Hydrogeol J
DOI 10.1007/s10040-017-1568-2

PAPER

Groundwater overexploitation: why is the red flag waved? Case study on the Kairouan plain aquifer (central Tunisia)

Sylvain Massuel[1] · **Jeanne Riaux**[2]

Received: 13 May 2016 / Accepted: 8 March 2017

Abstract In many parts of the world, groundwater users regularly face serious resource-depletion threat. At the same time, "groundwater overexploitation" is massively cited when discussing groundwater management problems. A kind of standard definition tends to relegate groundwater overexploitation only as a matter of inputs and outputs. However, a thorough state-of-the-art analysis shows that groundwater overexploitation is not only a matter of hydrogeology but also a qualification of exploitation based on political, social, technical, economic or environmental criteria. Thus, an aquifer with no threat to groundwater storage can rightly be considered as overexploited because of many other prejudicial aspects. So, why is groundwater overexploitation so frequently only associated with resource-depletion threat and so rarely related to other prejudicial aspects? In that case, what really lies behind the use of the overexploitation concept? The case of the Kairouan plain aquifer in central Tunisia was used to analyze the way that the overexploitation message emerges in a given context, how groundwater-use stakeholders (farmers, management agencies and scientists) each qualify the problem in their own way, and how they see themselves with regard to the concept of overexploitation. The analysis shows that focusing messages on overexploitation conceals the problems encountered by the various stakeholders: difficulties accessing water, problems for the authorities in controlling the territory and individual practices, and complications for scientists when qualifying hydrological situations. The solutions put forward to manage overexploitation are at odds with the problems that arise locally, triggering tensions and leading to misunderstandings between the parties involved.

Keywords Over-abstraction · Groundwater management · Water-resources conservation · Socio-economic aspects · Tunisia

This article is part of the topical collection "Groundwater-based agriculture in the Mediterranean"

✉ Sylvain Massuel
sylvain.massuel@ird.fr

[1] IRD, UMR G-EAU, 361 rue J-F Breton, BP 5095, 34196 Montpellier cedex 5, France

[2] IRD, UMR G-EAU, BP 434, 1004 Tunis, Tunisia

Introduction

Overexploitation of groundwater has been presented as a major issue, dominating debates on water for several decades (i.e. Mitchell et al. 2012). Underlying these messages, there is the threat of a widespread decline in the quality and quantity of groundwater reserves. Although this can be justified in many cases where there is severe degradation of the water resource, the rhetoric on overexploitation is becoming increasingly common in all contexts. Yet it would seem inappropriate to qualify the exploitation of confined and unconfined bedrock, karst and alluvial aquifers, in semi-arid or humid tropical conditions, using the same set of criteria, for instance a water-table drop over a few years. While it would be typical in semi-arid conditions, it would be seriously worrisome in a tropical context. There is, therefore, a need to question this concept of groundwater overexploitation, the meaning that is given to it and what it implies. The usual discourse surrounding overexploitation comes with strong catastrophist undertones, especially when it is linked to messages on climate change and the threats it poses for food security. However, does overexploitation only embody the risk of exhaustion of underground reserves? In other words, what is implicated by

Published online: 03 April 2017

the "red flag" waving every time groundwater levels decline? What are those alarm bells hiding?

Social science research has already demonstrated a number of negative effects resulting from the general use of this concept, including an abrogation of the responsibilities of public water sector action in the growing scarcity of resources (Wester et al. 2009) or, contrastingly, the authorities using the concept to justify their management choices (Budds 2009). The aim of this paper is to take another look at the question of overexploitation by combining hydrogeology and anthropology for a more in-depth approach. Bringing these disciplines together will allow for examination of the assumption that behind the concept of overexploitation, there is an array of issues that are not all directly related to the "water resource". The message on overexploitation would thus conceal deeper-seated social and political problems. If that is the case, it is then necessary, and possible, to analyze the discourse of the various stakeholders waving the overexploitation flag, and that of scientists in particular.

To that end, the concept of overexploitation will be reviewed on the basis of the current state of knowledge, with special focus on the production of hydrological knowledge, which will point to the well-established nature of the overexploitation message, which must be accepted as is. Rather than seeking a single, relatively synthetic definition, the sheer variety of definitions put forward in the literature will help to look more closely at what overexploitation means through the diversity of its interpretations. The analysis will thus begin with the use of the concept in one unique context— in a case study—and thus a specific meaning, to identify the more general questions that it raises.

The case of the Kairouan plain and the Merguellil River basin is ideal for such investigation. It is an area for which there is significant hindsight, having been the site of several research programs since 1996. The study mobilized an inductive reasoning following the *grounded theory* of Glazer and Strauss (1967). This qualitative approach consisted in collecting data (observations, measurements, bibliography, interviews etc.) on the three main categories of water actors identified in the Kairouan plain case study (farmers, public management agents and scientists). Data were gathered in the field with farmers and well owners, and in the public decision and scientific arenas (congress and meetings, reports, publications, archives analysis and in-depth interviews with selected actors). In a second stage, the construction of hypothesis was carried out incrementally. Hypothesis were confronted with new field data and constantly reformulated until reaching a consensus on the interpretation of the situation (Olivier de Sardan 2005, 2015). During 4 years (2012–2016), the work was carried out collectively, associating anthropologist and hydrogeologists, from the data collection to the analysis (a so-called "socio-hydrological approach", see Riaux and Massuel 2014).

The paper will be presenting the analysis of the notion of aquifer overexploitation according to the hydrological literature and highlighting its very situated significance implying the case study analysis. The history of the groundwater exploitation in the Kairouan plain will be traced focusing on the relatively recent emergence of an overexploitation concern on the Kairouan aquifer. Then the aquifer overexploitation seen by the different water actors (farmers, public officials and scientists) will be described and analyzed. Finally, the discussion will be evidencing the difficult dialog between actors underlain by serious misunderstandings about what the aquifer overexploitation embodies because they all tend to view their own concern in the overexploitation meaning.

What does groundwater overexploitation embody?

A persistent kind of sophism

In the rhetoric most frequently put forward in the various political or scientific arenas, the idea of overexploitation is often presented in the introduction to discussions on groundwater management. The usual argument is split into three phases that follow on logically from one another: (1) water tables are falling and there is the risk of a shortage or the shortage has already been ascertained; (2) the development of irrigated farming is the main reason for this; (3) use of the resources must be regulated.

The paper by Petit (2004) on groundwater governance clearly illustrates this progression of ideas:

> Far from being a widespread phenomenon, overexploitation affects groundwater in regions with semi-arid and arid climates, as well as more temperate areas. As such, since the end of the Second World War, the development of irrigation and green revolutions has played a significant role in supply crises. Efforts to prevent overuse of groundwater correspond to a form of sustainable governance of these resources.

Reports on recent research into alternatives to the centralized management of groundwater often start the same way—for example, Steenbergen (2006) says:

> In many areas of Asia and the Middle East, intensive aquifer use has been the single major factor that transformed the rural economy in the last 25 years. It has boosted crop production and improved access to relatively clean drinking water. Some lesser-known positive effects are that lowered water tables reduced non-beneficial evapotranspiration and increased the capacity to buffer storm water. Yet in many areas the miracle created by intensive aquifer use is under strain.

> Overuse of groundwater is by now documented in several rural economies in Asia and the Middle East. The consequences differ between places, but are often alarming: declining, sometimes vanishing water tables, saline water intrusion, increased levels of arsenic and fluoride in drinking water, land subsidence. There is a search for solutions. Literature makes several suggestions such as groundwater pricing, defining rights and concessions, participatory groundwater management.

Without calling into question the relevance of the works that start like this, there are a number of consequences when arguments are constructed this way. Firstly, the phenomenon of overexploitation, its causes and the need to improve groundwater management are taken as the starting point to the discussion. Then, the overexploitation phenomenon itself is taken for granted, with its definition established elsewhere and universally accepted. The sequence of arguments clarifies several assumptions (on the phenomenon, its causes and the solutions to be implemented) and generalizes their validity, with figures and bibliographic references to back them up.

This is a fallacy in the form of *petitio principia*, in other words, a kind of circular reasoning where the conclusion is part of the initial premise. Specialists in water resources, hydrologists, hydrogeologists and geologists are hence implicitly seen as guarantors of the reality of overexploitation. This infers that they have an unequivocal definition of aquifer overexploitation, applicable in all circumstances because it refers to physical considerations (falling water table, salinization, contamination or terrain subsidence). However, a rapid overview of the literature shows that the hydrologists barely use the notion of overexploitation and prefer using intensive use (i.e. Llamas and Martinez-Santos 2006) or unregulated exploitation (i.e. Sanz et al. 2016). Furthermore, groundwater is not even explicitly addressed in water legislations of many countries and when it is, most of the legal definitions address the issue of sustainability. The Spanish Water Code of 1985 converted into legal term the concept of aquifer overexploitation: "An aquifer shall be considered to be overexploited, or in danger thereof, if the subsistence of the reserves existing therein are being placed in immediate danger as a result of annual withdrawals that are in excess or very close to, the average annual volume of the renewable annual resources, or which give rise to serious deterioration in the quality of the water". Other definitions can be indirect and very evasive like in the Tunisian Water Code (Art. 15, 1973) about the conservation areas: "the rate of exploitation of existing resources may endanger the quantitative and qualitative water conservation". In the European Water Framework Directive (2000/60/EC), the term of "available groundwater resource" is defined in article 2, definition 27: "… the long term annual average rate of overall recharge of the body of groundwater less the long term annual rate of flow required to achieve the ecological quality objectives for associated surface waters specified under Article 4, to avoid any significant diminution in the ecological status of such waters and to avoid any significant damage to associated terrestrial ecosystems.". Aquifer overexploitation seems to be a common designation of a large variety of poorly defined situations that have in common some perception, real or not, often deviated of negative and perhaps irreversible evolution by some sectors of Society.

The (rare) people having worked on this topic affirm that the concept of overexploitation is complex and that, while a consensual scientific definition exists, it very often differs from that generally put forward due to a misconception, or indeed the omission, of the specific subsurface flow processes (i.e. Collin and Margat 1993; Custodio 2000).

Reminder about groundwater level fluctuation

Before going any further, it is important to understand the concept of groundwater balance. This overall (and not merely local) state of the groundwater is achieved when inputs are equivalent to outputs, so a constant resource is maintained (Alley et al. 2002). As such, piezometric levels may fluctuate around a constant inter-annual level following the natural seasonal cycle of recharge and discharge. These fluctuations demonstrate the regulatory function that aquifers play, especially their crucial role in semi-arid areas where they can reduce the impacts of dry spells on water availability. In the case of unconfined aquifers, a regional imbalance between inflows and outflows leads to a readjustment of levels and the volume of water stored, with greater and lesser inertia and amplitude depending on the aquifer's hydrodynamic properties. If a negative imbalance persists, the non-renewable stock is consumed and the groundwater's regulatory role is threatened. The reserve may eventually be depleted and water availability strictly limited to seasonal recharge. When the imbalance is due to intensive exploitation (elimination of recharge and/or abstraction), it is important to ascertain whether the disparity is temporary, i.e. the levels will readjust and reach a new equilibrium, or more permanent, i.e. the balance will never be re-established.

However, due to the length of time required to readjust the balance (sometimes several decades), exploitation of an aquifer with an imbalanced regime is often confused with excessive exploitation. The geological nature of the aquifer can be part of the confusion with different hydraulic properties and dynamics (e.g. karst versus hard-rock aquifer). Clearly there are no universal physical boundaries determining the excessive nature of exploitation of an unconfined aquifer with variable reserves. Every case is unique and abstraction always occurs at the expense of another flow. The same is true of the water quality. Defining the overexploitation of an aquifer is therefore more a case of defining the limits to be set for its exploitation, i.e. what is acceptable for society (e.g. Margat

1977; Custodio 2002). In the case of a confined fossil aquifer or an aquifer with very low recharge, the concept of balance is non-existent, so talk of overexploitation is nonsensical.

A catch-all meaning

The questions of "what is reasonable" and "over what time period" therefore logically come into play. This is reflected in the concept of "safe yield" (e.g. Lee 1915; Meinzer 1923) and, more recently, "sustainability" (see WCED 1987; Llamas 2009). With these concepts, the criteria defining the limitations of non-detrimental exploitation, i.e. overexploitation, are no longer merely technical (excessive drawdown reducing yield from pumping infrastructures) but also include environmental, social, economic and/or political aspects (Margat 1977; Loucks 2000; Alley and Leake 2004). It is then necessary to define indicators to measure the damage. These indicators are generally focused on the condition of the resource and must be able to qualify all situations; they are therefore poorly suited to specific cases. Reflections on the criteria to be taken into account (time period, uncertainties, baseline condition and concepts) gives rise to a series of controversies, even more so since these considerations evolve over time. A series of conferences of the International Association of Hydrogeologists held in Spain between 1989 and 1992 (e.g. Candela et al. 1991; Dijon and Custodio 1992), to discuss the concept, the real meaning and situation of aquifer overexploitation, the definition of the concept of overexploitation and the choice of relevant indicators struggled to reach a consensus (e.g. Custodio 2002; Devlin and Sophocleous 2005). The notions of *safe yield* or *rational yield* thus lost their relevance and were abandoned.

At the same time, there are misconceptions about the basic hydrogeological principles. For example, Brown (1963) and Bredehoeft et al. (1982) talk about the "water budget myth" which clearly illustrates the discrepancy in the use of the fundamental concepts. The authors point to the all too common misunderstanding, whereby the exploitable quantity (i.e. the volume that does not lead to any excessive modification in the reserve) is assimilated with natural recharge (i.e. safe yield). This measurement of exploitable volumes is based on the water budget method, which does not account for the aquifer's reaction to changes to components in the balance. In most cases (non-isolated systems), this volume does not have any connection with the safe yield. In fact, it is more closely related to the recharge induced by the change in flows when there is an imbalance between inputs and outputs (capture). This justifies the need for hydrodynamic modelling that takes into account the relationships between the different physical components in a water system (e.g. Massuel et al. 2013).

Hydrogeologists are falsely taken for the guardians of a consensual definition of groundwater overexploitation because groundwater overexploitation does not refer only to hydrogeological notions. It is now clear that groundwater overexploitation is much more than a hydrogeological matter. Besides, a generic definition of "overexploitation" does not exist in the hydrogeological literature. Such a definition inescapably remains linked to context because it depends on a specific environment and a specific sociopolitical situation. Hydrogeologists alone are unable to select the "right" interpretation of overexploitation, they can only investigate the effects of the different interpretations.

Nowadays, the notion of groundwater overexploitation most often refers to a severe deficit between inputs and outputs in an aquifer system over an extended period. This "operational" definition is based on the concept of water balance, where the specialists estimate the various components by recording the processes and flows to optimize exploitation while conserving the renewable reserve and groundwater levels.

The difficulty of accurately defining the term "groundwater overexploitation" implies several things. On the one hand is the impossibility of applying a general formula to decide whether or not a situation is actually a case of overexploitation. As such, no decision concerning groundwater can be based on a "neutral" or "objective" interpretation of the situation. On the other hand, and as a result, a drop in piezometric levels can give rise to a multitude of reactions. The meaning given to the term overexploitation very much depends on the criteria that it is measured against and the actors defining those criteria. The question is not about defining indicators, but how to interpret them within situations where the meaning of overexploitation is different because concerns are different at one point. An example would be if, in a case A, environmental concern was dominant for society and in a case B agricultural development concern was dominant, and in both cases the groundwater exploitation led to a significant drop of the water table. A multi-attribute indicator based on water level and ecosystem conservation would conduct the stakeholders to qualify their groundwater situation as overexploited in case A and not in case B. Simply because it is acceptable in case B to get more land for cultivation at the expense of biodiversity, whilst it is not in case A. And both would be right. As a result, the overexploitation issue may be stated on the grounds of different facts or phenomena. The assumption can be made that, depending on how they see the problem or the solutions to overcome it, the various parties expounding the overexploitation message can raise very different questions. In other words, in a same situation, the overexploitation flag waved by different stakeholder groups may conceal some very diverse concerns. This does not mean that the overexploitation concept is inappropriate to use for dealing with groundwater problems. This only means that those concerns have to be understood for dealing with the right water problems and not stubbornly trying to solve sometimes irrelevant generic problems.

The case of the Kairouan plain aquifer in central Tunisia is the perfect example. It has been known to be overexploited for

decades with a serious drop of the water table of 30 m in 40 years (Leduc et al. 2007; Le Goulven et al. 2009; Besbes et al. 2014). The main identified water problem is the groundwater reserve depletion threat, whilst the developing water access inequity due to the drop is ignored. This enables an in-depth analysis with a view to identifying what the concept of overexploitation embodies for the different stakeholders involved.

The Kairouan plain aquifer: from valuable extraction to unsound overexploitation

The Merguellil basin and the Kairouan plain aquifer

The wadi Merguellil basin is representative of the water problems in the Mediterranean region. The climate is semi-arid with 300–500 mm of total annual rainfall. This non-perennial stream is fed by a 1,200-km^2 catchment and used to run through the north of the Kairouan plain downstream over a 700-km^2 area before the construction of the El Haouareb dam to end up in a dry salt lake, the sebkha Kelbia (Fig. 1). In the watershed, three major aquifers supply drinking water and agriculture. In the Kairouan plain, irrigated agriculture based on groundwater supply from the thick Mio-Plio-Quaternary semi-confined aquifer (200–500 m of saturated layer) has developed extensively since the 1980s. High-value crops are now cultivated (mainly horticulture and orchards) but are much more demanding in water than traditional rainfed crops (Leduc et al. 2007; Le Goulven et al. 2009).

This area is particularly relevant when looking at the question of groundwater overexploitation because it contains some of the largest reservoirs in central Tunisia, which are also the most intensively exploited. In the face of the rapid, widespread drop in piezometric levels (around 1.5 m/year), the threat of depletion of the groundwater reserves emerged. The overexploitation red flag has been waved for 20 years now, as Besbes et al. (2014) summarize well: "among overexploited aquifers, a number of them occupy a special position in terms of risk, due to the significance of their intrinsic resources and their level of overexploitation [including the Kairouan plain aquifer]". Nonetheless, the Kairouan plain aquifer is a vast reservoir (3,000 km^2 and up to 500 m of saturated thickness) becoming semi-confined and multi-layered toward the Eastern part. The water salinity values range from 2 to 6 g/L with no evidence of vertical stratification (see for more details Ben Ammar et al. 2009). The mean annual recharge was estimated at 65 hm^3 by Nazoumou and Besbes (2001). In its northern part only, Massuel et al. (2017) estimated the total groundwater withdrawals for irrigation and drinking water supply at around 285 hm^3 in 2010. The geometry and water balance are sufficiently well known to put the imminent risk of depletion of the resource into perspective. Around 10% of the geological reserve (gravitational water) has been consumed over 40 years of intensive exploitation (Jerbi et al. 2014). This means at least 150 years of

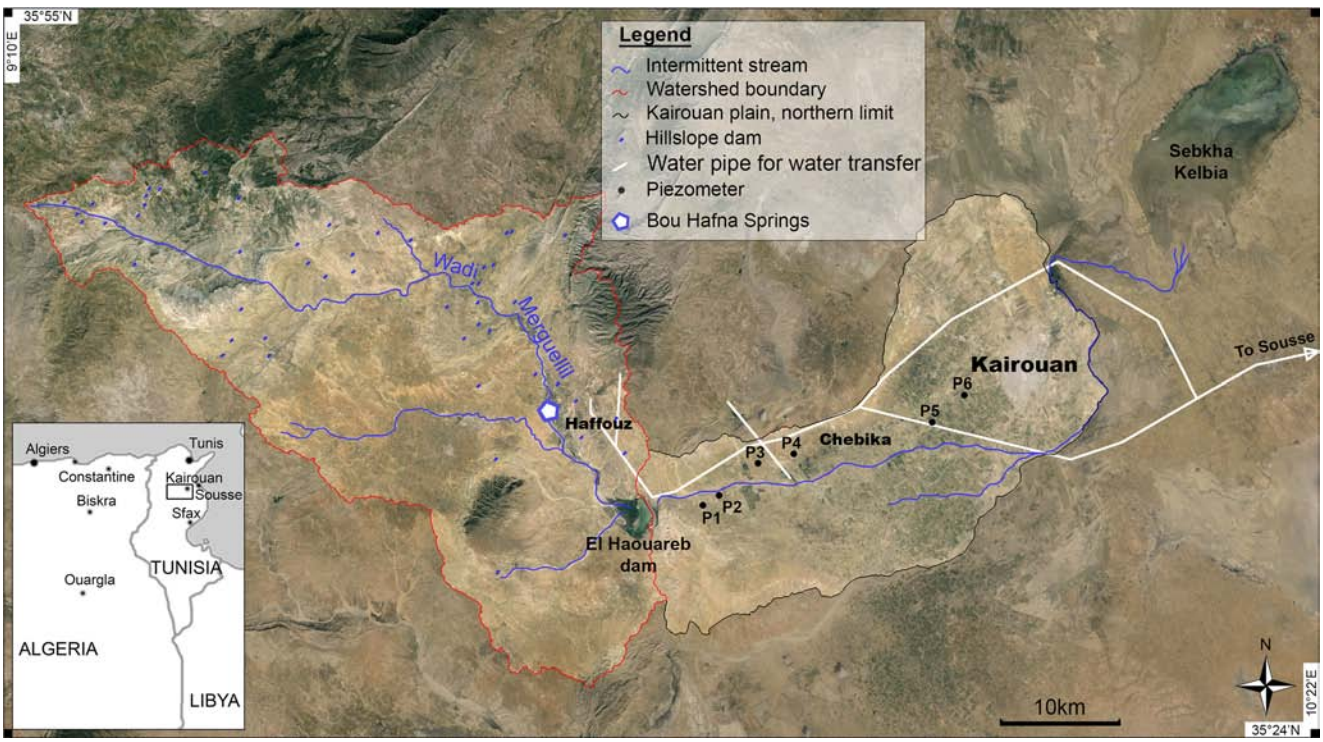

Fig. 1 Map of the study area

exploitation remaining at the present pace. It is therefore worthwhile comparing the rhetoric on overexploitation with the reality of the situation, and taking a look at the history of the river basin's development policies.

An historical journey from exploitation to overexploitation

For the past hundred or so years, the Merguellil River basin has been subject to massive, ongoing public intervention, contributing to a profound transformation of the region's hydrology. A short analysis of these policies and the messages that go with them shows that the discourse moved on from "valuable extraction" to "unsound overexploitation".

Firstly, the desire to develop irrigated agriculture on the Kairouan plain has resulted in a century's worth of public intervention. Although spate irrigation is a very ancient practice in the area around Kairouan (Penet 1908), irrigated areas were developed in the upstream part of the basin from the 1920s onwards. Initially, the waters of the Merguellil were used to supply colonial farm holdings. Soon, however, the river water was no longer able to satisfy demand, and the ensuing conflicts were resolved by granting farmers' rights to groundwater (Belaïd and Riaux 2013). The colonial farm holdings were brought into the state domain at the time of independence, and were then turned into agricultural cooperatives in the 1960s (Zghal 1967). From the 1970s onwards, the state created small public irrigation schemes supplied by communal boreholes. Eventually these boreholes were unable to meet the demand and in the 1980s, farmers began to use private wells and boreholes, encouraged by state subsidies and credits (Jouili et al. 2013). While the original objective was to develop subsistence farming associating both dry and irrigated agriculture, in the end, intensive irrigated agriculture dominated. This is when the risks of a decline of the resource were first highlighted. In parallel with this agricultural development, an alarmist discourse developed around the concept of overexploitation, pointing to the growing number of private abstraction points. In other contexts, this process was pointed out as a "silent revolution" (Llamas and Martinez-Santos 2006). Yet the process was underway, and the benefits were such for those able to use groundwater that there was no turning back. The demand management policies implemented since the 1990s do not appear to have been effective in curbing the rise in groundwater abstraction. According to an inventory of wells conducted in 2010 (Geohydro, unpublished report, 2010), the total number of structures tripled in 25 years in the study area, going up from 650 in 1985 to 2200 in 2010.

Alongside agricultural development, the transfer of water from the wadi Merguellil towards the coastal region of the Sahel to supply towns with drinking water has also had a considerable impact upstream in the basin. From the early twentieth century, the Compagnie des Eaux du Sahel (Sahel water board) was granted rights on the water from the Bou Hafna springs located on the banks of the wadi Merguellil (Fig. 1) to supply water to the coastal city of Sousse (Tixeront 1953). From then on, the volumes of water transferred from the upstream portion of the basin towards the coast increased proportionally to urban demand, increasing from 3 hm^3/year in 1903 to more than 10 hm^3/year in the 2000s. According to Besbes (1967), the original operating strategy was to pump at a rate exceeding renewal capacity on a provisional basis, in order to take the groundwater level down to a target depth. The goal was to minimize losses through direct evaporation and underground transfers to neighboring aquifers that were more difficult to exploit. After that, there would be a return to a normal operational pumping rate, matching the renewal rate, to maintain constant levels. Over time, the provisional pumping regime became permanent and has even been gradually stepped up.

The region's history testifies to strong growth in groundwater abstraction, but at the same time, hillslope water conservation measures have influenced groundwater recharge. While erosive processes were already established as a problem during the Protectorate, it was only at the time of independence, as part of works to "overcome underdevelopment" that "water and soil conservation" projects —hillslope tanks, small dams and step-like benches—were introduced in the upstream portion of the basin (Côte 1964). These developments have continued until the present day, in the framework of strategies introduced by the Ministry for Agriculture and backed by international donors. They are justified by the need to control erosion, recharge aquifers, develop small-scale irrigation and limit silting of the dam located downstream. From the 1990s onwards, however, controversies emerged concerning the impact of these structures, which has been rising since the mid-1970s, on surface runoff.

In 1989, the construction of the El Haouareb dam on the Wadi Merguellil also led to considerable impacts on the processes involved in recharging the Kairouan plain aquifer. The idea for the dam goes back a long way (Coignet 1917, quoted by Baduel 1987) and was motivated from an agricultural development viewpoint; however, it was the need to protect the town of Kairouan following devastating floods in 1969 that finally justified its construction. The dam was also intended to supply an irrigated zone covering some 2,500 ha while benefitting the recharge of the Kairouan plain aquifer through controlled releases; however, things did not turn out as expected: little water was actually stored and the seepage in the underneath fractured limestone could not be controlled, inhibiting flood releases and keeping a very localized contribution to recharge (Alazard et al. 2011; Ben Ammar et al. 2009). This also gave rise to controversy and triggered debates. For some people, the dam was responsible for evaporation loss and an alteration to the Kariouan plain aquifer's recharge, while for others, the dam had the potential to fulfil its flood protection role while allowing water to seep into the

groundwater system, but it did not receive enough water flow upstream because of the water and soil conservation infrastructures. For this latter group, there is therefore a need to increase inflow rates into the dam reservoir: a project to transfer water from the neighboring dam is currently under study (Studi 2014).

The various elements in the history of hydro-agricultural development of the Merguellil basin illustrate the different periods of state intervention in the Kairouan region. The Protectorate period was marked by the production of water management plans (i.e. Tixeront 1953). Then, with independence (1956) came a period of widespread, proactive intervention affecting the physical, productive and social landscape of the area, inspired by the plans drawn up previously (Pérennès 1988). This went on until the 1980s when the liberal shift of the policies led to a decline in state services and the encouragement of private initiatives, especially in the realm of agricultural development. At the same time, there was a gradual move away from encouraged exploitation, necessary for development, as described by Nullet (1938): "the development of this area [the civil district of Kairouan] will only occur when all of its water resources have been mobilized", to a more negative view that exploitation that had become "too intensive". This shift in the message led to the emergence of the concept of overexploitation in the 1980s and a polarization of discourse on the impact of water management on groundwater (i.e. Hamza 1983). For example, through the analysis of literature one sees the concepts put forward to justify hillslope developments shift away from the notion of "oversupply" from the groundwater system (optimizing exploitation) to that of "resupply" (offsetting exploitation; Tixeront 1957; Montoroi et al. 2002). Current operational logic tends to go away from drawing water off from a reserve or intercepting a flow at a certain point in the water cycle. Interception obviously affects what happens to that flow for the rest of the cycle. The logic have moved on from an approach aiming to maximize the intercepted flow to a logic of minimizing interference, based on assessment criteria that change over time.

What is more, management policies are now conceived in an "integrated" manner, as testified in the development masterplans produced by the Ministry of Agriculture's central department (Besbes et al. 2014). Yet, in practice, development action is highly sectoral and the action of various authorities involved remained very compartmentalized. What with hillslope developments, agricultural development, dam management and drinking water supply, the approaches to resource management sometimes appear contradictory. For instance, the hillslope development planning policy is torn between two main objectives: promoting the local development with irrigation from small reservoirs as demanded by the rural development authorities and favoring the drinking water supply through artificial groundwater recharge from the same reservoirs as demanded by the national drinking water supplier.

This leads to controversy over the usefulness and impact of these developments. Against this background, the problem of overexploitation crystallizes the discourses and sees each stakeholder position themselves with regard to a given, but unexplained, issue.

There's no smoke without fire: what does overexploitation actually mean for stakeholders involved in water management?

In this section, the way that overexploitation takes form for the various stakeholders in water is analyzed. Clearly, a discourse that has become so widespread and is taken for granted in the way that overexploitation is must be rooted in facts, findings or perceptions. Looking beyond the discourse, how real is the "problem" for the stakeholders involved? How do they make their diagnosis?

Three categories of stakeholders have been identified in the analysis. They all have a role to play in elaborating the discourse on overexploitation: (1) farmers, directly affected by environmental changes that impede their practices, (2) resources specialists, engineers or researchers who measure, quantify and seek to explain the processes, (3) the regional agricultural authority whose role is to implement the policies drafted at national level in close liaison with its engineers specialized in the resource.

Farmers face problems with water access

Farmers on the Kairouan plain actually talk very little about overexploitation. The following testimony sums up their point of view: "groundwater is retreating and we are chasing it". For them, the problem is not about water scarcity, but about a fall in groundwater levels making access to water increasingly complicated. This viewpoint seems to be commonly shared by rural population in the Maghreb (i.e. Bekkar et al. 2009).

Through their pumping practices, they have direct experience of the fall in piezometric levels: the change is tangible and visible for them. It is hard to ignore because the change has been fast and widespread (a drop of 1–2 m/year). On the other hand, farmers do not have a clear opinion on the reasons for this fall. For many of them, groundwater moves in the same way as an underwater stream does. Some of them, who live near the recharge zones, observe the rising levels after floods; they logically make an analogy with the heavy rainfall. Others say that local abstraction is too high, after noticing drawdown caused by two structures that are too close to one another or by a catchment for drinking water supply; however, these farmers are used to a changing hydro-climatic context, with sometimes considerable variations. The "retreat" of the groundwater system is just an additional hazard for many of them. It is not necessarily irreversible and there is

thus no need to determine its precise origin. In fact, in response to the question of the future of groundwater, many answered that "what lies underground is God's will and beyond our knowledge". Other than the fall in water tables, changes in water quality have also had noticeable effects such as soil degradation and a fall in agricultural yields. Again, the farmers witness spatial variability in water quality and, when they can, mix waters of different qualities, for example to offset excessive salt levels in well water.

There are therefore visible changes, noticeable from one generation to another and engendering multiple constraints for farmers. These mainly concern the depletion or the fall in output of wells. Water becomes harder to get to and existing access to water cannot be seen as durable. Yet to remain in the area, farmers need to irrigate and therefore improve their access to groundwater. To this end, they are adapting their abstraction techniques in a variety of ways: making traditional open wells deeper (2–4 m every 2 years) and using centrifugal diesel pumps; digging at the bottom of depleted wells (a technique that helps them get round the ban on pumping beyond depths of 50 m) and a switch to centrifugal or submerged electric pumps or to deep boreholes (90–120 m) combined with a submerged pump. This latter option guarantees access to groundwater for several decades, depending on the quality of the structure; however, this technical work requires sums of money that smallholders do not necessarily have available—also it requires authorization for deepening the well or for deep boreholes, while in other cases, the work is done unlawfully. All of this also implies a clear land tenure situation (land title and no inheritance disputes) or a sound network of influence, which is more likely for larger farm owners. This is clearly perceived by smallholders who call out the severe inequality in access to the resources required to adapt and worry more about the depletion of their own well than about groundwater in general. They condemn the state's withdrawal from water supply (deterioration of public boreholes) and the incompatibility of the solutions put forward by the authorities (technology package, deficit irrigation and credits) with the finances of smallholdings. As a result, for the majority of farmers interviewed, the question of preservation or depletion of the reserve is not their main concern. Of course they have questions about the future but for them, as long as they are able to adapt to constraints on water access, they will continue to do so. Those who are unable to will leave, as many families already have done. The aim then is to draw maximum benefit from groundwater to make provision for a more difficult future.

Resource specialists are faced with a process that is difficult to qualify

The second group of stakeholders is made up of specialists in the resource, i.e. people who produce technical and scientific knowledge on the Kairouan plain aquifer system such as hydrologists and hydrogeologists, engineers and academics, consultants, and so on. Like farmers, the specialists have observed a considerable fall in piezometric levels since the mid-1970s (Fig. 2). This ongoing decline is the outcome of a marked imbalance between inputs and outputs in the aquifer system (Leduc et al. 2007). Occasional adjustments are observed, as is often the case in semi-arid regimes where extreme wet weather events, with decennial, centennial or even millennial cycles, suddenly fill aquifer reserves. The millennial flood of 1969 (Bouzaïane and Lafforgue 1986) is a perfect illustration for the Kairouan region: measurements show a rise in piezometry of up to ten or so meters around the main infiltration zones (P1 and P2 in Fig. 2). It took almost 5 years for the infiltrated water to spread throughout the groundwater system leading to an overall rise, or more accurately, the absence of a fall (P5 and P6 in Fig. 2).

Adjustments occurring over the long term are attributed by resource specialists to the construction of the El Haouareb Dam to retain floodwaters at the entry to the plain, modifying the recharge processes which now only occur via seepage from the reservoir. The falling groundwater level is also a response to abstraction for irrigated farming which has been developing and intensifying since the end of the 1960s; no significant return flows to groundwater from over-irrigation have been recorded to date. The aquifer system of the Kairouan plain, therefore, shows erratic fluctuations in piezometry over time and space, with the adjustment of surface-water regimes stemming from climatic variability or long-term changes. The ongoing nature of these overall changes combined with uncertainties about the hydrodynamic processes and parameters of the Kairouan aquifer system mean that it is difficult to clearly determine whether the adjustments observed are permanent or if a new balance will eventually be achieved—in other words whether the reserves will be depleted before a new balance can be reached. Current research efforts are currently focused on this point; however, for the specialists, it is clear that the successive occurrence of several extreme weather events, such as the 1969 floods, will not enable a return to the levels recorded before the fall.

This latter point is important because it represents a proof of an irreversible change which alone embodies the threat of resource depletion and dodges the possibility of reaching a new balance that would be synonymous with a reduction rather than an exhaustion of the reserve. The incapacity of the system to retrieve a previous state is systematically seen as unsustainability, while the crucial question, but rarely asked, would be: will it be able to stabilize with the new conditions or not? And the answer would then be a matter of research accuracy. This shortcut between the threat of reduction and exhaustion of the reserve is even made with no discussion about the relevance of the choice of the baseline condition, i.e. here

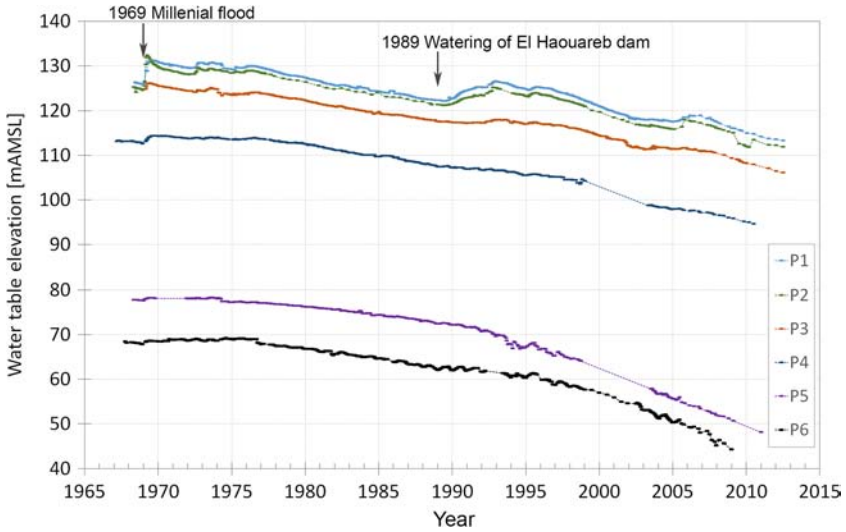

Fig. 2 Water-table evolution of the Kairouan plain aquifer. The six piezometers are located on Fig. 1; *P1* and *P2* are located close to a recharge area (wadi Merguellil until 1989 and El Haouareb dam from then on); *P3* and *P4* are further away but still influenced by strong seasonal recharge events; *P5* and *P6* are far from any deep infiltration area and show the general static water level of the Kairouan plain aquifer

defined arbitrarily as the water level observed with the very first measurements in 1967.

At the same time, the methods frequently used to fund research require scientists to make their research applicable in operational terms or, at the very least, aligned on the main contemporary societal water-related issues, i.e. water crisis and/or risks of scarcity (Trottier 2008). Overexploitation is one such issue. In the Kairouan plain, the overexploitation issue supports many research projects, including the projects funding this study. The discourse on overexploitation is regularly used as a means to promote the knowledge produced and attract donors. Some of these research projects, undoubtedly useful, are not necessarily linked to a regional issue, leading to the use of generic tools or methodological tests. In practice, many complementary researchers are focusing on finding better technical and institutional options to sustain the use of groundwater, but the results may be unrelated to the questions that stakeholders on the ground are actually facing. For example, the difficult access to declining water tables and inherent inequities are either not addressed, or, research on deficit irrigation is achieving good theoretical results but is entirely out of line with the will of the farmers who first of all want to secure their livelihood.

The authorities are losing control of the situation

In an international context where the focus is on preservation, condemning the excessive exploitation of non-renewable or scarce reserves, the Tunisian water authorities need to change their standpoint. Until recently, their aim was to develop irrigated agriculture, but now development plans target sustainable, integrated, efficient resource management. As such, for the Kairouan plain, the falling piezometric levels provide a very negative indicator. "How do we curtail this phenomenon?" is the question they have to answer, while the region's socio-economic development means that groundwater resources will have to be exploited increasingly. In fact, the Kairouan administrative bodies are primarily faced with a multiplication in the number of pumping points, unlawful pumping points in particular, resulting in a well-established inversion of supply and demand. They previously thought they had control over the situation but deem it is now getting out of hand. This realization is nothing new. The fall in groundwater levels was recorded in the 1970s (e.g. Besbes 1975) and regulatory measures were introduced (no-pumping zones and structures subject to authorization); however, these measures are not abided by: individual groundwater withdrawals are increasing and the fluctuation of the piezometric levels can no longer be qualified as "normal".

Today, the various authorities concerned are feeling the effects of their past actions. Development policies were forcibly imposed in a period where control over resources and their exploitation was the state's main goal. As such, there was no waiting to see the effects of developments before launching new projects. One objective followed another, at a rate faster than the inertia imposed by aquifers. Today, quite suddenly, the state's services are seeing that the decisions made did not all have the expected outcome, especially where that expected outcome has changed over time, with the shift from exploitation to the preservation of resources.

For the authorities, the overexploitation issue arises when the controlled imbalance (between inputs/outputs) enforced on the resource no longer appears to be reversible. The emergence of the issue comes at a time when the authorities are realizing that they are not simply going to be able to do a U-turn. However, it is not only a matter of the loss of control over hydrological processes. The authorities also have less control over populations: the number of cases of illegal tapping of water demonstrates this. Since the 2011 revolution, this phenomenon has gathered pace: farmers are forcibly setting out

their claims before an overwhelmed administration (Gana 2013), leading to ever-increasing numbers of wells and boreholes.

Caught between the need for social peace, agricultural development and the conservation of resources, the local authorities are seeking solutions to contradictory claims from their departments and from farmers. The solutions put forward are still largely based on increasing supply (new boreholes, new transfers, non-conventional water sources, desalinization, etc.). Today, debates focus on greater control over abstraction, but the implementing conditions are still at the investigatory stage, in a political context where the state's authority on the ground remains weakened. All of these measures and the ensuing debates at regional and national level demonstrate the administration's desire to regain control of the situation. The alarmist discourse on overexploitation and the need for more far-reaching management of the phenomenon could thus be seen as an argument used by the authorities to assert their legitimacy, which would not necessarily be a negative intention.

On the ground, the fall in piezometric levels is observed by all stakeholders and is seen as a known fact. Never, in living memory, in the administrative records or measurements, has such a phenomenon been seen in Kairouan. From a hydrogeological viewpoint, there has been an unprecedented shift in the surface/groundwater balance that is unlikely to be reversed naturally. There is therefore a real problem with the resource. Nonetheless, for water users, the problem emphasized is actually not the "resource". The farmers' accounts and practices show that for them, the problem lies in access to water, with concerns over the capacities of smallholders to "follow the water" and ensure their future in the region. For the authorities, the problem is more about maintaining public authority and the capacity of public officials to affirm their legitimacy on the ground, leading to efforts on increasing the water supply or reducing the demand doomed to failure from the very beginning. Against this background, focusing discourse on overexploitation tends to embody the multiple challenges while concealing the specific problems of each party. The next section looks at the consequences of this dual phenomenon of embodiment and concealment of problems in the notion of overexploitation.

Discussion: is overexploitation a dialogue of the deaf?

"Overexploitation" covers a wide array of social, institutional and political issues, engendered by the fall in piezometric levels, among other factors. In fact, by raising the alarm over overexploitation, the situation is reduced to a question of resources, and thus of balance of stocks and flows. This analysis of the situation, mainly put forward by the "specialists" provides the basis for action plans produced by the authorities concerned; however, these solutions are not applicable to the full range of problems encountered by stakeholders concerned by groundwater. This creates tensions and misunderstandings between the different parties involved. Two sides to the question are analyzed here: the relationships between the authorities and farmers when it comes to regulating use, then the relationships between the authorities and the specialists with regard to the role of science in policy-making.

From uses to regulation of uses

The public authorities are currently attempting to establish control over agricultural groundwater withdrawals. To this end, the national government is introducing rules and providing management instruments focused on the risks of overuse of groundwater resources. However, the local application of these policies is meeting with resistance: the scarcity of human resources makes it difficult to implement an effective water police, especially since farmers are developing ways of camouflaging their pumping sites. The farmers themselves encounter problems accessing water, which they overcome through a variety of technical solutions and "institutional arrangements", often by circumventing the law. Consequently, the authorities now find themselves unable to estimate the number of abstraction points and related withdrawals in the Kairouan plain aquifer system. In partnership with international organizations, the Tunisian water administration have initiated "participative projects" to raise farmers' awareness of the overexploitation issue (e.g. GIZ, AGIRE project, unpublished document, 2015), but they remain unconvincing since most of the stakeholders are excluded from the process.

All of these actions contribute to the administration's loss of credibility in the farmers' view. Firstly, the farmers no longer believe the alarmist messages about depletion of the resource: "they've been telling us not to pump for 20 years now, saying that if we go on, there'll be no water left, yet we keep on digging and we always find water". Next, there have been cuts in staff numbers and outreach operations meaning fewer people in the field and creating a distance between farmers and public officials who "view the problems from their offices". Another reason for this loss of credibility probably lies in the fact that every time claims are made somewhat forcibly, the outcome is a local increase in supply (i.e. a new public borehole). However, the farmers' grievances with the authorities go further than that: in response to the discourse on resource conservation, farmers issue recriminations about the sharing of those very resources. On a regional scale, people in Kairouan accuse the Tunisian government of depriving them of a large part of "their water" to transfer it to "hotels on the coast". In a context of indictment of regional inequalities within the country (Ayeb 2011), it will be increasingly difficult to ignore this criticism. Likewise, the "social" issue of the future of smallholdings raised by the farmers is given little attention

by the administration, which focuses its action on larger farms that are more efficient than smaller ones and better able to apply the "technological package" that promises to save on water. The smallholders' claims are gaining force in a post-revolutionary context of political mobilization and condemnation of social injustice (Fautras 2015). The increasingly forceful expression of these claims is putting the authorities in a difficult position. It seems unlikely that a consensus can be reached by farmers and the authorities regarding the overexploitation issue as it is currently presented.

Between science and policy

One can see here that stating water management problems in terms of overexploitation does not help resolve the difficulties related to water in the field. So why does the problem continue to be presented in this way? The history of the relationships between resource specialists and the authorities can partially explain why.

In Tunisia, there is a very strong historical link between science and policy in the field of water (Siino 2004). Since the time of independence, Tunisian hydrological science has been focused on action: scientists were funded or even recruited by the Ministry of Agriculture to disseminate knowledge on water resources and organize exploitation. From then on, the administration's requirements guided the direction taken by research and the scientists' conclusions-oriented public action. This may in fact be why the specialists are the first to wave the overexploitation red flag: they are the first to observe the effects of the actions implemented in the past. Due to the integrative nature of aquifers, with their very long response times, the impacts of decisions made are not often felt soon enough to prevent further ill-advised decisions being made. By the time the effects can and have been observed, they are the outcome of a series of decisions that it would be difficult to overturn. At that point, ringing the overexploitation alarm is in some way equivalent to stating the science and technology cannot control nature and flows.

The Tunisian authorities' stance on the overexploitation issue prompts that of the scientists to some extent. For the authorities, the first step in solving the problem is raising the population's awareness to the existence of an issue that only public action can tackle. Science therefore needs to produce an alarmist discourse and provide arguments to back up the policies that control and restrict individual action; however, from a different viewpoint, while the scientists have to magnify the issue to legitimize public action, society also asks them to provide solutions to the problems they raise. When scientists respond with increasingly in-depth analyses of the different variables in the water balance, the authorities rather ask for "operational knowledge". Specialists of the resource are asked to provide "scientific" answers to eminently political questions: "How do we manage water in order to achieve our development and social harmony objectives without overlooking resource conservation goals?"

This interaction places hydrological scientists in two diverging roles: on the one hand, they are asked to supply arguments for or against a particular form of water management. Yet, depending on the adopted point of view and in a context of strong uncertainties specific to semi-arid environments, different studies may come up with contradictory results. This is the case, for example, for the causes of the fall in surface runoff in the upstream portion of the Merguellil basin. For some, it is the outcome of the fall in groundwater levels upstream due to increased abstraction (Kingoumbi 2006), while for others, hillslope developments are responsible for the fall in runoff coefficients (Lacombe et al. 2008). These conflicting results, rather classical in scientific debate, push scientists to develop their knowledge of hydrological processes further; however, more specialized research goes against the authorities' operational requirements, so they end up accusing the scientists of failing to provide adequate responses to the questions they are asked.

On the other hand, scientists are assigned the role of "experts", in other words, their work has to result in political positioning in regards to the decisions to be made. As Budds (2009) noted in Chili, the aim is to base public decisions on scientific knowledge, which is seen as objective and apolitical; however, as the current state of knowledge on overexploitation demonstrates, that aim is utopian. To overcome this impossibility, scientists provide the authorities with decision aids: integrated models and forward-looking scenarios. Then improbable scenarios can arise such as the immediate division by two of the pumping (Studi 2014).

In response to problematization in terms of overexploitation, research focuses on the "resource", its characteristics and dynamics, either to deepen and specialize knowledge or to simplify it to produce decision aids. In fact, this leads to a dead end: the specialists are unable to provide scientific responses that satisfy the managers, and the knowledge produced becomes increasingly remote from the realities seen on the ground. This all results in a dialogue of the deaf and an exacerbation of the misunderstandings and tensions between stakeholders.

Conclusion

Through the Tunisian case study, it can be seen that in certain contexts, discourse on overexploitation of groundwater actually has little to do with knowledge of the resource itself. On the contrary, the results confirm that the scientists' focus on hydrological processes and the balance in the large yielding aquifers is a response to requests from other arenas—water managers in some cases and politicians in others. Yet waving the overexploitation red flag is a way of turning attention away

from other issues that have little to do with hydrology, but are more socio-political in nature such as inequalities in water access or definitions of the role and organization of administrations. Faced with the water-related issues (access, use or management), each stakeholder sets up solutions depending on the problem that they encounter; however, because the problems are not the same for everyone, they all head in different directions, leading to misunderstandings, contradictions and tensions. As such, stating water problems in terms of overexploitation turns out to be counterproductive. A poorly stated problem leads to ill-adapted solutions, i.e. the question of efficient use is a relevant angle for the economy, but related to a non-issue if it is seen from the viewpoint of the resource.

In the discourse on overexploitation, the question of sustainability of resources is often emphasized, as if this was everyone's concern, whereas in fact the problems encountered by stakeholders in water (authorities, farmers, scientists and the environment) are barely, if at all, included in the discussion. This partially explains why the solutions put forward over the past few decades in water policies based on scientific work do not work. The proposed rules and incentives are not effective or are not applied because they go against the problems that each stakeholder is trying to handle. This is what led Shah et al. (2003) to affirm that the problems of groundwater depletion in India will only find solutions in local initiatives, from the populations directly affected by the problem.

However, in countries like Tunisia, with technocratic, centralized regimes, it appears difficult to change the state's position with regard to water resources. Since independence, a large part of the Tunisian government's tangible action in its territory and populations is based on the mobilization and control of water. Another challenge would be to help those scientists spurred on by the lofty intentions of funding for research to realize that their scientific developments are not always linked to the operational issues that justify them.

The overexploitation issue is therefore not only about its definition and quantification. In other words, it is not merely a matter for hydrologists. After looking at the history of discourse on overexploitation and its meanings in clearly defined contexts, it is possible to identify what lies behind all the red flag waving. For instance, in the case of the Kairouan plain, behind the laudable goal of preserving the resource, appears the authorities' desire to restore their lost control on the agricultural development—which is not necessarily a negative point—and somehow a growing awareness that science and technology cannot control nature. If scientists apply these conditions, they will be able to determine whether or not the problem falls within their area of competence and then, where appropriate, develop the research protocols suited to the issue.

Acknowledgements The authors would like to thank the Tunisian farmers and local institutions for their kind collaboration in this project, the French National Research Agency for funding the Groundwater ARENA project (CEP S 09/11) and the MISTRALS/SICMED action for supporting the DYSHYME project.

References

Alazard M, Leduc C, Virrion R, Guidon S, Ben Salem A, Travi Y (2011) Estimating groundwater fluxes by hydrodynamic and geochemical approaches in a heterogeneous Mediterranean system (central Tunisia). In: Conceptual and modelling studies of integrated groundwater, surface water, and ecological systems. Proceedings of Symposium H01, IAHS Publ. 345, IAHS, Wallingford, UK, pp 253–258

Alley WM, Leake SA (2004) The journey from safe yield to sustainability. Ground Water 42:12–16

Alley WM, Healy RW, LaBaugh JW, Reilly TE (2002) Flow and storage in groundwater systems. Science 296(5575):1985–1990

Ayeb H (2011) Social and political geography of the Tunisian revolution: the alfa grass revolution. Rev Afr Polit Econ 38(129):467–479

Baduel PR (1987) Politique tunisienne de développement hydro-agricole (1881–1983) [Tunisian policy of hydro-agricultural development (1881–1883)]. Maison de l'Orient et de la Méditerranée, Lyon, pp 147–174

Bekkar Y, Kuper M, Errajh M, Faysse N, Gafsi M (2009) On the difficulty of managing an invisible resource: farmer's strategies and perceptions of groundwater use, field evidence from Morocco. Irrig Drain 58:252–263

Belaïd H, Riaux J (2013) Appropriation et gestion des eaux en Tunisie à l'époque coloniale: une histoire de dépossession(s)? Cas du kairouannais [Water grabbing and management in the colonial Tunisia: a history of expropriation(s)? The case of Kairouan]. Rawafid 18:13–36

Ben Ammar S, Jeribi L, Favreau G, Zouari K, Leduc C, Oi M, M'barek J, Beji R (2009) Evolution de la recharge de la nappe phréatique de la plaine de Kairouan (Tunisie centrale) déduite de l'analyse géochimique [Evolution of the water table recharge in the Kairouan plain (central Tunisia) inferred from geochemistry]. Sécheresse 20(1):87–95

Besbes M (1967) L'exploitation du synclinal oligocène du Bou Hafna – Tunisie [Exploitation of the Oligocene synclinal]. Mém Assoc Int Hydrogéol 8:542–544

Besbes M (1975) Étude hydrogéologique de la nappe de Kairouan sur modèle mathématique [Hydrogeological study of the Kairouan plain aquifer with numerical modelling]. DRE, Tunis, Tunisia

Besbes M, Chahed J, Hamdane A (2014) Sécurité hydrique de la Tunisie: gérer l'eau en condition de pénurie [Water security in Tunisia: managing water in shortage condition]. L'Harmattan, Paris, 358 pp

Bouzaïane S, Lafforgue A (1986) Monographie hydrologique des oueds Zéroud et Merguellil [Hydrological monograph of Zéroud and Merguellil]. DGRE-ORSTOM report, DGRE, Tunis, Tunisia

Bredehoeft JD, Papadopulos SS, Cooper HH (1982) Groundwater: the water budget myth. In: Scientific basis of water resource management. Studies in Geophysics, National Academy Press, Washington, DC, pp 51–57

Brown RH (1963) The cone of depression and the area of diversion around a discharging well in an infinite strip aquifer subject to uniform recharge. US Geol Surv Water Suppl Pap 1545C:69–85

Budds J (2009) Contested H2O: science, policy and politics in water resources management in Chile. Geoforum 40:418–430

Candela L, Gómez MB, Puga L, Rebollo LF, Villarroya F (eds) (1991) Aquifer overexploitation. Proc XXIII Congr Intern Assoc Hydrogeol, Puerto de la Cruz, Tenerife, Spain, April 1991

Collin J, Margat J (1993) Overexploitation of water resources: overreaction or an economic reality? Hydroplus 36:26–37

Côte M (1964) La conservation des eaux et des sols en Tunisie [Water and soil conservation in Tunisia]. Méditerranée 2(3):219–242

Custodio E (2000) The complex concept of overexploited aquifer. In: Aspectos éticos, tecnológicos y económicos, Series A, no. 2, Fundación Marcelino Botín, Madrid 45 pp

Custodio E (2002) Aquifer overexploitation: what does it mean? Hydrogeol J 10:254–277

Devlin JF, Sophocleous M (2005) The persistence of the water budget myth and its relationship to sustainability. Hydrogeol J 13:549–554

Dijon R, Custodio E (1992) Groundwater overexploitation in developing countries: report of an interregional workshop. United Nations Department of Technical Cooperation for Development, New York

Fautras M (2015) Land injustices, contestations and community protest in the rural areas of Sidi Bouzid (Tunisia): the roots of the 'revolution'? Spatial Justice 7. http://www.jssj.org/article/injustices-foncieres-contestations-et-mobilisations-collectives-dans-les-espaces-ruraux-de-sidi-bouzid-tunisie-aux-racines-de-la-revolution/. Accessed March 2017

Gana A (2013) Aux origines rurales et agricoles de la Révolution tunisienne [Back to the rural and agricultural origins of the Tunisian revolution]. Maghreb Machrek 215:57–80

Glazer BG, Strauss LA (1967) Discovery of grounded theory for qualitative research. Aldine, Chicago

Hamza A (1983) La problématique de l'exploitation "minière" des eaux de surface et souterraine de la région de Khit el oued [The issue of mining exploitation of surface water and groundwater in the Khit el Oued region].Report, DGRE, Tunis, 27 pp

Jerbi H, Massuel S, Tarhouni J, Lachaal F, Riaux J, Burte J, Leduc C (2014) La nappe de la plaine de Kairouan soumise aux changements globaux: quels effets sur la ressource? [The Kairouan plain aquifer under global changes: what effects on the resource?]. 3rd international symposium Eau-Climat'2014: Regards Croisés Nord-Sud, Hammamet, Tunisia, 2014, pp 1–6

Jouili M, Kahouli I, Elloumi M (2013) Appropriation des ressources hydrauliques et processus d'exclusion dans la région de sidi Bouzid (Tunisie centrale) [Ownership of water resources and processes of exclusion in the Sidi Bouzid region (central Tunisia)]. Etudes Rural 192(2):117–134

Kingoumbi A (2006) Modélisation hydrologique d'un bassin affecté par des changements: cas du Merguellil en Tunisie Centrale [Hydrological modelling of a changing watershed: the case of the Merguellil basin, central Tunisia]. PhD Thesis, ENIT, Tunis, Tunisia, 225 pp

Lacombe G, Cappelaere B, Leduc C (2008) Hydrological impact of water and soil conservation works in the Merguellil catchment of central Tunisia. J Hydrol 359(3):210–224

Le Goulven P, Leduc C, Bachta MS, Poussin JC (2009) Sharing scarce resources in a Mediterranean River Basin, Wadi Merguellil in central Tunisia. In: Molle F, Wester P (eds) River basin trajectories: societies. Environments and Development, Wallingford, UK, pp 147–170

Leduc C, Ben Ammar S, Favreau G, Béji R, Virrion R, Lacombe G, Tarhouni J, Aouadi C, Zenati Chelli B, Jebnoun N, Oi M, Michelot JL, Zaoauri K (2007) Impacts of hydrological changes in the Mediterranean zone: environmental modifications and rural development in the Merguellil catchment, central Tunisia. Hydrol Sci J 52(6):1162–1178

Lee CH (1915) The determination of safe yield of underground reservoirs of the closed basin type. Trans Am Soc Civ Eng 78:148–251

Llamas MR (2009) Sustainable groundwater use and overexploitation. Ground Water 3:135–158

Llamas MR, Martinez-Santos P (2006) Significance of the silent revolution of intensive groundwater use in world water policy. In: Rogers PP, Llamas MR, Martinez-Cortina L (eds) Water crisis: myth or reality. Taylor and Francis, London, pp 163–80

Loucks DP (2000) Sustainable water resources management. Water Int 25(1):3–10

Margat J (1977) De la surexploitation des nappes souterraines [On aquifer overexploitation]. BRGM, Orléans, France, pp 393–408

Massuel S, George BA, Venot J-P, Bharati L, Acharia S (2013) Improving assessment of groundwater-resource sustainability with deterministic modelling: a case study of the semi-arid Musi sub-basin, South India. Hydrogeol J 21(7):1567–1580

Massuel S, Amichi F, Ameur F, Calvez R, Jenhaoui Z, Bouarfa S, Kuper M, Habaieb H, Hartani T, Hammani A (2017) Considering groundwater use to improve the assessment of groundwater pumping for irrigation in North Africa. Hydrogeol J. doi:10.1007/s10040-017-1573-5

Meinzer OF (1923) Outline of ground-water hydrology with definitions. US Geol Surv Water Supply Pap 494, 71 pp

Mitchell M, Curtis A, Sharp E, Mendham E (2012) Directions for social research to underpin improved groundwater management. J Hydrol 448–449:223–231

Montoroi JP, Grünberger O, Nasri S (2002) Groundwater geochemistry of a small reservoir catchment in central Tunisia. Appl Geochem 17(8): 1064–1071

Nazoumou Y, Besbes M (2001) Estimation de la recharge et modélisation de nappe en zone semi-aride: cas de la nappe de Kairouan, Tunisie [Recharge estimation and water table modelling in semi-arid zone: the case of the Kairouan plain aquifer, Tunisia]. IASH Publ. 269, IAHS, Wallingford, UK, pp 75–88

Nullet E (1938) Rapport sur l'organisation du paysannat dans le Contrôle Civil de Kairouan [Report on the organization of the peasantry in the Civil Control of Kairouan]. Fonds des Ponts et Chaussées SG5 188(6), National Archives, Tunis

Olivier de Sardan J-P (2005) Anthropology and development: understanding contemporary social change. Zed Books, London

Olivier de Sardan JP (2015) Epistemology, fieldwork and anthropology. Palgrave, Basingstoke, UK

Penet P (1908) Les syndicats d'inondation de la Plaine de Kairouan. Zeroud et Merguellil [Flood union in the Kairouan plain]. Bull Dir Agric Commer Colonisation 48:443–478

Pérennès JJ (1988) La politique de l'eau en Tunisie [Water police in Tunisia]. Maghreb Machrek 120:23–41

Petit O (2004) La surexploitation des eaux souterraines: enjeux et gouvernance [Groundwater overexploitation: challenges and governance]. Nat Sci Soc 12(2):146–156

Riaux J, Massuel M (2014) Construire un regard sociohydrologique (2). Le terrain en commun, générateur de convergences scientifiques [Building a sociohydrological perspective (2): sharing fieldwork to develop scientific convergences]. Nat Sci Soc 22:329–339

Sanz D, Calera A, Castaño S, Gómez-Alday JJ (2016) Knowledge, participation and transparency in groundwater management. Water Policy 18(1):111–125

Shah T, Deb Roy A, Qureshi AS, Wang J (2003) Sustaining Asia's groundwater boom: an overview of issues and evidence. Nat Res Forum 27:130–140

Siino F (2004) Science et pouvoir dans la Tunisie contemporaine [Science and power in modern Tunisia]. Karthala-Irenam, Paris

Steenbergen F (2006) Promoting local management in groundwater. Hydrogeol J 14(3):380–391

Studi (2014) Établissements d'un diagnostic concerté et bilans actualises des trois barrages de Kairouan dans un contexte de changement climatique, volet 2 [Concerted diagnosis and updated water budget of the three dams of Kairouan in a context of climate change, part 2]. CRDA Kairouan/GIZ, Tunis, 132 pp

Tixeront J (1953) L'alimentation des villes en eau potable en Tunisie [Urban drinking water supply in Tunisia]. Hydraulique and Hydrologie, Direction des Travaux Public, Tunis 1(1), 35 pp

Tixeront J (1957) L'équipement hydraulique de la Tunisie, [Hydraulic equipment in Tunisia]. Hydraulique and Hydrologie, Direction des Travaux Public, Tunis 1(5), 55 pp

Trottier J (2008) Water crisis: political construction or physical reality? Contemp Polit 14(2):197–214

WCED (World Commission on Environment and Development) (1987) Our common future, The Brundtland report, Oxford University Press, Oxford, UK, 383 pp

Wester P, Mollard E, Silva-Ochoa P, Vargas-Velàsquez S (2009) From half-full to half-empty: the hydraulic mission and water overexploitation in the Lerma-Chapala Basin, Mexico. In: Molle F, Wester P (eds) River Basin trajectories: societies, environments and development. CABI, Wallingford, UK, pp 75–98

Zghal A (1967) Modernisation de l'agriculture et populations semi-nomades [Modernization of agriculture and semi-nomadic populations]. Mouton, The Hague