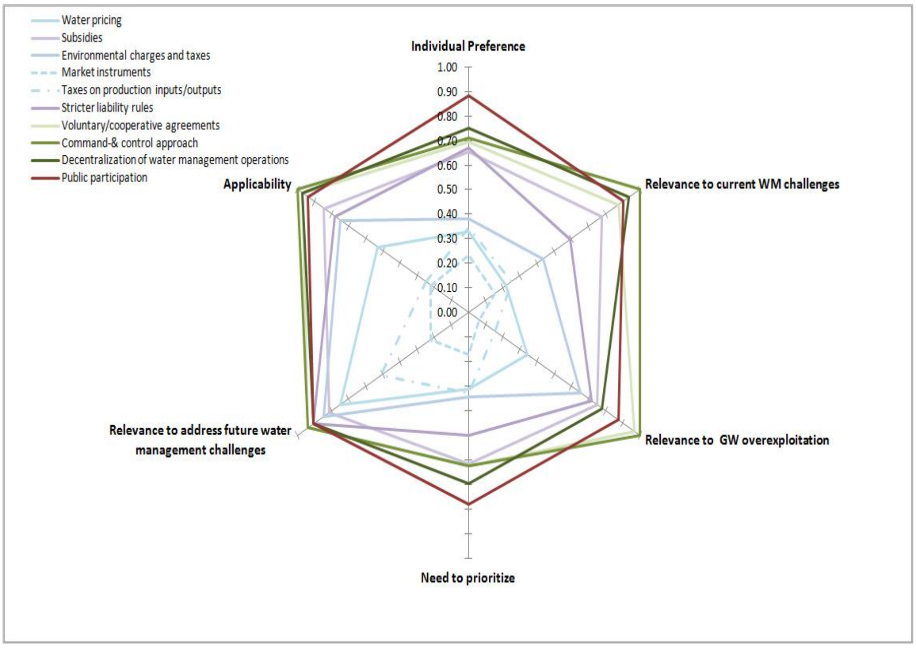

Figure 6: Prioritization of instruments for addressing current and future water management challenges

Instruments and approaches that seemed to be most relevant and applicable comprise public participation in combination with decentralization of irrigation water management and enhancement of regulatory approaches (stricter liability rules and command-and-control policy approaches). Water pricing, as well as measures that could impose additional economic burden on water users are not favoured when compared to other softer approaches; it can be thus be argued that socio-economic considerations and broader agricultural policy goals are reflected both in the perceptions of the different water user groups, and of secondary stakeholders dealing with everyday water management issues.

The overall process of evaluating potential responses was complemented through a last step, implemented through a survey for evaluating perceptions on potential policy pathways, The main results are discussed in the following paragraphs and pertain to the analysis of issues relating to: (a) water conservation in irrigated agriculture, (b) ways of incentivizing water saving and changing demand patterns, (c) means for regulating groundwater abstractions, , and (d) ways of enabling public participation and involvement in decision-making.

Water conservation in irrigated agriculture

Promoting water conservation in the agricultural sector are of primary importance. The main issues of concern that were examined in the last evaluation step were related to the enhancement of efficiency in water use, the adaptation of crop choices to water availability, the promotion of a more efficient way of sharing water among the different water users and the equitability of tradable water use rights.

Incentives for water saving – Change of demand patterns

Although it seems to be generally believed that margins to reduce water use in agriculture are limited, further investigation was undertaken as to ways of providing additional incentives for the adoption of improved water use practices. These could entail the enhanced application of volumetric charges and the development of financing mechanisms to provide aid to those who decide to invest in new technologies.

Regulation of groundwater abstractions

The effective implementation of command-and-control regulatory approaches for individual groundwater abstractions is being advocated as a priority solution for addressing groundwater overexploitation. Views concerning the stricter enforcement of regulations were analysed, particularly with regard to the: (a) feasibility, applicability and effectiveness of controls over water abstractions, especially in the case of private boreholes and wells; (b) the empowerment and political willingness of the State to strictly enforce the pertinent legislation; (c) compensation for environmental damage through the setting of relevant environmental taxes and charges, and ways through which these charges could be defined; and (d) the development of collective schemes for irrigation water supply, so as to prevent individual abstraction, and ways through which the costs for the development of such systems should be recovered.

Public involvement and participation

Enhanced involvement of stakeholders and water users, especially farmers, in decision-making is identified as a key priority in the effort for the protection of groundwater bodies and enhancing the efficiency of agricultural practices. Stakeholder perceptions on how user involvement and public participation should be pursued are diverse, based on the common view that current efforts need to be strengthened. Approaches range from enhancing the involvement of the general public and water users, to the strengthening of the role of NGOs for pursuing inclusive processes, and to awareness campaigning and reinforcement of civic responsibility.

6. CONCLUDING REMARKS

The analysis of the groundwater quality around the korba region has demonstrated a high contamination with nitrates, derived from agricultural activities and high bacteria levels. In the other side, the quality of groundwater has demonstrated an excess in dissolved salts in irrigation waters due to the overexploitation of the aquifer

and sea water intrusion. This water bad quality became the major problem of farmers in this region and some of them claimed that they were forced to change their agricultural crops to others tolerant to high salt levels, sometimes, they even abandon their lands.
Results from stakeholder consultation and workshops in the framework of the INECO project support a set of main options identified by the project, including approaches for regulation and control of groundwater abstractions, promotion of water reuse, efficiency improvements in irrigation water use and also the strengthening of the overall socio-economic and institutional environment. Answers indicate strong support for measures related to water saving, and particularly towards improving efficiency in irrigation, including the encouragement of different cropping choices by the State, the provision of incentives for water saving, and the adoption of water efficiency standards. Emphasis is also placed on the pricing of water services, supporting the mandatory connection of water users to collective systems that prevent individual abstractions, while charging these connections at partially socialized cost in order to maintain affordability and acceptability. Furthermore, there is some implied support to the generation of cross-subsidies among different water users.
Concerning public involvement and participation, responses indicate that public participation is currently insufficient but very much desired. It is also clearly evident that access to information is considered inadequate by the majority of stakeholders questioned, and that the accessibility and relevance of available information need to be improved. However, there is also a strong preference towards the enhancement of command and control regulatory measures, as well as the introduction and strict enforcement of legislation.

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