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Incorporating the social dimension into hydrogeochemical investigations for rural development: the Bir Al-Nas approach for socio-hydrogeology

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Abstract A replicable multidisciplinary approach is presented for science-based groundwater management practices: Bir Al-Nas (Bottom-up IntegRated Approach for sustainabLe grouNdwater mAnagement in rural areaS). This approach provides a practical example of the concept of "socio-hydrogeology", a way of incorporating the social dimension into hydrogeological investigations, as reinforced by the translation of the Arabic *bir al-nas*: "the people's well". To achieve this, hydrogeologists act as "social hydrologists" during their monitoring activities, which often bring them into contact with local communities and end users (and polluters) of water. Not only can they retrieve reliable information about traditional know-how and local issues, but they can also change the public perception of science/scientists to create the basis for mutual collaboration and understanding in view of implementing improved integrated groundwater management. The final outcomes are expected to be an increased awareness of communities at the local level and a clear understanding of their water issues and needs from the very early stages of the investigation. Although the importance of using such methods in groundwater analysis and management is widely recognized, hydrogeological investigations are currently dominated by sectorial approaches that are easier to implement but less sustainable. The pressure of population growth, the shift towards more water-dependent economies, climate change and its impact on water availability will require scientists to use a more integrated approach, such as Bir Al-Nas, when dealing with increasing water pollution and water-scarcity issues.

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Introduction

Groundwater is still the least understood component of the water cycle, although it supplies nearly half the world's drinking water and around 43 % of all water consumed in irrigation (GWP 2012a). Despite the efforts of the international hydrogeological community, groundwater has traditionally received (and still receives) less attention than surface water, especially where integrated water resource management (IWRM) is concerned. The recent increase in the demand for water, food, energy and industrial processes, due to both population growth and a shift towards a more water-dependent economy, led to a change in groundwater perception and a severe rise in global groundwater abstraction (Foster and Chilton 2003; Giordano 2009; Siebert et al. 2010; Van der Gun 2012). This dramatically changed the role groundwater played in human society, particularly in the irrigation sector, where it triggered a so-called "agricultural groundwater revolution" (Giordano and Villholth 2007; WWAP 2012), significantly enhancing food production and rural development. This intensification of groundwater use is also known as the "silent revolution" because individual farmers took it upon themselves to irrigate their own land without centralized management or government coordination (Llamas and Martinez-Santos 2005). As a result, although the "worldwide boom in groundwater abstraction" positively contributed to the economic development of many rural areas (Shah et al. 2007), it introduced new problems by modifying local and global water cycles, environmental conditions, and ecosystems. Nowadays, irrigated agriculture is the largest global consumer of groundwater resources, with the largest groundwater-dependent agro-economies being in South and East Asia (GWP 2012a). Estimated groundwater consumption rates for irrigation range from the highest values in Asia (398,631 Mm^3/year, 38 % of the total area actually irrigated with groundwater) to the lowest in Africa (17,863 Mm^3/year; Siebert et al. 2010). Remarkable differences are found in the latter between Northern Africa, with an estimated consumption of 15,685 Mm^3/year (and 32.8 % of the total area actually irrigated with groundwater) and Sub-Saharan Africa, with significantly lower groundwater exploitation (2,178 Mm^3/year and 5.7 % of the total area actually irrigated with groundwater; Siebert et al. 2010). These numbers draw attention to the need to increase control over the rate at which groundwater (especially fossil groundwater) is abstracted and to the possible negative effects of agricultural return flows, notably in shallow aquifers.

Groundwater pollution, aquifer salinization and overexploitation are becoming increasingly serious global concerns (Custodio and Bruggeman 1987; Shah et al. 2000; Custodio 2002; UNESCO-ISARM 2004; Zuppi 2008; Edmunds 2009). These issues are even more crucial in areas where the average rainfall is low and water resources are unevenly distributed or scarce, and in areas where aquifers sustain different ecosystems upon which people depend (World Bank 2007; IWMI 2008; Re and Zuppi 2011). Indeed, the use of groundwater for irrigation in arid and semi-arid zones can significantly alter aquifer water balance (due to high evaporation), thus contributing to water and soil salinization, which is the case in the Mediterranean Basin, where groundwater plays a major role in the water economy of most of the rim countries, especially in the Middle East and North Africa Region (MENA), where it is the main supply source for almost all applications (MED EUWI 2007). Given the current water demand for irrigation, the role of groundwater is crucial in a region where the gap between water supply and demand is estimated to increase fivefold by 2050 (i.e., from 42 km^2/year in 2012 to 200 km^2/year in 2050; WPP 2013).

It is therefore of paramount importance to develop new integrated strategies to preserve natural groundwater quality, to protect it from further contamination and to promote new, sustainable management practices at the local and regional level. If groundwater resources are carefully managed, they can make a significant contribution towards meeting water demands, agricultural needs and adapting to global climate change, especially in coastal regions (WWAP 2012).

The impact of irrigation in arid-prone areas and the interaction between surface water and groundwater in irrigation are both issues that need to be addressed by considering local policies and priorities, i.e., not only local hydrogeological settings and agro-economic realities (GWP 2012a), but also local knowledge and needs. Consequently, implementing adequate management practices requires a combination of sound institutional arrangements, full involvement of the local community, and the alignment of agricultural development goals with (ground)water availability.

It is obviously challenging to identify the most effective approach, but one of the key elements is to ensure that groundwater management strategies are based on a full understanding of local peculiarities and needs. As Foster and Ait-Kadi (2012) highlighted, "the failure of groundwater management often results from inadequate governance arrangements, rather than from lack of knowledge about sustainable yield or pollution vulnerability of aquifers". Hence, hydrogeologists willing to promote science-based management practices must ensure that the concerns about groundwater contamination and depletion (based on a deep investigation into hydrogeological conditions) are complemented by a comprehensive analysis of the social (water-related) issues and of the existing conflicts in water use. This could help in raising awareness of local populations about environmental issues and eventually make them willing to play a leading role in water resource management and protection. In other words, hydrogeologists cannot avoid considering the social management implications of their studies and investigations. Adopting a more holistic approach by combining geosciences and social sciences clearly facilitates the assessment of the relations between groundwater and society, and necessarily involves considering not only how human activities can affect groundwater, but also how groundwater affects human activities. Hydrogeologists should contribute to reducing the dualism between groundwater resources and society by strengthening the role of groundwater in the hydrosocial cycle (which deliberately attends to water's social and political nature; Linton and Budds 2014).

In order to be effective, management practices have to be based on robust and reliable data, and must benefit from integrated analysis, international cooperation and knowledge sharing. These aspects are fundamental in enhancing and disseminating information, developing and promoting approaches and tools that can be replicated in other case studies, and highlighting priority issues at the regional and global level.

Groundwater protection involves controlling water abstraction rates to avoid overexploitation (which occurs when withdrawals exceed natural replenishment rates), and preserving the natural quality of an aquifer by assessing its vulnerability to contamination. Moreover, groundwater should be analyzed from different perspectives to ensure that it is adequately included in IWRM processes (Foster and Ait-Kadi 2012), and studied in synergy with the other components of the water cycle (taking into account the social perspective and the interaction between land use and water needs).

Within this emerging need, the "Bir Al-Nas" (acronym for Bottom-up IntegRated Approach for sustainabLe grouNdwater mAnagement in rural areaS) approach was developed with the overall objective of proposing a replicable example of a new integrated socio-hydrogeological approach for science-based groundwater management practices. In Arabic, *bir al-nas* means "the people's well", emphasizing the effective willingness to include the social dimension into hydrogeological investigations. These practices should also aim to obtain reliable information in order to provide advice and support integrated management practices for sustainable development. This paper presents the Bir Al-Nas approach, proposed as a tool for promoting the development of socio-hydrogeological investigations in rural areas.

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Public participation and stakeholder engagement as a fundamental prerequisite for including groundwater in IWRM

It is well known that the most effective approach to tackling water security problems is Integrated Water Resources Management (IWRM; GWP 2000; McDonnell 2008). Considering the complex nature of the water cycle, IWRM provides the most coherent way of balancing environmental sustainability, economic efficiency and social equity, and can therefore lead to effective long-term solutions to water problems. However, it is challenging to implement integrated, multidisciplinary investigations because sectorial, compartmentalized approaches are often favored (Foster and Ait-Kadi 2012). This preference is mainly due to the fact that sectorial water strategies are less complex to manage, and thus easier to implement (Biswas 2004). Being a "hidden resource", groundwater is often not adequately taken into account and this results in biased management plans. On the other hand, in groundwater-centered investigations, hydrogeologists tend to forget to adequately address the socio-economic drivers of resource use and pollution load, as well as the institutional framework related to land-use and water management. Both cases lack a full understanding of the original problem and its implications, and thus inevitably only lead to partial solutions. Trends should therefore be reversed to favor a holistic approach that should no longer be considered as a sort of Nirvana, or ideal vision the world should aspire to, but as a concrete possibility (Molle 2008).

Nonetheless, it must be recognized that in some cases IWRM is seen as a goal rather than a tool for solving a specific issue (Giordano and Shah 2014). For example, some scientists often consider IWRM as a pure conceptual and academic exercise, while other stakeholders frequently consider it as a "ticked box on the way to securing funding for a project or program" (McDonnell 2008). Consequently, in many parts of the world, water problems fail to be efficiently addressed because proposed solutions are set on management principles which do not adequately consider real-world problems (Giordano and Shah 2014).

In addition, it is also difficult for IWRM to reach far enough down the social scale because groundwater withdrawal is often unregulated or in some cases illegally performed, especially in developing regions (Foster and Ait-Kadi 2012). Therefore, the first step towards finding a solution should be to gain a clear understanding of the problem and of the nature of all the information that is required to support IWRM (McDonnell 2008). In order to incorporate local knowledge and aspirations, it is important to shift from a top-down (supply-led) to a bottom-up approach (Sabatier 1986; Van der Gun 2012). Indeed, public engagement is fundamental to the success of IWRM so that its concrete implementation adequately addresses local issues and emergencies.

In practical terms, this can be achieved by using participatory planning and implementation processes. As stated in Principle 10 of the 1992 Rio Declaration on Environment and Development (UNCED 1992), environmental issues, like water management, are "best handled with the participation of all concerned citizens at the relevant level", and this can be achieved through methods that increase transparency, participatory decision-making and accountability (Jansky et al. 2005). In other words, this means providing people with adequate information on both the issues and the proposed management plans, and involving all the stakeholders in the activities and decision-making processes that may affect them.

In general terms, public participation can be described as a "process involving the public in problem solving and decision making that uses public input to make better decisions" (IAP2 2014), also including groups that are usually marginalized. In this framework, stakeholder engagement refers to the involvement of those affected by a decision, as well as those able to influence its intended outcome (e.g., non-public stakeholders such as international donor agencies; Jansky et al. 2005).

Furthermore, it is important to note that 'public engagement' has different implications in different fields. For example, for water users it primarily refers to access, whereas for water managers it is about their involvement in management functions, and for water governance it means participation in allocation, rulemaking and public auditing (Mollinga 2010). It is therefore essential to find the right degree and level of engagement in order to address a problem adequately, especially when dealing with groundwater issues (Foster and Ait-Kadi 2012; Gleeson et al. 2012).

Effective public engagement will not only result in a more conscious use of water resources, but may eventually lead to long-term participatory bottom-up management actions, as is the case for one of the most successful collaborative projects for agricultural development in Andhra Pradesh, India (FAO 2013). Attempting to promote a more holistic approach to groundwater issues is not a novelty, as proven by the implementation of several participatory groundwater monitoring and management initiatives worldwide (e.g. Chebaane et al. 2004; Lorato et al. 2006; van Steenbergen 2006; Gomani et al. 2011; Berahmani et al. 2012; Camona et al. 2013). However, despite increasing attention to these issues, only a small number of hydrogeological investigations use integrated and participatory approaches.

Nonetheless, the growing uncertainty associated with climate variability, population growth and the increase in water demand, should encourage the scientific community to engage in social issues. As far as groundwater resources are concerned, hydrogeologists have a key role to play: they should work towards turning these good examples of virtuous studies that are still few and far between into normal practice.

Socio-hydrogeology: enhancing the role of hydrogeologists as advocates for public engagement in water management and governance

The rapid increase in groundwater abstraction in the last few decades has generated significant socio-economic benefits (Foster and Chilton 2003), although in more recent years we have started to experience some of the

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negative externalities of its, often uncontrolled, withdrawal. To avoid further degradation, it is therefore fundamental to make the end users aware not only of the effects of groundwater overpumping, but also of the excessive use of fertilizers in rural areas, and the inadequate (or absent) wastewater treatment plants and sanitation facilities in urban and peri-urban zones.

On the other hand, managers and policy makers should gain a better understanding of water users' needs and to fully consider all the implications of new management strategies (e.g., limitation of fertilizer use or water abstraction limits) on the people whose lives and wellbeing are strongly water-dependent (e.g., farmers/irrigated agriculture, especially in regions affected by physical and economic water scarcity).

On the basis of the aforementioned considerations, a new approach to groundwater investigation is proposed called "socio-hydrogeology", whose aim is to provide management practices with better support, i.e., robust hydrogeological data coupled with a more comprehensive assessment of the socio-economic implications of the (ground)water problem in question.

In agreement with the general definition of socio-hydrology—the science of people and water (Sivapalan et al. 2012)—socio-hydrogeology aims not only to study the mutual relations between people and groundwater (i.e., the impact of human activities on the baseline characteristics of an aquifer and the impact of groundwater—its quality, its presence/scarcity—on human wellbeing and life), but more generally to foster the inclusion of the social dimension in hydrogeological investigations. This means ensuring that the results of scientific investigations are not only based on real needs and local knowledge, but are also adequately disseminated to end users (and polluters). Indeed, hydrogeologists play a key role in socio-hydrogeology as they can act as advocates for science-based management and participatory approaches to groundwater protection and sustainable development.

As hydrogeologists are often involved in fieldwork when they perform monitoring activities, they (and their teams) are the first point of contact for well holders and farmers. They are therefore a sort of mediator between theory and practice, or between the problem and the (potential) proposed solution. Although many hydrogeologists generally have discussions with farmers and well holders while they perform field activities, this precious contact time could be used more profitably if it were structured better. Specific time could be allocated to retrieving important information from local stakeholders and raising awareness about the negative implications of incautious practices. There are also times when hydrogeologists are willing to involve local stakeholders, but linguistic gaps hinder communication and knowledge exchange. Therefore, a structured approach to communicating with local farmers/well holders, that may eventually become a compulsory component of fieldwork, would facilitate public engagement.

As previously mentioned, involving local stakeholders is increasingly seen as a way of strengthening the likelihood of implementing more effective management practices for water protection. Historically, especially in rural areas, local people are constantly adapting to new situations, while learning to diversify their practices (Van der Gun 2012). Hence, if they were adequately involved, they might be interested in new strategies that would improve their activities (and help protect the natural environment). At the same time, in a situation of mutual trust, scientists could learn to include local knowledge in their investigations, favoring the implementation of holistic approaches which would be tailored to site-specific needs. This would eventually guarantee that the information and advice provided after hydrogeological investigations are not only credible and relevant, but also legitimate (i.e., information and proposed solutions are respectful of stakeholders' divergent issues and values; Cash et al. 2003).

Based on these premises, socio-hydrogeology can be seen as a discipline that embeds the social dimension into hydrogeological and hydrogeochemical investigations. This is coherent with the concept of groundwater sustainability as "a value-driven process of intra and intergenerational equity that balances the environment, society and economy" (Gleeson et al. 2012).

The key aspects of socio-hydrogeology are:

- Assessing the impact of human activities on groundwater resources
- Evaluating the (socio-economic) impact of groundwater resources (and its changes in terms of both quality and quantity) on human life and wellbeing
- Identifying the stakeholders involved in a specific groundwater issue, their relations (e.g., power, knowledge flux, financial transfer) and possible existing conflicts
- Promoting better use of the outcomes of a hydrogeological investigation
- Attempting to bridge the gap between science and practice
- Demystifying science and scientists

The last point is fundamental because only trust in scientific outcomes can lead to successful and conscious cooperation. Furthermore, it is quite difficult to reverse pollution trends by implementing direct control over farmers (e.g., top-down approaches for reducing groundwater abstraction and/or fertilizer use), especially in regions where aquifers are the principal source of irrigation (Berahmani et al. 2012), unless they are fully aware that they will benefit from new policies and that their real needs are taken into account while new measures are being decided upon.

Given the aforementioned key aspects of socio-hydrogeology, it can be considered as a subdiscipline of socio-hydrology, defined by Sivapalan et al. (2012) as "a new science that treats people as an endogenous part of the water cycle", "aimed at understanding the dynamics and co-evolution of coupled human-water systems", although it has a slightly different approach. While the key element of socio-hydrology is to include humans and their actions into the water cycle with the "the purpose of predicting the dynamics of both" (Sivapalan et al. 2012), the peculiarity of socio-hydrogeology is the focus on the reciprocity between groundwater and its consumers/polluters (i.e., "how human actions exert pressure on groundwater resources" and "how scarce and/or polluted groundwater influences human wellbeing"). A full understanding of the socio-hydrogeological issues at stake can become the basis for a comprehensive socio-hydrological investigation, aimed at including the underground component of the water cycle in complex system modelling. In addition, the direct collaboration with (ground)water end users can facilitate retrieving information useful for completing historical analysis; hence, gaining a better understanding of the evolution of a community in the investigated basin. In fact, as one of the key aspects of socio-hydrogeology is engaging water users/polluters in order to favor knowledge sharing, it can also provide useful information for the study of human–aquifer co-evolution dynamics, as promoted by socio-hydrology for river basins (Di Baldassarre et al. 2013). Together, they may eventually lead to effective integrated water-resource management plans. Indeed, both disciplines attempt to respond to the argument that scientists are too isolated from the real world, and share the common goal of achieving long-term sustainability of water resources. Therefore, when socio-hydrology tries to explicitly consider the co-evolution of humans and water in a specific water body or a basin, it should favor the inclusion of the groundwater part of the water cycle through a socio-hydrogeological approach. This would ensure that groundwater is also included in the long-term predictions promoted by socio-hydrology. Indeed, clearly identifying the mutual relations between humans and groundwater is fundamental for a complete assessment and a more accurate prediction of future trajectories of the co-evolution of coupled human and water systems, which are described as being the main objectives of socio-hydrology (Sivapalan et al. 2012). Despite the similarities in their "intentions", the two interdisciplinary fields also show some differences, although they should not be considered as being opposed to each other. The main difference is that socio-hydrology is concerned with analyzing the drives and fluxes of studied systems (Srinivasan et al. 2012; Di Baldassarre et al. 2013; Sivapalan et al. 2014; Viglione et al. 2014) and how they are related (in terms of both quality and quantity), whereas socio-hydrogeology is concerned with identifying the cause-and-effect relationship between groundwater and society, by responding to the following key questions:

- Who is affected (directly or indirectly) by the groundwater system in question?
- Is the project/investigation likely to raise conflicts at local, regional, or international levels? If so, how can hydrogeologists avoid this and who can help?
- Which group of stakeholders is more likely to effectively support the concrete implementation of the management suggestions resulting from a hydrogeochemical investigation?

Only by embedding these questions into our hydrogeological research can we ensure that project results go beyond the academic sphere and have real, positive impacts on local populations. Furthermore, such an approach can help scientists to make optimal use of hydrogeological information and outcomes, which are obtained, in most cases, using the best available technology and tools. Indeed, robust information is an integral part of any decision-making and management process (Baldwin et al. 2012), but only when knowledge is adequately transferred to final users and relevant stakeholders. As pointed out by Boreux et al. (2009), one of the main obstacles to effectively managing natural resources is weak knowledge transfer and communication between scientists and local communities.

Although with different approaches, both socio-hydrogeology and socio-hydrology aim at observing and understanding the coupled human-groundwater system, by assessing how one component affects the other and, possibly, how they co-evolve. In this way both disciplines can underpin the effective implementation of IWRM, focused on control and management of water systems. Socio-hydrogeology will not only create room for future public participation activities (supporting the design of a framework where participation results are really taken into account in decision-making processes, instead of just being a consultation exercise), but it will also allow science and groundwater scientists to be demystified, facilitating the promotion of groundwater-user networks supported by experts.

Socio-hydrogeology from theory to practice: the Bir Al-Nas approach

The Bir al-Nas (Bottom-up IntegRated Approach for sustainabLe grouNdwater mAnagement in rural areaS) approach attempts to create the basis for the concrete implementation of new socio-hydrogeological investigations. More specifically, it aims to:

1. Develop a replicable example of a multidisciplinary approach for science-based groundwater management practices
2. Enhance rural development strategies by strengthening the role of hydrogeologists as advocates for public engagement in water management and governance
3. Promote better communication between scientists and stakeholders (including decision makers) in order to build trust for more reliable and sound management of groundwater resources

One of the key elements of the approach, as previously mentioned, is including the social dimension in hydrogeological investigations to promote effective public participation. In order to potentially identify all the people involved in a given hydrogeological project, by considering who can promote the implementation of science-based management practices and how they may be able to do so, Bir Al-Nas foresees two basic (but effective) key actions (Fig. 1):

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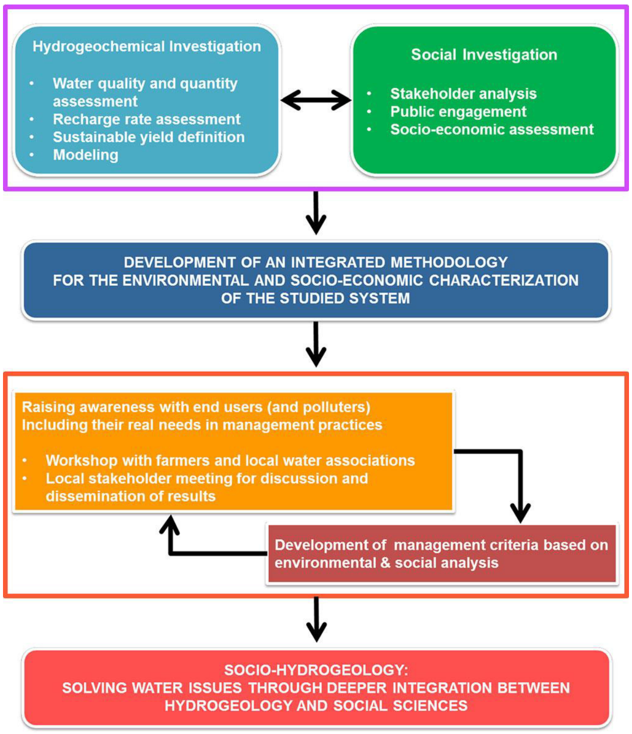

Fig. 1 Schematic description of the Bir Al-Nas approach for socio-hydrogeology

- A preliminary stakeholder analysis (SA), aimed at identifying the relevant stakeholders, highlighting their power relations, existing conflicts in water resource use and management, and understanding who can influence the success of the proposed strategies and the implementation of the new management strategies based on the outcomes of the hydrogeological/ hydrogeochemical investigation
- Direct engagement and confrontation with well owners and farmers to (1) address the research more effectively, (2) retrieve reliable information about water and land use, and (3) disseminate the results while performing capacity building

These actions should be part of every hydrogeological and hydrogeochemical investigation (especially regarding rural development), and should consider, according to the scale of the investigation, all the people and institutions who are directly or indirectly affected by the project (Jansky et al. 2005).

Stakeholder analysis (SA)

To approach hydrogeochemical investigations in the most effective way and make use of all the available scientific knowledge, it is fundamental to identify the actors who are influenced by or who influence the project/ groundwater issue in question. The first step of the Bir Al-Nas approach is therefore to conduct a stakeholder analysis (SA) prior to the investigation. Reed et al. (2009) define SA as a process that outlines the aspects of a social and natural phenomenon affected by a decision, "that identifies individuals, groups and organizations who are affected by or can affect" a (part of a) phenomenon. It is important to note that SA should not be considered as a goal in itself, but as a preliminary assessment that enables researchers and planners to foster public engagement without excluding any actors, and avoids empowering/ marginalizing certain groups. When it is carried out correctly, SA identifies existing or potential conflicts between stakeholders (Friedman and Miles 2006; Prell et al. 2007) and can prevent the creation of new ones during the execution of a project.

As far as water management is concerned (especially IWRM), it is important to engage all the stakeholders involved in the water resources in question (e.g., consumers, polluters, managers) in order to successfully implement new practices and achieve more sustainable goals. In addition, thanks to the SA, all the relevant stakeholders, including policy makers, can be involved since the early stages of the project and be engaged in a mutual learning experience (Beck et al. 2011). This not only can help in raising awareness on both the environmental issues at stake and of the objectives of the hydrogeological investigation, but also permits to strengthen the dialogue with policy makers and water end users, thus facilitating the implementation of effective science-based management practices. By using this approach, hydrogeologists could manage boundaries between knowledge and action in ways that simultaneously enhance the credibility and legitimacy of the produced information (Cash et al. 2003). Indeed, if the main prerequisite for science-based

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management is sound knowledge, scientists and policy makers must also take into account the need to adapt new policy decisions to real people (Brunner and Steelman 2005). As previously mentioned, by acting as advocates for groundwater management and protection, hydrogeologists can enhance communication between all the stakeholders in every phase of the project, and provide support in implementing new groundwater management based on the real needs of local population.

Out of the different possible approaches to SA, the Bir Al-Nas framework opted for social network analysis (SNA), which investigates and categorizes the relationships between stakeholders (Reed et al. 2009), and identifies the key actors that are likely to positively influence the implementation of new management practices resulting from a hydrogeochemical investigation.

More specifically, one of the most effective methodologies is the Net-Map toolbox (Schiffer and Hauck 2010), a low-cost, easily implementable research tool that aims to make implicit knowledge about networks explicit (Schiffer and Waale 2008). By applying SNA, it is also possible to notice the presence of (and get in touch with) minorities, marginalized groups and 'informal sectors', who, despite being directly affected by the water issue in question, might not be considered through a traditional approach.

Public engagement

The key to successful implementation of effective management practices is to ensure that end users are engaged throughout the project; therefore, Bir Al-Nas foresees direct collaboration with end users, facilitated by structured interviews and questionnaires that are administered directly by the hydrogeologists while performing in situ measurements and monitoring campaigns. This can be considered as interactive public participation, where farmers are involved in joint analysis and contribute to the development of action plans (Mollinga 2010).

The public participation of local farmers, landowners and local water authorities is essential to the development of the project as it fosters the adoption of effective and sustainable management practices. In this regard, direct engagement and confrontation with well owners and farmers will allow hydrogeologists to tackle the investigation more productively (which involves being able to conduct seasonal studies if they are given permission to include the selected wells in the monitoring network), and to retrieve reliable information on water and land use. To this end, during the field campaigns, well owners of the sampled sites and farmers may be asked to respond to structured interviews on water and agricultural practices (see electronic supplementary material, ESM). The collected information is then used to support the interpretation of hydrogeochemical data and to support evidence from the stakeholder analysis.

The proposed questionnaire (ESM) was designed to be simple, easy to understand, transparent, and easy to re-adapt to other case studies, in order to ensure the successful participation of the stakeholders (Henriksen and Barlebo 2008). Structured interviews that are administered directly by hydrogeologists during field-work activities would obtain direct and reliable information on regional characteristics and priorities, local activities (e.g., water use and withdrawal, abstraction rates for different purposes, kinds and quantity of fertilizers used, kinds of crops cultivated and farmer's perception on surface water and groundwater), gender issues (Who is responsible for working in the fields? Who is responsible for water management?), and perceived impacts of water pollution (Table 1). As previously mentioned, the collected information can be used to support hydrogeochemical data interpretation and identify priorities, gaps and challenges to address, hence favoring a bottom-up approach that is based on farmers' real needs and perceptions. Their involvement is fundamental because they not only represent the end users, but they also play a key role in implementing successful management practices and effective local actions. Indeed, embedding farmers' knowledge into investigations can facilitate the understanding of the historical evolution of the region with respect to demographic development and land use, and can be of valuable support to hydrological modeling. To ensure that privacy is respected, Bir Al-Nas foresees an informed consent form to be signed prior to each interview. The form explains what will happen to the information, explicitly mentions that data will only be used in disaggregated form, and asks for permission to take pictures (or videos) during the sampling phase.

The main rationale behind the interviews is to create momentum for dialogue about local groundwater issues, as people with different interests are only willing to cooperate if they understand why it is necessary and how they will benefit from it (GWP 2012b). Information sharing is undoubtedly the best way to achieve this goal.

Back to the farmers

The Bir Al-Nas approach attempts to bridge the gap between science and society by making the end users more aware of both the water issues and the power they have to reduce groundwater pollution. Therefore it is fundamental for the results of hydrogeological and hydrogeochemical investigations to be adequately disseminated to the general public through specific outreach activities so that they do not remain solely in the scientific or political arena.

In order to raise awareness about the effects of water overexploitation and depletion at the local level, besides involving well owners and farmers as previously described, the Bir Al-Nas approach foresees the organization of specific meetings and workshops with the aim of communicating the results of the investigation. At these events, well owners receive a document containing all the chemical results of the water in their well and warnings about water use (e.g., distribution maps that compare results with drinking water standards, piezometric variation maps, and crop vulnerability maps). Similarly, a final meeting with local stakeholders and policy makers (e.g., delegates from the agricultural ministries, regional commission for agricultural development, trade unions,

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Table 1 Summary of the purposes and information obtained with the structured questionnaires proposed by Bir Al-Nas

Questionnaire section	Purpose	Information obtained
Personal information	Retrieve information (to be treated anonymously) on the rural population	Gender, age, education, occupation, contacts
Water use	Retrieve information on regional characteristics to support data interpretation	Information about the well, groundwater withdrawal rates, current groundwater uses, perceived trends of groundwater quality
Use of groundwater for irrigation purposes	Retrieve information on local activities and priorities to support data interpretation	Kinds of crops cultivated, kinds and quantity of fertilizers used
Awareness of water issues	Know farmers and well holders perception about water issues	Perception of: water scarcity, climate change, integrated water resources management and groundwater pollution
Potential for participation	Evaluation of the potential for the implementation of participatory monitoring and management initiatives	Farmers' role in groundwater protection, perceived groundwater issues in the region, perception of scientists and policy makers regarding local groundwater management

consumers etc.) is organized at the end of the project to share final results and achievements. Disseminating results on a political level helps to promote responsible use of groundwater and conjunctive use and management of water resources for irrigation practices (e.g., groundwater, surface water, treated wastewaters and rainwater harvesting). This also maximizes the chances of 'regional transfer' of good practices and know-how. Additionally, the use of alternative communication plans (e.g., advocacy materials, school training sessions, public water outreach conferences, projections) to build "groundwater awareness campaigns" that are addressed to households, citizens and local authorities are an asset.

Strengths and weaknesses of the Bir Al-Nas approach

Overall, the Bir Al-Nas approach allows hydrogeologists to become acquainted with the impact hydrogeological changes have on rural society. In fact, although it is well known that

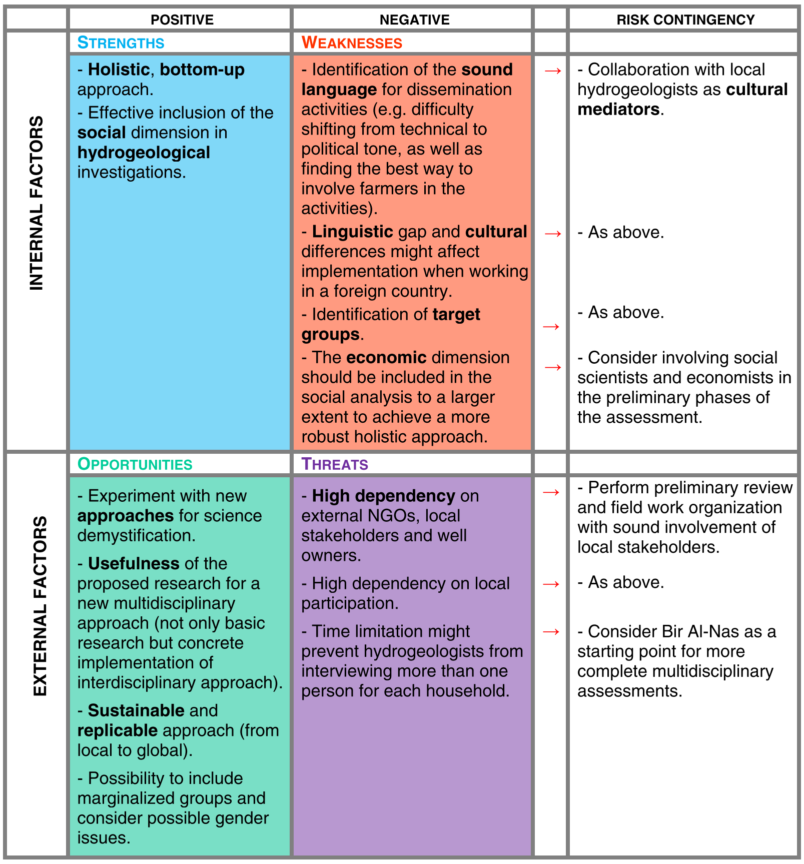

Fig. 2 SWOT (strengths, weaknesses, opportunities and threats) analysis of Bir Al-Nas approach and associated risk contingency plan

environment and society are interlinked and co-evolving (Montanari et al. 2014), hydrogeological/hydrogeochemical investigations often neglect (or marginalize) the social implications of groundwater issues. Although it is not always possible to control the impact natural environments (and their changes) have on human beings (especially in the case of natural disasters), it is definitely possible to control the impact human activities have on natural environments, especially by educating people to have a wiser, more conscious approach to natural resources.

Therefore, one of the main strengths of the Bir Al-Nas approach is its attempt to incorporate social drivers into hydrogeochemical investigations. In addition, such an approach can favor the inclusion of marginalized groups and include references to gender issues related to groundwater use/pollution: women make up a large portion of the worldwide agricultural workforce but are often under-represented at all levels.

In this regard, some possible limitations of the approach are that hydrogeologists mainly interact with one person (depending on who is at home/in the field at the moment of sampling) and that the normal time schedule for sampling campaigns and in situ measurements is often incompatible with administering the questionnaire to more than one household member (which would allow women to be the main contributors to the discussion). Despite these limitations, Bir Al-Nas is a reasonable compromise in cases where a full socio-economic analysis is not possible, especially in contexts where formal farmer (or consumer) associations are not present.

Lastly, Bir Al-Nas was designed to be a replicable model for implementing a socio-hydrogeological approach in rural regions, regardless of the location. Indeed, this approach can be implemented both in developed and developing countries provided that researchers completely respect local cultures and traditions. When different cultural sensitivities are at stake, it is fundamental to understand the ways in which human–water relationships reflect natural processes, as well as the sociocultural relationships and norms (Klaver 2012). Therefore, implementing the Bir Al-Nas approach correctly and effectively requires full collaboration with local institutions and researchers. The latter can also be involved as cultural mediators. Moreover, a gender-balanced working team can often facilitate the correct approach to households and farmers, and it can help to adequately tackle social and gender issues.

It must be stressed that Bir Al-Nas focuses on the emerging issue of the need for hydrogeologists to be familiar with the basic concepts of social sciences: public participation, cultural issues and different cultural approaches to water (Fig. 2). However, this approach does not aim to replace a pure social analysis, nor does it substitute multidisciplinary projects, instead it paves the way for holistic assessments, which are a starting point for projects where a full multidisciplinary investigation cannot be implemented.

Conclusions

It has been pointed out that the main reason for weak or scarce groundwater management is often inadequate governance arrangements, rather than lack of scientific knowledge about the hydrogeological processes (e.g., aquifer vulnerability, sustainable yields, recharge rate; Foster and Garduño 2012).

Indeed, one of the causes of such poor groundwater management is insufficient communication between the relevant stakeholders involved in a specific groundwater issue. Accordingly, hydrogeologists should ask themselves whether they are making the best use of the results of their investigations and whether their attempts to improve national and local groundwater governance are adequate.

In order to promote the concrete implementation of sound science-based groundwater management practices, hydrogeologists should become acquainted with the social implication of aquifer-related issues. This means using a new socio-hydrogeological approach in which hydrogeologists are advocates for groundwater management and protection, and are able to promote and implement a bottom-up approach in order to embed local know-how into management strategies.

This newly established field allows hydrogeologists to focus on mutual relations between groundwater and society and to foster 'horizontal' (e.g., between state and non-state actors or across sectors such as agriculture or energy) and 'vertical' (between various levels) cooperation.

All this can be achieved by creating a network of mutual trust between hydrogeologists and end users (and polluters) which (1) strengthens connection and knowledge transfer, (2) favors the communication and outreach of scientific results (i.e., to use available information more productively, and potentially to incorporate the use of new dissemination tools), and (3) paves the way for participatory groundwater monitoring activities.

Furthermore, this approach can contribute towards bridging the gap between scientists and citizens (i.e., science and scientist demystification), and changing their public perception: scientists and academics are still too often accused of being isolated from "the real world", especially regarding rural development. Moreover, involving local knowledge can facilitate the implementation of adapting management to changing conditions (like climate change) and can embed social uncertainty into hydrogeological modeling.

The Bir Al-Nas approach is an initial attempt to put the concept of socio-hydrogeology into practice through hydrogeochemical and social analysis, the latter performed by means of a stakeholder analysis and structured interviews with the people involved in the groundwater monitoring network. This novel approach presents a standardized baseline method focused around hydrogeologists, which is easy to understand and implement, flexible, not too time-consuming and offers the chance to implement preliminary public engagement with limited effort.

The final outcomes are expected to be an increased awareness of local communities and a clear understanding of their water issues and needs from the very early stages of the investigation. If end users of water are adequately informed about both the status of their water resources and the role they can play in protecting the environment for the benefit of future generations, they can potentially pave the way for smarter agricultural practices.

The Bir Al-Nas approach is currently being implemented and tested in the Grombalia Basin, which is located in the semi-arid peninsula of Cap Bon, North-East Tunisia (Tringali 2014). This area was chosen because it represents issues shared by most of the coastal aquifers in the Mediterranean Basin (i.e., aquifer pollution and salinization, water overexploitation, saline-water intrusion, and agricultural return flow). In addition, this area has been the subject of several national and international investigations and projects (e.g., Kouzana et al. 2010; Ben Hamouda et al. 2011; Ben Moussa et al. 2010, 2011a, 2011b, 2012; Cary et al. 2013), which have resulted in a good knowledge of the baseline condition of the natural environment and well-established cooperation between the local institutions working in the region. This makes the area adequate for testing the new proposed methodology. One of the main goals is to create room for more cooperation between hydrogeologists and local stakeholders, thus favoring better consultation with end users, and new approaches tailored to local issues and priorities. Therefore, the results will be shared with all the farmers involved, and compared with the interpretation of the outcomes of the structured interviews in order to propose science-based management plans to the key stakeholders that were identified in the stakeholders network analysis.

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