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# Agricultural Use of Groundwater and Management Initiatives in the Maghreb: Challenges and Opportunities for Sustainable Aquifer Exploitation

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# Agricultural Use of Groundwater and Management Initiatives in the Maghreb:

## Challenges and Opportunities for Sustainable Aquifer Exploitation[1]

## Summary

The intensive use of natural resources in the Maghreb, in particular by the agricultural sector, is creating an urgent need to design governance mechanisms at both the local and national level. Groundwater has become one of the most fragile of these resources. The rapid development of groundwater use for irrigation in the Maghreb has resulted in significant agricultural growth, but in many regions, such development has become unsustainable because of aquifer overexploitation or water and soil salinization. Adequate instruments to address this unsustainable use are not easy to design and implement, for there are many informal groundwater withdrawals by farmers, and water resource management organizations have limited intervention capacity. The paper examines groundwater use and management in Morocco, Algeria and Tunisia based on a study of national institutional and policy mechanisms and nine (9) local case studies. Overexploitation creates environmental, economic and social risks, and there are already significant identifiable impacts in several of the case studies. Farmers address the problem of decreasing borehole flow-rates (or water salinization) either by constantly investing more in order to continue to have sufficient quantities of fresh water for their crops, or by adjusting their cropping systems to adapt to this decrease. In the absence of specific policies, there are increasing differences between those farms that have the resources to continue investing more in order to have sufficient water, and those that have to adapt their crops to the shortage. Legal frameworks have laid management foundations, but they only have a limited impact, in particular, because of the generally informal nature of such uses. Different strategies are currently being discussed at national level, and are often focused on contractual approaches with the farmers. Concomitantly, some collective initiatives have

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been conceived at local level. The range of policies implemented to address this unsustainable use is very broad-based, and entails both increased water resources and the adoption of instruments to limit increases in withdrawals. These instruments are based on control and incentive mechanisms. In the cases considered, jointly used instruments have made it possible to limit increases in withdrawals and to facilitate water enhancement, without, however, restoring the resource-use balance. The design and implementation of strategies for sustainable aquifer exploitation require the building of coalitions of actors, which should include organizations responsible for water resources, those involved in agriculture, but also - and especially - farmers. Support could be provided to the formation of such coalitions and to their reflections on possible options to assist an agricultural economy based on sustainable aquifer use.

## 1. Introduction

The growth of the agricultural sector in the Maghreb has increased the pressure on natural resources such as water, soil and forests. Innovative governance mechanisms will be required to address the overexploitation of these resources. These governance mechanisms are increasingly less frequently designed and coordinated at the national level alone, but have become more focused on the local level. Groundwater is one of the resources that has been made fragile as a result of agricultural development. Indeed, for about sixty years, the dissemination of borehole drilling and pumping methods has led to the rapid development of ground water use for irrigation in the Maghreb. These countries have become one of the world's main regions for the intensive use of groundwater for agriculture (Siebert, 2010). This revolution, 'silent' - because it is often carried out informally by farmers outside the scope of public policies (Llamas, 2008) - has created significant agricultural growth.

However, such development has created extremely strong pressure on water resources. In North Africa, the renewable groundwater resource mobilization rate (withdrawal-to-recharge ratio) is high (Bzioui, 2005). The average groundwater exploitation rate in Northern Algeria is 80%. The estimated number of aquifers in Tunisia is 273, 71 of which are overexploited at an average rate of 146% (TICET, 2009). Overexploitation has also been noted for most of the large aquifers in North Africa, such as the Souss, Tadla, Berrechid and Saïss aquifers in Morocco, those of Bas-Cheliff, on the Mascara Plain and Mostaganem Plateau in Algeria, and the Sisseb el Alem aquifer in Tunisia (Bahir and Mennani, 2002; Boudjadja et al., 2003; Loucif, 2003). These imbalances will become more pronounced in the future according to climate change model predictions. In addition to the predicted rise in temperatures, which will create higher evapotranspiration, rainfall in the Mediterranean area is expected to decrease (Christensen et al., 2007). This could reduce aquifer recharge and increase farmers' use of these aquifers to compensate for the widening imbalance between evapotranspiration and precipitation.

In an increasing number of regions, such agricultural development becomes unsustainable due to aquifer overexploitation but also soil salinization, when groundwater is or becomes salty. The impacts of this unsustainable exploitation are becoming visible in either soil salinization in Bas-Cheliff in Algeria or the sharp decline in irrigated agriculture in coastal Chaouia in Morocco. Moreover, irrigation using groundwater is often carried out in the case of intensive farming, which is demanding in terms of inputs and creates a risk of groundwater contamination by nitrogen fertilizers.

Small family farms with limited capacity to drill deeper or to continue their activity in other regions, are most vulnerable to such unsustainable soil and water uses. In the absence of any management of this unsustainable use, the entire local agricultural economy has become fragilized with cascade effects on rural development, agricultural sub-sectors and, ultimately, the food security of the countries concerned.

In the countries where: (i) the organizations responsible for groundwater resource management have significant financial and human resources; and (ii) groundwater users are officially registered with these organizations, different approaches have been tested to tackle aquifer overexploitation. In these countries, the legislative framework and institutional resources have made it possible to design and implement joint strategies to control farming practices in order to ensure the viability of such uses. These approaches have often turned to standard Integrated Water Resource Management instruments such as pricing and quotas (Montginoul and Lenouvel, 2009). Such an approach is also enshrined in the European Water Framework Directive. In France, in particular, this approach is implemented through groundwater contracts or under Water Development and Management schemes at aquifer level. This is the case on the Beauce Plain, where every farmer has a multi-year quota (Petit, 2009). These approaches are based on the capacity to control and measure users' groundwater withdrawals. Such contractual approaches have also been applied to the diffused pollution of the aquifers (Barbier and Chia, 2001).

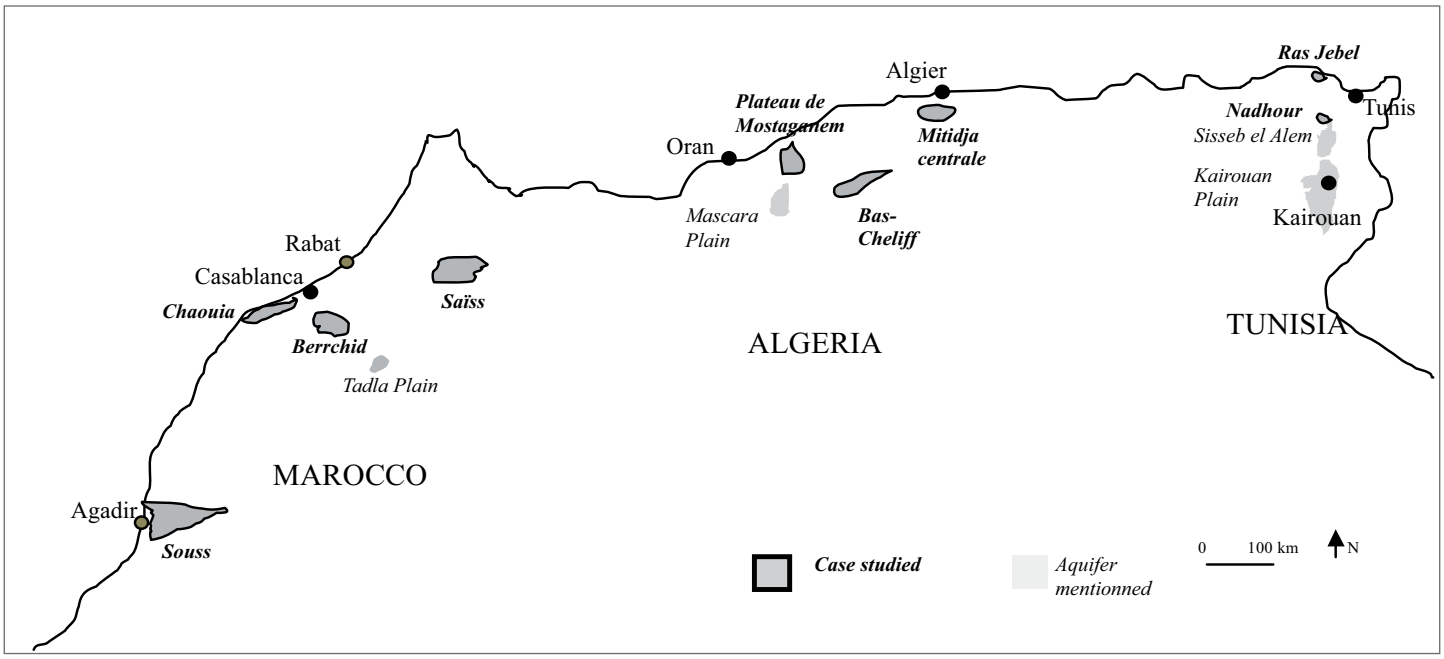
However, in many other countries, the two prerequisites of resource management organizations' capacity and official registration of users are not met (Mukherji and Shah, 2005). While many community groundwater management systems exist in these countries, they usually only concern a limited number of small areas (van Steenbergen, 2006). In the Maghreb in particular, the large number of farmers using groundwater, their informal use of it, and the weak management institutional mechanism make direct control of users difficult, at least in the medium term. Moreover, the design and implementation of strategies to ensure the viability of the aquifer/soil system are not easy for several reasons. First, water resource and user impact dynamics are complex. Second, there is no framework for consultation between irrigated agriculture and water resource management actors. Finally, in Algeria, Morocco and Tunisia, much of the land is farmed by tenant farmers who use water and soil resources intensively and who leave the area to settle elsewhere once these resources have degraded, which could be

qualified as 'mining' behavior. Therefore, alternative ways must be found, both in terms of strategies and to ensure the participation of the different actors in designing these strategies. The aim of this paper is to analyze the existing situation of groundwater overexploitation in Morocco, Algeria and Tunisia: farmers' strategies, the potential risks incurred by this overexploitation, but also, and especially, the different public and private initiatives taken to tackle it. This analysis will identify some areas of reflection to ensure the sustainable management of the system formed by the aquifers and the farmers who depend on them.

The case studies concern aquifers which are overexploited and where the public authorities are trying to ensure the sustainability of the irrigated aquifer-agriculture systems. The paper will briefly examine those aquifers that the public authorities plan to exploit in a 'mining' manner without any resource-use balance consideration. In particular, in Southern Algeria and Tunisia, the governments have not pursued a conservation logic for the aquifers of the Northern Sahara Aquifer System, but rather one of supporting their exploitation. In the case studies, the main focus will be agricultural use, since this is by far the most important use (for example, 95% of the Souss aquifer withdrawals are for agriculture use), and also because the other uses are far more easily controlled.

The study is focused on several levels. On the one hand, national public policies are reviewed, including those already officially defined, or even implemented, and ongoing discussions. Then, different local cases studies were examined in order to assess the local impacts of unsustainable groundwater use. The case study selection criteria were the existence of a high risk of unsustainable water table use and the objective of a diversity of situations. The case studies concern: the regions of Souss (Souss and Chtouka aquifers), Saïss, Berrchid and coastal Chaouia in Morocco, regions of the Mostaganem Plateau, Bas-Cheliff and the central zone of Mitidja in Algeria, and the regions of Nadhour and Ras Jebel in Tunisia (Fig. 1). The information presented is either the result of the team's earlier work, or was gathered from specific interviews with the national organizations, and in each case study with local organizations and around ten farmers in each case.The paper first presents groundwater use trends in the three countries, then the individual (sometimes collective) strategies implemented by farmers to address decreasing groundwater levels. Thereafter, it assesses the risks incurred by unsustainable groundwater uses. The different local and public policy initiatives implemented are analyzed, followed by a few thoughts on how to achieve the sustainability of the systems formed by the aquifers and their dependent irrigated agriculture.

**Figure 1 : Geographical Distribution of Case Studies**



## 2. Agricultural Use of Groundwater

### 2.1 Resources of Significant Importance...

In Tunisia, the number of surface wells doubled in 20 years, from 60,000 in 1980 to 120,000 in 2000. This growth has also continued over the past ten years (Ben Boubaker, 2010). Groundwater now represents about 52% of the water used in Algeria, 44% in Tunisia and 14% in Morocco (refer to Table 1). Falling borehole costs were the main driver of this growth. It is worth noting that, in the three countries, farmers mentioned that the sharp fall in borehole costs was the result of the introduction of drilling machines of Syrian origin. Other factors also played a role in this rapid growth of groundwater-based irrigation. Thus, the decline in average farmed areas has stepped up pressure to intensify cropping systems. Moreover, in Algeria, in the early 2000s, drought led to the urgent rechanneling of dam water intended for agriculture to towns to make up for the shortfall in drinking water. Many farmers whose dam water allocation was reduced or cancelled then dug wells or drilled boreholes.

### 2.2 Yet Fragile

The main impact of overexploitation is decreasing aquifer levels. In Morocco, the water table of the Saïss deep aquifer has fallen by an annual average of 3 metres over the past 20 years. The water volume stored within the Berrchid aquifer fell from 1500 million m3 in 1980 to 800 million m3 in 2009, according to the Bouregreg-Chaouia Basin Agency. Dewatering has already been observed on the periphery of this aquifer. The Bouregreg-Chaouia Basin Agency predicts that the aquifer could be completely dewatered by 2025. Moreover, when the aquifer is located in a coastal area, overexploitation may lead to saline infiltration as in the case of the Chaouia coast in Morocco where, due to a sharp rise in salinity, farmers have had to return to rain fed agriculture. This salt-water wedge caused by groundwater overexploitation is also present in many Algerian (Boudjadja et al., 2003) and Tunisian (Cap Bon coastal area in North-Western Tunisia) coastal aquifers.

Lastly, in North-Western Algeria and in many oasis regions of the three countries, groundwater is naturally salty: its use in irrigation creates a risk of soil salinization (Trabelsi et al., 2007; Gaaloul, 2008). In the case of the Nefzawa area in Tunisia, salinization has risen as a result of overexploitation (Zammouri et al, 2007). In the Cheliff valley in Algeria, irrigation with salty groundwater has led to an increase in secondary soil salinization which rose by 35% between the 1950s and the 2000s (Douaoui et al., 2005). In the case of Bas-Cheliff, ongoing sodification of soils is causing their gradual de-structuring (Bouarfa et al., 2009).

The main aquifer shared by the three countries is the Western Sahara Aquifer System, which extends from Algeria to Tunisia and Libya; 2.2 billion cubic metres per year are abstracted from this aquifer - a volume higher than the 1 billion cubic metre recharge (Bzioui, 2005). Although stored volumes are very significant, the concentration of abstraction points is creating a sharp drop in piezometric levels in certain areas. The piezometric level has thus fallen by over 100 metres in the Ghadames area (Horriche and Besbes, 2008) and led to the disappearance of artesianism in many regions (Mamou et al., 2006). There are also different common aquifers between Morocco and Algeria, some of which are also overexploited, but less significant in terms of size and economic importance (UNESCO, 2011).

**Table 1 : Renewable Water Resources used in the Maghreb**

| | Morocco | | Algeria | | Tunisia | |
|---|---|---|---|---|---|---|
| | Mobilizable Resources | Resources Used (all uses) | Mobilizable Resources | Resources Used (all resources) | Mobilizable Resources | Resources Used (all uses) |
| Total Volume (Billion m3/year) | 23.0 | 19.2 | 18.9 | 6.4 | 4.8 | 2.4 |
| Of which surface water | 83% | 86% | 65% | 48% | 56% | 22% |
| Of which groundwater | 17% | 14% | 35% | 52% | 44% | 78% |

*Source : Agoussine and Bouchaou (2004); Bzioui (2005); Algerian Ministry of Water Resources (2011); Plan Bleu (2007)*

## 3. Farmers' Strategies to Address the Impacts of Unsustainable Groundwater

It is possible to distinguish between two groups of strategies adopted by farms to address the impacts of the above-described unsustainable use of aquifers (Bekkar et al., 2009; Berrahmani et al., submitted). A first group consists of strategies that may be qualified as 'chasing strategies'. These strategies consist in investing in order to obtain sufficient fresh water to maintain the farm's production system. Where the aquifer is deep, farmers initially try out 'vertical' strategies by drilling deeper. This strategy requires investment resources. It also often entails bypassing legal control mechanisms for these boreholes. In Tunisia, farmers declare boreholes for domestic or non-farm use in order to obtain a legal electricity connection, then ask for it to be changed to the 'agricultural use' category, so as to obtain a lower tariff. Where the aquifer is shallow and boreholes already reach its substratum, farmers adopt 'horizontal' strategies', by seeking water further away (up to a few kilometres) and piping it back to the farm. In a few schemes in the Cap Bon region in Tunisia, faced with water salinization, farmers mix groundwater with better quality - but more expensive - public network water. Finally, when it becomes too expensive to bring the required water to the cropping system in place, the choice is often made (if the farmer has the resources), to move to other areas where water is still accessible in order to continue with the same cropping system, especially market gardening.

The second group comprises strategies that may be qualified as 'adaptive', i.e. the farmers seek to adapt their cropping systems and pathways to a drop in available water resources in terms of quality and/or quantity (Hartani et al., 2009). In some cases, these adaptation strategies may be collective. In Souss, groups of farmers collectively manage irrigation areas using groundwater. Faced with falling collective borehole flow rates, some of these groups have collectively converted their irrigation system to a localized irrigation system. For farmers pursuing this strategy, when water becomes too scarce or salty, the final options are to return to rain fed crops, and often to supplement agricultural income with an off-farm job, which could lead to migration towards the towns.

The key criterion for the selection of a particular strategy is access to capital (Berrahmani et al., submitted). Moreover, farmers who are able to find the necessary amounts to drill boreholes also often have the necessary social networks for drilling despite administrative bans. The decrease in groundwater levels thus implies greater differentiation between farms, with direct consequences on the territory and rural development.

In most of Tunisia (with the exception of the oasis areas), irrigation schemes using groundwater are usually managed by farmer groups known as Agricultural Development Groups (GDA). Farmers in some GDAs have collectively defined a few adaptation strategies. For instance, GDAs in the Nadhour region have stopped supplying water to farms outside the scheme, or else, at the start of the year, limit irrigated areas per farmer to reduce pressure on the water tower. However, based on GDAs studied in this same region (Nadhour), farmers are unable to coordinate themselves to diversify their produce and irrigation dates and times. Specialization of all the farmers in the same financially profitable irrigated crops causes water consumption peaks, both during the year and day.

## 4. Risks Incurred by Unsustainable Groundwater Use

### 4.1 Evolutions Related to Aquifers Depth

When aquifers are overexploited, the types of risks and speed with which they appear, depend above all on the depth of these aquifers. A first group of superficial aquifers that have substrata less than 150m below ground level may be considered. Among the cases studied, these are located in the Chaouia, Berrchid and Nadhour regions as well as the Mostaganem Plateau. In these cases, farmers often have to manage a rapid decrease in aquifer flow rates, especially where aquifer productivity is weak (as in the case of the Nadhour region). In the case of the Chaouia, Berrchid Nadhour regions, less than 30 years have lapsed between the beginning of the intensive use of groundwater and the emergence of an agricultural crisis due to a shortage of water. In the longer term, there is a dewatering risk and for most farmers, a return to rain fed agriculture.

The second group corresponds to the deep aquifers such as Souss and Saïss in Morocco, the Bas-Cheliff and Mitidja aquifers in Algeria and those located to the west of Kairouan in the Merguellil Plain in Tunisia. In these cases, decreasing groundwater levels initially lead to an increase in drilling and pumping costs. Already, small farms in the Souss and Saïss Plains no longer have the resources to drill individual boreholes. The smallest farms that are unable to find another form of supply (collective borehole, agreement with borehole owners, and supply from surface water resources) will have to return to rain fed agriculture. For these deep aquifers, the evolution dynamics are slower than for the superficial aquifers: the risks might only appear in several years and only concern, the next generations of farmers.

### 4.2 Local Risks

Local economic development is affected by overexploitation when farmers can no longer manage to maintain the chasing strategies without moving, or are unable to define local adaptive strategies that will provide them with sufficient income. In particular, the decrease of farm activities leads to a downturn in all the other related economic activities, especially upstream agricultural (inputs) and downstream (marketing).

Coastal Chaouia in Morocco represents an example of the strong impact of overexploitation on agricultural dynamics and the local economy. Groundwater has been used intensively since the 1970s, initially for citrus fruit production then for horticulture (mainly tomatoes and potatoes) and fodder crops. Groundwater overexploitation has caused the infiltration of sea water in coastal areas, and a drop in piezometric levels more in the interior. Since the 1980s, farmers have been compelled to adapt to the water shortage situation with actions such as borehole deepening, bringing water to their farms from wells sunk in other areas, or renting land upstream in the same area or in other regions. In the coastal area, citrus fruit, which is highly sensitive to salinization, has been replaced by market gardening, which itself has decreased significantly in favour of more salt-resistant but less profitable crops (such as cauliflowers or maize). The shortage of high quality groundwater was the key motivating factor in the area's shift from intensive, export-focused agriculture to the current situation of crisis and fragile farms. The entire downstream agriculture sector has been completely destabilized by this crisis: the number of cooperatives involved in market gardening exports has fallen from 120 in the 1980s to 3 today. Many farmers, both in the coastal area and in the interior, are leaving every year in search of work in the towns and only cultivate rain fed cereal crops on their plots.

### 4.3 National Level Risks

The 'agricultural crisis' as experienced by coastal Chaouia could lead to an exodus of people in search of work. It is also leading to another type of exodus: that of farmers who have the resources to invest and who will continue their 'chasing strategy' in other areas, which could also lead to greater pressure on groundwater resources in these other regions.

Lastly, overexploitation will have an impact on the food security of the three countries. However, there is no quantified estimate of this risk for the Maghreb. Postel (1999) suggests an estimate of 10% of global agricultural production based on groundwater overexploitation.

# 5. Institutional Frameworks and Local Initiatives

## 5.1 National Strategies Being Designed

### Legal and Institutional Frameworks

The three countries have Water Laws that include specific clauses concerning groundwater: the 1975 Water Code in Tunisia, the 2005 Water Act in Algeria and the 1995 Water Act in Morocco. All these codes make provision for granting permits for groundwater exploitation, systematically in Algeria, for boreholes deeper than 50m in Tunisia, and for boreholes exceeding the locally defined thresholds in Morocco. The water codes of the three countries provide for the establishment of quantitative protection areas, where the drilling of new wells and boreholes is either subject to authorization (protection areas in Tunisia and in Morocco) or completely banned (protection areas in Algeria and interdiction zone in Tunisia).

The institutional mechanisms for groundwater management vary widely from country to country. In Morocco, the basin agencies are the key aquifer management actors under the oversight of the State Secretariat for Water and Environment. They are responsible for groundwater resource studies, the implementation of water resource development policies as well as of control measures. In Tunisia, the Ministry of Agriculture and Environment with its different national directorates and regional administrations (especially the Regional Agricultural Development Divisions) is responsible for the monitoring and control of groundwater exploitation. In particular, these organizations manage an observation network concerning the country's aquifers. They also prepare the studies for the assessment and establishment of the general inventory of these resources. In Algeria, the roles are much more distinct. The National Water Resource Development Agency (ANRH) is responsible for aquifer studies, the Basin Agencies are mainly tasked with water user registration, and the Wilaya Water Directorates (DHW) are responsible for water policing.

These differences between the three countries have led to differences in the design of management mechanisms. In Morocco, it is the role of the basin agency to organize consultations between the actors, whereas in Tunisia, the issue is considered above all as an internal matter for the Ministry of Agriculture and Environment. In Algeria, the Ministry of Water Resources organizes inter-institutional consultations between basin agencies, ANRH and DHW. The actual activities carried out by these organizations may vary from region to region.

Integration between the administrations responsible for agricultural development and those responsible for water resource protection is carried out at both the local and national level to ensure public policy coordination. At the national level, joint inter-ministerial working committees exist in Algeria and Morocco to try to harmonize the respective policies. At local level, discussions are held between the different administrations and the actors (refer to examples below). However, this integration is not easy as is shown in Tunisia and Morocco by the concessioning of agricultural public enterprise land to private entrepreneurs with a view to agricultural intensification. This concessioning takes place with unseay integration of the issue of the relevant groundwater resources to be used when defining development plans.

Overall, the Moroccan basin agencies, the ANRH and DHW in Algeria, and the Directorate-General of Water Resources at the Ministry of Agriculture and Environment in Tunisia have a professional culture based on hydrological and hydro-geological expertise. They attach great importance to data acquisition and the operation of models that will facilitate the preparation of water resource inventories. These organizations have less knowledge of the agricultural sector and, in particular, have only limited information on aquifer users. They also lack human resources for coordinating the multi-actor consultation process. These tasks are often assigned to private consulting firms in Tunisia and Morocco for limited periods.

Furthermore, Algeria, Tunisia and Libya have tasked the Sahara and Sahel Observatory with coordinating the exploitation of the water of the North-Western Sahara Aquifer SystemIn practice, the Observatory is mainly responsible for conducting hydro-geological studies and communicating the forecasts for borehole drilling projects in each country to the other member countries.

### Innovative, but not yet Formalized National Approaches

In the three countries, various policies are under discussion to ensure sustainable aquifer management. In Tunisia and in Morocco, a specific groundwater management strategy is being designed. The main focus of these strategies is on local contractual mechanisms, which would lead to integration of the different policies, in particular those relating to supply and demand management.

Thus in Morocco, the Secretariat for Water and Environment has proposed the introduction of groundwater contracts for the main overexploited aquifers. These groundwater contracts, which have to be signed between the different public administrations and user associations, should incorporate all the measures to be taken in a particular area to protect water resources

and their exploitation. Such contracts are envisaged or are being executed for about ten aquifers. In 2011, the only groundwater contract signed has been the Souss-Massa Aquifer Framework Agreement.

In Tunisia, there is long-lasting reflection begun in the late 1990s (Water Sector Study), on the opportunity for participatory groundwater management. Since the 1990s, the Ministry of Agriculture's general policy has been to support the formation of groups of farmers, known as GDAs, and which are called upon to become local partners in public policy implementation. In keeping with this general approach, the aim is to task the GDAs with groundwater management in their areas of operation and in particular, borehole control. Currently, there is only one case where such an approach has been initiated in practice (the Bsissi GDA in the Gabès Governorate).

The proposed contractual approaches in Morocco and in Tunisia are different. The Moroccan approach has from the outset focused on large aquifers, whereas the Tunisian approach will, a priori, apply more easily to smaller-scale aquifers. In the case of Tunisia, while the local scale makes good sense for the actors, the issue of selecting the appropriate level for defining consultation among actors and determining public policies on a broader scale (aquifer, watershed, even nationwide) is not obvious due to the existence of significant inter-basin transfers.

## 5.2 Local Negotiations

### In Morocco, Negotiations Centered Around the Basin Agency

In Morocco, initiatives to set up management mechanisms are often taken at regional level (basin agency, regional council), with little intervention from the national level, which, in particular, has not yet proposed a methodological framework for the preparation of groundwater contracts. Horizontal cooperation is being set up: agencies are exchanging information directly among themselves on how to organize the impounding of drilling machines. The most striking local example of this initiative is that of the Souss and Chtouka aquifers. In 2004, the Souss-Massa Regional Council launched a study to define a regional development strategy. A key factor was agriculture, whose Achilles heel was aquifer overexploitation. Indeed, from 2003, overexploitation in the Guerdane sector had resulted in water table levels over 300 metres below ground level and very low borehole productivity. As a result, 11,900 hectares of orange groves in that region (Houdret, 2008) were abandoned. In 2005, the Souss-Massa Basin Agency launched an initiative to control borehole drilling. In 2006, 70 drilling machines were impounded. In the same year, at the initiative of the regional council, a framework agreement was signed between this council, the Agricultural Development Authority, the basin agency, the Chambers of Agriculture, the Regional Water Users Federation and three Agricultural Professional Organizations for the marketing of market garden produce and citrus fruits. This agreement has four (4) thrusts: (1) actions to reduce water consumption and increase water productivity, in particular with support to reconversion from gravity and overhead irrigation to localized irrigation, and the strengthening of water policing; (2) research aimed at ensuring more efficient irrigation water use and assessment of waste water reuse potential; (3) research on the use of deep aquifers; and (4) construction of some small dams. Each thrust was scheduled to be implemented by way of specific agreements. The financing required to implement this framework agreement is estimated at about 3.5 million Moroccan dirhams (about 310,000 euros). This financing is planned to come from the contributions of farms of over 15 hectares. This category of farm does, in fact, comprise about 20% of farms and 80% of water withdrawals. Even though this framework agreement is not officially a groundwater contract, in practice, it plays such a role.

Implementation of this agreement mainly concerns the first thrust. Coordination between the Souss-Massa agency, the Agricultural Development Authority and the local branches of the Ministry of Interior has led to the impounding of many illegal drilling machines. Controls are carried out by employees of the agency and the development authority, on the basis of calls from the local authorities or farmers. Between 2006 and 2009, 120 machines were impounded. In 2010, none were impounded, which is considered by the Basin Agency as a sign of the sharp decrease in illegal borehole activities. This experience underscores the importance of building coalitions of actors. However, regardless of the possibility that new illegal boreholes are still being drilled, legal borehole drilling is continuing. Indeed, farmers may request the replacement of a borehole which has dried up by a deeper one. The other key component of this thrust is the shift towards localized irrigation. In 2010, 16,000 hectares of the 30,000 ha to be equipped over the 2008-2012 period were equipped for this method. The third major initiative is the study of a 10,000 hectare irrigated area using desalinated sea water in the Chtouka zone.

In contrast, in the Saïss zone in Morocco where the aquifer is deep and where falling groundwater levels have not yet had economic consequences, the Basin Agency is struggling to convince the other public organizations to limit withdrawals, and in particular not to issue new permits. This difference of opinion is one of the major constraints impeding the definition of a management contract for the Saïss aquifer.

**Negotiations in Algeria outside Formal Frameworks**

In two of the case studies in Algeria, negotiations brought the local actors together, although they were not held in a formal context. In 2010, the Mostaganem Chamber of Agriculture took the initiative to apply for authorization to drill new boreholes on the Mostaganem Plateau the operationalization of the Mostaganem desalination plant may enable to increase agricultural use of the aquifer. It proposed to establish an order of priority for these authorizations by emphasizing boreholes for livestock, potatoes and citrus fruit. This initiative was backed by the DHW and the Mostaganem Wilaya Agricultural Services Delegation, as well as three professional associations for the 3 sectors concerned. The Prefecture finally decided to postpone the decision to issue authorizations following the assessment of available resources after the plant's entry into service. This initiative is, however, an innovative example of a local coalition involving government services and farmer associations. Similarly in the central area of Mitidja, in Chebli Region, recharge basins were constructed in 2004. These basins have no longer been supplied since 2008 owing to the construction of a diversion sill built to convey the water from the El Harrach Wadi to the new Douira dam. Farmers mobilized themselves to request the resumption of groundwater recharge operations (which finally happened in April 2011) and also held discussions with the public authorities on a future breakdown of water from the spring upstream from the Wadi between the volume taken to supply the dam and that intended for groundwater replenishment.

## 5.3 Farmers' Points of View and Collective Initiatives

The main reason for interaction among farmers is the shared use of boreholes. There are many forms of informal arrangements in Morocco and Algeria among farmers to obtain such access. Although varied (ranging from a solidarity grant to an agricultural production partnership) (Boudjelal et al., 2011), they do not include the existence of groundwater markets as identified in India (Shah, 2009) where farmers without groundwater access may directly contact several others who own boreholes in order to purchase water.

Farmers' points of view on the relevance and legitimacy of well and borehole drilling controls vary greatly from one situation to another. Controls carried out by the farmers themselves exist in some traditional systems such as the khettara (underground drainage galleries) in Morocco, where the communities ban boreholes in the khettara catchment areas. However, such controls stem from the historically grounded legitimacy of the communities to harvest and manage groundwater for the farmers' collective. In the other regions, farmers questioned underscored the equal rights of all farmers to drill (Bento et al., 2009).

Outside these khettara areas, farmers consider that borehole control falls above all within the remit of the State (Bekkar et al., 2009). However, the willingness of farmers to subject themselves to such controls may also differ from area to area. Thus, in Morocco, different surveys have shown that half the farmers questioned from Souss and Saïss mention such controls as possible solutions to overexploitation. In contrast, only 8% of Berrchid farmers and none from Chaouia mention such a demand regulation policy (Faysse et al., 2011). Similarly, the 30 farmers questioned on the three study sites in Algeria raised the relevance of increasing resources, but none mentioned more stringent borehole control. In Nadhour in Tunisia, 15% of the 33 farmers questioned mention, among the possible solutions to overexploitation, stricter control of illegal boreholes. Thus, in some areas there is a willingness among farmers to accept control mechanisms provided they are implemented fairly and transparently.

## 6. Wide Range of Instruments Implemented and Envisaged

The different instruments used or envisaged to address unsustainable aquifer use may be grouped under three categories: those aimed at increasing water resources, those aimed at reducing withdrawals, and those aimed at compelling farmers not to increase withdrawals.

### 6.1 Policies Aimed at Increasing Water Resources

Tunisia was the first country to implement supply-side management policies to address aquifer overexploitation, that is by increasing available water resources. In Algeria and Morocco, although policies aimed at increasing water resources have long been pursued, they have only very recently been specifically designed to address groundwater overexploitation.

#### Aquifer Recharge and Establishment of Irrigation Areas using Surface Water

Aquifer recharge initiatives have existed in Tunisia since 1992 and represented 64 million m3 in 2006 for 21 aquifers according to the 2007 National State of the Environment Report. Water released from the Nebhana dam onto the flood plains made it possible to recharge the Kairouan aquifer. In the North, water from the Medjerda valley is transferred to the coastal area of Ras El Jebel and injected into the aquifer through about a dozen sites which are old quarries or wells. In the latter case, while the recharge impact is highly visible in the infiltration areas, the volumes injected (about 500,000 m3 yearly) are insufficient to have an impact on the whole aquifer. Recharge is also carried out using treated waste water in the Korba region. In Algeria, recharge basins have been used in the central area of Mitidja (see below). Lastly, in Morocco wadi weirs have been built to encourage the infiltration of flood waters into the Ghmat (in Haouz) and Souss wadis.

The other policy for increasing water resources is the design of irrigated areas using surface water from a neighbouring basin. This is the case with the above-mentioned Ras El Jebel scheme as well as several irrigated areas in Cap Bon in Tunisia, where a network distributes water transferred from the Medjerda wadi. In Morocco, the Guerdane irrigated area is supplied from a dam upstream in the Souss basin. Other projects are also under study in Morocco: an irrigated area on the Saïss plain from the Mdez dam under construction, an irrigated area in coastal Chaouia using water from the Oum Rbia, and in the longer-term, the transfer of water stored in the North (mainly from the El Wahda dam) to central Morocco, which would ensure the supply of drinking water as well as supply to new irrigated areas.

Whether they concern aquifer recharge or the establishment of irrigated areas by water transfer, these policies are implemented with difficulty due to the fact that in an increasing number of watersheds, the main surface water resources are already mobilized, leading to steadily lower regulated volumes for future dams. Thus, although the project for an irrigated area in the Chaouia zone supplied by water from the Oum Rbia wadi has existed since the 1990s, this project has since inception had to face the fact that the water from this wadi is already over-allocated.

#### Non-Traditional Water Resources

There are various projects underway for the creation of non-traditional water resources, which should indirectly ease the pressure of agricultural uses on groundwater. Thus, two irrigated areas will be created using waste water from Berrchid and neighbouring Settat towns. In Algeria, there is ongoing reflection on the systematic use of treated waste water from the major towns and cities for irrigation. The Tunisian administration has long developed such use of treated waste water. There is no denying that the results are mixed; farmers are reluctant since they cannot use this water to grow high-value added market garden crops. The Tunisian administration is currently conducting recharge programmes using treated waste water. The other non-traditional resource is desalinated sea-water. In Algeria, over 20 such plants have been designed for the main towns and cities. The objective is that, once these plants are operational, dam water can be rechanneled to agriculture. In Souss, as mentioned above, a 10,000 ha irrigated area using seawater is being studied for the irrigation of market garden crops and citrus fruit exports.

These supply-side approaches should provide a welcome breath of fresh air. However, the volumes generated are often fairly low in relation to ground water shortfalls. Among the cases studied, there is no example where a supply-side policy sufficed on its own to restore a resource-use balance, which is why it is important to combine such policies with demand-side management approaches.

### 6.2 Demand-side Incentive Policies for Agricultural Water

#### Support to Reconversion to Localized Irrigation

The main incentive policy is support to the reconversion of farms to more efficient irrigation methods, in particular localized irrigation. This is the flagship measure of national water saving programmes in the three countries, with specific subsidization mechanisms. In Morocco, subsidization rates have gradually increased, reaching 80% to 100%

of the investment costs (with ceilings per item of equipment). In Algeria, equipment was initially financed to the tune of 100% at the start of the National Development Plan in 2000, but has since fallen back to about 50%. In Tunisia, subsidies are about 40% to 60% of the total investment amount. However, dissemination of this innovation varies from region to region. While the equipment rate is high in Tunisia, it remains low in many regions of Morocco and Algeria (only 40% in the Berrchid Plain in Morocco). The main constraints include cumbersome administrative procedures (Bekkar et al., 2007). Another constraint is that, in the three countries, in order to submit the subsidy application form, it is necessary to obtain groundwater abstraction authorization. Some actors, in particular, the Chambers of Agriculture in Morocco, are asking to discontinue this linkage. They argue that it is preferable that a farmer, although irrigating without authorization, does so using localized rather than gravity irrigation.

Such conversion will result in an efficiency gain at plot level of about 40%, even though this gain falls at watershed level, because part of the gravity irrigation water percolates, replenishing the ground water aquifer. Indeed, the main attraction of localized irrigation is the enhancement of the water productivity due to a fall in labour costs and an increase in yields. However, without technical support, localized irrigation performance falls far short of the theoretical potential (Vidal et al., 2001). In addition, when farmers shift from gravity to localized irrigation, there is often an extension of the irrigated areas, related to a significant increase in the productivity of the factors of production (capital, labour) rather than a drop in pumped volumes (Bachta et al., 2004; Al Atiri, 2007). The conversion to localized irrigation sometimes results in more intensive agricultural activity and, ultimately, higher water consumption (Bouarfa, 2004; Molle et al., 2006). Thus, in coastal Chaouia, although the localized irrigation equipment rate is about 90%, the aquifer remains highly overexploited. Therefore, reconversion to localized irrigation remains more of an instrument to support farmers in adapting to a water shortage crisis (because the value-added is increased by m3) than as an instrument to reduce abstraction.

#### Individual Groundwater Withdrawal Fees

In theory, fees may both foster water-saving behaviour and finance infrastructure development and agricultural support activities. Such fees are provided for under Tunisian and Moroccan law (for example, in Tunisia, they are two millimes per m3, i.e. about EUR 1 per 1000 m3 for groundwater) but are not applied. Attempts to introduce local fees to finance operations for funding supply-side policies have also been made, but with limited implementation to-date. In the Ras El Jbel region, the administration has unsuccessfully tried to ensure that farmers who benefit from groundwater recharge pay fees. In Souss, the framework agreement made provision for farmers with over 15 hectares to finance different activities defined in the agreement, but the current recovery rate is low (about 15% in 2011). In the study on the Massa Plain Seawater Desalination Project, one option under discussion is the equalization of fees: whatever water source (dam, groundwater or desalination plant) farmers might use, they would pay the same price. Similarly, in Tunisia, the administration is considering a trinomial fee in the GDAs which would take into account GDA fixed and variable operating costs and groundwater use. The administrations are trying to find more efficient methods to obtain payment of these fees. In Morocco, for instance, a 2010 Decree allows these fees charged by the basin agencies to be considered as taxes. In Tunisia, their collection through the electricity bill is being considered.

There are other incentive policies, although on a smaller scale. In Souss, services of the Ministry of Agriculture disseminate climate data in order to support farms (in practice the largest), with a view to enhancing irrigation management. Indeed, many studies conducted in Morocco show strong water saving potential through better installations and enhanced management of localized irrigation, which sometimes use double the amount of water required (El Fanani, 2009). Lastly, other policies are proposed by certain actors. Farmers in Nadhour propose to lower the electricity night tariff to encourage farmers to irrigate during that period. An insurance scheme has been proposed by Berrchid farmers: insurance would be taken out for farmers who opt not to drill so that their rain fed crop revenue (in particular from wheat) would be guaranteed even in the event of a dry year. In Souss, the basin agency has initiated a study on water enhancement to be able to channel agricultural production over time towards those crops that have the highest water productivity.

### 6.3. Policies to Regulate Agricultural Water Demand

In the three countries under study, it would be extremely costly to control the amounts abstracted from all the existing wells and boreholes. Therefore, the administrations have tended to focus on control of new drillings and the depth of the existing withdrawal points. This is easier when the groundwater table is at a depth of over 70m, in which case it is no longer possible for farmers to drill wells manually. They must then use drilling machines – which makes control possible.

In Algeria, borehole control policies have been implemented since the late 1980s, with in particular, a ban on new boreholes in Collective Farms (EAC) which had been established after the break-up of self-managed domains (large-scale public farms). In Tunisia, boreholes are banned both in the protection and irrigated areas. In Morocco, the ban on

borehole drilling is determined by the agencies for aquifers considered as being overexploited. The forthcoming identification of protection areas, in accordance with the provisions of the 1995 Act, should reinforce the legality of such action.

These borehole drilling bans are unevenly implemented. In Chaouia, although boreholes are officially banned, there is no control in practice. In the other cases studied in Morocco, there has been growing interest in borehole control. In Souss, Saïss and the Berrchid Region, the administrations are beginning to control borehole drilling, in particular by impounding drilling machines. The Souss agency is also trying to organize the drilling machine sector, especially through the establishment of a professional association, which could become a management interlocutor. In Algeria, some farmers have served prison sentences for illegal drilling. In Tunisia, controls have been less stringent. Moreover, since the events of January 2011, the public administrations have a much weaker presence and fewer activities in rural areas. In the Nadhour region, a local official estimated that, in the spring of 2011, 70 of the existing 210 illegal boreholes had been drilled since January 2011.

Implementation of borehole controls in some regions of the three countries has helped to hold back farmers in their rush to drill. However, there is still a largely unresolved issue of how to ensure the fair and transparent implementation of such controls. Farmers do not have the same resources to be able to bypass the regulations; the strengthening of water policing, if not specifically backed by a policy specific for small-scale farms, could create even greater widening of the gap between farms in a position to drill and those compelled to adopt adaptive strategies. Lastly, control of abstracted volumes through electricity consumption is envisaged in Tunisia, but not yet implemented.

In Morocco, in Saïss, Souss and the Berrchid Region, the basin agencies have adopted a common method for obtaining the registration of existing boreholes. Farmers are invited to declare their borehole over a given period, during which registration applications will be subject to a field investigation and, in general, approved. Then, at the end of the period, the agency will declare the final suspension of withdrawal permits. Such a regularization period is being carried out in 2011 and will be completed in February 2012 in the cases studied in Morocco. In the past, farmers have remained cautious regarding this type of initiative, and only declared the borehole if they needed a deepening authorization or a subsidy for localized irrigation. However, the threat by a basin agency to close illegal boreholes could become more credible since applications for legalization in the Berrchid Region concerned about half the agency's estimated number of boreholes in April 2011.

Table 2 presents the expected impacts of the different instruments discussed (increased supply, incentives and control), in respect of three criteria: increase in water resources, expected impact on groundwater withdrawals and water productivity. There appears to be no single instrument capable of being employed to simultaneously improve water productivity and reduce groundwater withdrawals. Furthermore, these instruments also differ in terms of the speed with which they can be implemented: subsidies and even regulation policies may be implemented within a much shorter timeframe than the reconversion of part of the local economy to non-agricultural activities. This demonstrates the need to combine approaches to limit groundwater withdrawal increases while maintaining farmers' income. It is, in fact, a series of combined control and support actions that underpin the Souss Framework Agreement.

## 7. Possible Approaches to an Agricultural Economy Based on Sustainable Groundwater Use that Takes into Consideration the Diversity of Farms

The foregoing analysis shows that public policies and coordination mechanisms have been initiated, and are evidence of the growing interest in the issue of groundwater overexploitation, even though such initiatives have for the moment not yet restored the resource-user balance in the aquifers studied. In any event, these promising initiatives show the relevance of an integrative approach, which, on the one hand, combines control and support actions and, on the other, is accepted by coalitions of local actors.

### 7.1 Use a Wider Range of Instruments and Monitor their Impacts

#### Efficiency and Equity of Control Instruments Used

Control of well and borehole drilling often appears as a necessary measure to ensure sustainable aquifer use. Unlike other cases described, for example in India (Shah, 2009), the main constraint to the implementation of such control is not its cost, given the fairly strong presence of local authorities in rural areas. It will depend, above all, on the strong determination and close involvement of the local authorities. Indeed, these authorities often have the impression of having to choose between short-term social peace and the less visible medium-term viability of the agriculture-aquifer system.

Moreover, there is the issue of equity, since farmers do not have the same resources to bypass the existing institutional control mechanisms. Thus, 70% of farmers questioned on the three study sites in Algeria underscored the importance of having networks to obtain drilling rights. Lastly, in Tunisia, the issue of a legitimate authority to carry out this control has arisen since the events of January 2011. In Tunisia and Algeria, due to the large number of boreholes connected to the power grid, it is possible to control water use through electricity consumption as is the case in India.

To address this problem of implementation and equity, one solution being prepared by the administration in Tunisia is to entrust small aquifer borehole control to farmers' associations. The outcomes of

**Table 2: Expected Impacts of the Different Instruments Implemented and Considered**

| Type of Policy | Instruments | Expected Impacts | | | Implementation |
|---|---|---|---|---|---|
| | | Increase in Water Resources | Reduction in Aquifer Withdrawals | Increased Water Productivity | |
| Policies for Increasing Water Resources | Aquifer Recharge | Yes | No | No | Ras Jebel, Central Mitidja, Souss |
| | Irrigated area using surface water or brought from other areaswaste water, seawater desalination | Yes | Incentive | No | Guerdane (Souss), Ras Jebel |
| Incentive Policies for Demand Management | Support reconversion to localized irrigation | No | Positive or negative impact | Strong impact | All areas |
| | Assistance for improved irrigation practices | No | No direct impact | Strong impact | Souss |
| | Tariffs | No | Weak impact | No | Souss |
| | Support conversion to crops enabling high water productivity | No | Positive or negative impact | Strong impact | Discussed in Souss |
| | Insurance mechanisms, non-agricultural employment | No | Incentive | No | Discussed but not planned |
| Demand Control Policies | Control of new boreholes and of the deepening of existing boreholes | No | Positive impact | No impact | In theory in all areas |
| | Registration of existing wells and boreholes | No | Improve control implementation | No impact | Souss, Saïss, Berrchid |

similar experiences at the international level using such an approach are not unequivocal. In Mexico, this approach has until now been considered a failure (Wester et al., 2009). In Spain, it only worked where water user associations emerged from projects developed by the farmers and not where they were set up by the administration (Rica et al., 2011). Moreover, in France, while farmers sometimes acknowledge the relevance of borehole control, they do not often want to directly control groundwater use and prefer to entrust responsibility for it to the State (discussions in Beauce and on the Roussillon case, Rinaudo et al., 2011). While the possibility of self-regulation seems possible in areas of limited size due to the fact that farmers know one another, it does not seem relevant for large aquifers such as the one in Sissseb El Alem. However, in the case of such large aquifers, the provision of maps indicating the positions of regularized wells and boreholes could enable farmers, without carrying out the control themselves, to at least control the fair and transparent implementation of water policing.

**Towards a Broader, More Integrated Range of Mobilizable Instruments**

All the measures to enhance water productivity at the individual (improved market access, higher yields, etc.) and collective (improved functioning of GDAs, etc.) levels will help to improve the adaptive capacity of farms. However, in the absence of control action, such policies could contribute to the maintenance of strong pressure on water resources. It would, for instance, be possible to support cauliflower or artichoke production in the Chaouia coastal area because these plants are salt-resistant. However, such support could lead to the maintenance of a situation where withdrawals remain much higher than the groundwater recharge. Such support would then be usefully combined with measures to limit withdrawal increases.

Different actions have already been identified as potentially interesting, but have to-date been little explored. Therefore, it will be useful to identify crops and sectors that will allow increased water productivity in order to design policies focused on the redirection of part of the farms towards these types of crops. Such policies would be based on incentives, since: the administrations do not have direct control over crops produced using groundwater, and none of the government services contacted has expressed any desire to carry out any control of agricultural produce. Similarly, local development opportunities fostering non-agricultural employment (rural tourism and industry) could be more closely incorporated into local discussions.

## 7.2 Catalyze Local and National-Level Coalition Building in order to Design, Coordinate and Implement Policies.

There is an ongoing reflection at national level in each of the three countries in a bid to establish connections between agricultural policy and water policy, taking into consideration issues such as food security or water resource accounting, including virtual water embedded in imports of agricultural products (Chahed et al., 2007). These studies deserve to be discussed among the ministries concerned to define more closely integrated public policies. At the same time, it would appear important to pursue the local testing of new approaches.

**Relevance of Coalitions**

The building of coalitions of actors capable of working together (Mollinga et al., 2007) seems to be an important stage in the design and implementation of policies to address unsustainable groundwater use for several reasons: (i) no instruments have emerged that are universally valid, but it seems more relevant to design series of locally coordinated instruments; (ii) some instruments make it necessary to think at the local development level, and not merely within a framework confined to agriculture and water resources; (iii) enough actors have to be gathered to ensure that the choices can be implemented. In many cases, such as those of coastal Chaouia or the Saïss aquifer, existing coalitions do not involve enough actors, and do not succeed in defining and implementing a strategy that would ensure the sustainability of the aquifers and the crops that depend on them.

Such coalitions could include the administrations responsible for agriculture and water resources, but also and especially the farmers who locally are willing to make proposals so that their activities can be sustained in their region. Experiences in Berrchid and in Chaouia (Faysse et al., submitted) show that farmers can be interested in participating in the design of management instruments.

These coalitions may also include the local communities (cf. the pivotal role of the Souss-Massa Regional Council), in order to consider possible solutions at local territory level, such as the creation of non-agricultural employment. The local entities of the Ministry of Interior could also play a role in this, with a view to providing local backing to water policing, especially in Morocco. These coalitions could be broader-based as shown by the relevance of involving the Power Generation and Distribution Utility (STEG) in Tunisia in linking electrification to borehole

drilling permits, and possibly the establishment of new types of tariffs and quotas.

**Opportunities for Supporting Coalition Building**

Coalition building is not an easy matter and could be supported in several ways. First, an actor may support the formation of these coalitions. In Morocco, the basin agencies are responsible for groundwater contract design, which provides a coalition building opportunity. This is what was proposed by the Bouregreg Chaouia Agency, which in the spring of 2011 took the initiative to hold meetings with the Governorates and courts to explain the importance of the overexploitation challenge and to ask these actors to implement borehole control or support the design of irrigated areas using treated waste water. However, in general, Morocco's basin agencies lack human resources to coordinate such activities. Moreover, since basin agencies are responsible for protecting water resources, this could affect their capacity to be recognized as a lead ntity in the debate (in France, local structures – for instance "Syndicats de pays", i.e., (communal planning associations, are sometimes given this role).

Secondly, it is often claimed that it is necessary to raise farmers' awareness on the issue of groundwater overexploitation. Although such a task is useful, especially in the acquisition by farmers of knowledge on the functioning of aquifers, sensitization to the problem and mainstreaming it into the debate must also involve the other organizations concerned such as government services, local communities, or public companies, e.g. power utilities.

Thirdly, there are few professional organizations especially for groundwater users (the Tunisian GDAs and Sousse Agricultural Water User Associations operating with boreholes could be considered as such associations). However, particularly in the regions of Berrchid or coastal Chaouia, there are no professional organizations maintaining strong ties with farmers using groundwater. In such cases, it will be necessary to identify other mechanisms to ensure farmer participation, for example through the existing professional organizations, even though they have no official water management responsibility. Moreover, in Berrchid, 42% of the land is farmed by tenants who attach considerably less importance to the sustainable use of the land they occupy. Therefore, it will be useful to develop specific approaches to involve owners in the discussions. Moreover, large farms often have more capacity than smaller ones to participate in coalitions of actors, in order to bypass the implementation of water access control mechanisms and to benefit from incentive instruments (e.g. conversion to localized irrigation). It is of particular interest to ensure that the discussions include these small farms.

Fourthly, the diversity of the initiatives taken in the Maghreb countries, but also at the international level, shows the importance of exchanges on these experiences. Such exchanges will be more fruitful if organized around concrete local initiatives rather than being confined to the legal aspects, and if they are open to countries with similar institutional and farm characteristics such as India and Mexico.

Lastly, it would be useful to have a formal, national framework for structuring and ensuring government recognition of possible agreements concluded at local level (in line with the approach recommended by Ostrom, 1990. The groundwater contract, as currently envisaged in Morocco, could provide an opportunity for such recognition of the initiative capacity of local actors, provided it is the outcome of joint drafting by all the actors.

**Acquire the Necessary Knowledge to Understand the Ongoing Dynamics and Analyze Available Options**

As mentioned in the introduction, until now, groundwater use has mostly been a silent revolution. In order to understand the ongoing local level dynamics, it would be necessary to examine past and current development of the territories where this intensive use of groundwater has emerged, in hydrological, social and economic terms. It would be useful to estimate the size of this groundwater use-based economy, especially to estimate the costs of the overexploitation and no management scenario, but also to compare such an estimate with the costs of possible management options.

Moreover, at both the national and local levels, administrations are moving forward with both supply and demand-side policies without having formally defined what relative weight to assign to these two types of policies. To our knowledge, there is still no estimate on a given case study in the Maghreb, of the anticipated costs and impacts of the different instruments envisaged in terms, for example, of resource use, water productivity and the impact on farm dynamics. Therefore, it would be useful to accompany the discussions on the proposed options - from the construction of a framework for mutual understanding and diagnosis among actors, up to the assessment of the costs and impacts of the different options under consideration, particularly in different existing types of farms.

## 8. Conclusion

Despite the urbanization of Maghreb societies, the rural areas will remain of critical importance in the years ahead. The numbers of rural dwellers in the three countries studied should remain stable until 2020 (Abis, 2007). Moreover, the agricultural sector remains one of the mainstays of the Moroccan, Algerian and Tunisian economies with respective agricultural GDPs of 18%, 11% and 13% (Hervieu et al., 2006). As elsewhere in the world, this agricultural sector has assumed increasing importance in public policies. Morocco, for example, has designed a large-scale plan for agriculture with its Green Morocco Plan. Groundwater exploitation has been one of the key drivers of agricultural growth in North Africa over the past few decades, following a phase of public investment in irrigated networks using surface water. However, this use has also become the main risk of unsustainable water uses for Morocco, Algeria and Tunisia, and one of the main frailties of the agricultural economies of these countries.

The three Maghreb countries have historically developed different strategies for addressing groundwater overexploitation. Thus, in Morocco and Tunisia, the option initially selected was to mobilize water resources and, more recently, to try to control irrigation water demand, especially in Morocco, through a determination to more actively enforce such control as provided for by law. In Algeria, on the other hand, a control policy has existed since the 1980s but it was only in the 2000 decade that the government began to attach more importance to a policy to increase water resources.

Overall, the policies implemented were sectoral, uncoordinated and did not collectively grasp the different risks related to unsustainable groundwater use in a given territory. This lack of a holistic vision reflects the absence at international level of donor-validated models to address decreasing groundwater levels, in situations where users are informal and water resource management systems have limited resources (Mukherji et Shah, 2005).

More recently, different initiatives have emerged, both in a bid to find innovative ways of mobilizing new water resources, but also by involving the different actors in the design of packages combining resource creation and use control instruments. In such a context where it is inconceivable in the short-term to envisage a management mechanism like the one used in Beauce (with the installation of meters and quotas for each farmer), different approaches have been tested. These experiences have often been replicated at the local and territorial levels of the aquifer.

Though several of the initiatives appear promising, to-date none of them has led to the restoration of the resource-use balance. In order to achieve the dual objective of an agricultural activity and the sustainable use of groundwater resources, the analysis presented here argues the need to combine different instruments. This constraint is also an opportunity, because such combinations of instruments will be far more acceptable to farmers than instruments that are solely focused on groundwater protection. Consensus could be reached among the different actors on this type of combination, which could be both the purpose and grounds for the establishment of local communities of actors that could take the initiative to develop such instruments towards achieving sustainable management of the agriculture-aquifer-soil system.

Building these coalitions could be the subject of support, as could their necessary reflection on possible options for supporting an agricultural economy based on sustainable aquifer use. Groundwater management requires the design of innovative territorial policies regarding both the instruments to be used and the manner in which they are developed and used.

Many overexploited natural resources in the Maghreb share similar characteristics to those of groundwater, for instance the difficulty of individually controlling the withdrawals of many informal users, the complex dynamics of these natural resources and the limited means of public organizations responsible for managing such resources. For example, this is the case for forests and steppe areas used for livestock grazing. The main management principles presented in this study, such as the opportunity to combine approaches, or build coalitions for reflection and management that encompass actors beyond the agriculture-natural resource tandem, will also be major factors for reflection on how to obtain the means of effective governance, combining local and national levels of these other natural resources.

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