IRRIGATION AND DRAINAGE
Irrig. and Drain. **69** (Suppl. 1): 155–167 (2020)
Published online 02 November 2017 in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/ird.2178

OVERLAPPING GROUNDWATER SERVICE MARKETS IN A PALM GROVE IN THE ALGERIAN SAHARA†

MERIEM FARAH HAMAMOUCHE[1,2,3]*, MARCEL KUPER[1,2], TARIK HARTANI[4] AND SAMI BOUARFA[5]

[1]*CIRAD, UMR G-EAU, Montpellier, France*
[2]*Institut Agronomique et Vétérinaire Hassan II, Rabat, Morocco*
[3]*AgroParisTech, Paris, France*
[4]*Centre Universitaire de Tipaza, Tipaza, Algeria*
[5]*GEAU Unit, INRAE, Univ Montpellier, Montpellier, France*

ABSTRACT

Groundwater service markets are important and dynamic institutions that provide water to a wide range of farmers in many regions. However, these institutions represent arenas of complex and often antagonistic relations, which determine which farmers gain access to water and how. This study analyses the emergence and functioning of groundwater service markets from a historical perspective to advance the understanding of the role of social power games in shaping these institutions. The study was conducted in the Sidi Okba oasis in the Algerian Sahara, where over recent decades, four (in)formal, often overlapping, groundwater service markets have emerged. These markets were shaped progressively by socio-ethnic antagonism, state intervention and economic competition between water sellers. By continuously adjusting these institutions, the highly diverse irrigation community prevented the emergence of a monopoly in groundwater sales and maintained the balance of power between water sellers and buyers by countering possible control of groundwater access by a single socio-ethnic or economic group. The demonstrated ability of the irrigation community to craft rules to ensure these groundwater service markets function should encourage public actors to mobilize this capacity to deal with the drop in water tables, which is one adverse outcome of the 'success' of these markets. Copyright © 2017 John Wiley & Sons, Ltd.

KEY WORDS: groundwater; water service markets; groundwater providers; power relations; state interventions; oasis

RÉSUMÉ

Les marchés de service d'eau souterraine sont des institutions importantes et dynamiques qui fournissent de l'eau à un large éventail d'agriculteurs dans de nombreuses régions du monde. Ces institutions sont historiquement construites et présentent des arènes de relations complexes et souvent antagonistes, particulièrement entre vendeurs et acheteurs d'eau. Ces relations déterminent à leur tour quels agriculteurs ont accès à l'eau souterraine, et comment. Cette étude analyse l'émergence et le fonctionnement des marchés de service d'eau souterraine d'un point de vue historique afin de mieux comprendre les enjeux sociaux dans le façonnage de ces institutions. Une étude de cas a été menée dans la palmeraie de Sidi Okba, dans le Sahara algérien, où, au cours des quatre dernières décennies, quatre marchés (in)formels de service d'eau souterraine—souvent se chevauchant—ont émergé. Ces marchés ont été façonnés progressivement par des antagonismes socio-ethniques, des interventions étatiques et des rivalités entre vendeurs d'eau cherchant à se positionner sur ces marchés devenus lucratifs. Grâce à l'ajustement continu de ces institutions, la communauté d'irrigants dans sa diversité a empêché l'émergence d'un monopole dans les ventes d'eau souterraine, en contrecarrant le contrôle possible de l'accès à l'eau souterraine par un seul groupe socio-ethnique ou économique. La capacité de la communauté d'irrigants à élaborer des règles pour assurer le fonctionnement de ces marchés de service d'eau souterraine, devrait encourager les acteurs publics à mobiliser cette capacité pour faire face au déclin des nappes, qui est en partie le résultat du succès de ces marchés. Copyright © 2017 John Wiley & Sons, Ltd.

MOTS CLÉS: eau souterraine; marchés de service de l'eau; fournisseurs d'eau souterraine; relations de pouvoir; interventions étatiques; oasis

*Correspondence to: Miss Meriem Farah Hamamouche, CIRAD, UMR G-EAU, 361 rue JF Breton, B.P. 5095, 34196 Montpellier Cedex 5, France.
E-mail: hfarah07@hotmail.fr; meriem-farah.hamamouche@cirad.fr
†Chevauchement des marchés de service d'eau souterraine dans une palmeraie au Sahara algérien.

INTRODUCTION

In arid and semi-arid regions, during the second half of the twentieth century, irrigated agriculture became increasingly dependent on groundwater (Shah *et al*., 2006; Bouarfa and Kuper, 2012). Groundwater is often believed to only be exploited by farmers through individual private wells and tube-wells (Margat and Van der Gun, 2013) as farmers sought to become independent from 'state' or 'community' controlled access to water (Kuper *et al*., 2009). Yet, in many cases, collective organizations developed around the exploitation of groundwater at the initiative of the state or of the farming communities themselves (Schlager, 2007; Rica *et al*., 2012; Frija *et al*., 2016). In some cases, formal and informal institutions were also set up to manage groundwater (Llamas and Custodio, 2002). However, most institutions emerged to overcome the difficulties linked to the access and distribution of groundwater (Dubash, 2002; Zhang *et al*., 2008). These institutions generally come into being when the actors are faced with the same environmental constraints (scarcity of surface water and a decline in water tables), economic problems (cost of an individual tube-well, small size of farms, and profitability of crops), or social constraints (marginalization of farmers) (Shah, 1993).

Groundwater institutions take different forms, depending on the physical, socio-economic and political situation (Schlager, 2007). For example, in South Asia, the most common institution are informal 'groundwater markets', which are extensively documented in the literature (e.g. Shah, 1985; Dubash, 2002; Mukherji, 2004, 2007). In the early literature on informal water markets, most researchers were enthusiastic about the key role played by these institutions in enhancing access to water by small-scale and marginal farmers, and about their positive impacts on equity, efficiency and productivity (Meinzen-Dick, 1998; Shah and Ballabh, 1997; Fujita, 2004). Easter *et al*. (1999) stated that 'water markets—either formal or informal—can be an efficient method for reallocating scarce water supplies'. For example, in Bangladesh, it was thought that private investment in providing groundwater service markets to farmers had generated 'immense benefits' and in many ways 'such phenomena are far more important institutions for human welfare than 'community irrigation' or other 'examples of collective action widely canvassed in the development literature' (Palmer-Jones, 2001).

On the other hand, there were also a few critical studies of informal water markets. For instance, certain researchers expressed doubts about the equity supposedly produced by water markets given the emergence of 'water lords', i.e. rich irrigators who were able to monopolize access to groundwater (Janakarajan, 1994; Adnan, 1999). This one-sided view of water lords exerting absolute power over water buyers was, however, contested by Mukherji (2004), who called for a better understanding of 'the relative power of water sellers and water buyers'. More generally, Mukherji (2004) highlighted some methodological limitations of the majority of studies on water markets whether enthusiastic or critical of such institutions, in particular the fact that the social relations in which water service markets were embedded were overlooked, and 'the role of power in shaping water markets has been completely ignored'. Most studies were limited to analysing the nature and way of functioning of water markets 'often to the level of rhetoric' (Prakash, 2005). To overcome these limitations, these authors advocated using a historical perspective in research on groundwater markets, as few studies grasped the 'nuances of unequal social relationships and natural and historical functions that shape and determine groundwater access and use' (Prakash, 2005). The question is, then, how socio-ethnic and socio-economic antagonisms shape and determine access to, and use of, groundwater to a diversity of farmers.

This paper analyses the emergence and functioning of groundwater service markets from a historical perspective to advance our understanding of the role of social power games in shaping these institutions. Through an empirical analysis, we show how state interventions and social power games shaped the different formal and informal groundwater markets involving multiple groundwater buyers and providers, which coexist in the same irrigated area. The case study was conducted in the ancient palm grove of Sidi Okba in the Algerian Sahara, where over a period of more than 50 years, different institutional arrangements of water allocation and distribution, including water service markets, emerged at different periods and around different water resources (surface water and groundwater). In this article, we focus on the institutional arrangements for the access to, and use of, groundwater. Several formal and informal groundwater service markets emerged in the last four decades in Sidi Okba, often with the help of the state, in order to provide different socio-ethnic groups of garden owners with access to groundwater. The coexistence of four groups of groundwater providers in the same irrigated system generated its own dynamics, further shaping groundwater service markets by creating competition for the water supply, resulting in rivalries in groundwater sales and the development of strategies by groups of groundwater providers who had discovered the economic interest in this activity. This case study is, therefore, particularly illustrative of the complex socio-ethnic and economic contexts with multiple power games in which water service markets emerge.

METHODOLOGY

Study area

The study was conducted in the Sidi Okba palm grove (733 ha), close to the city of Biskra near the southern

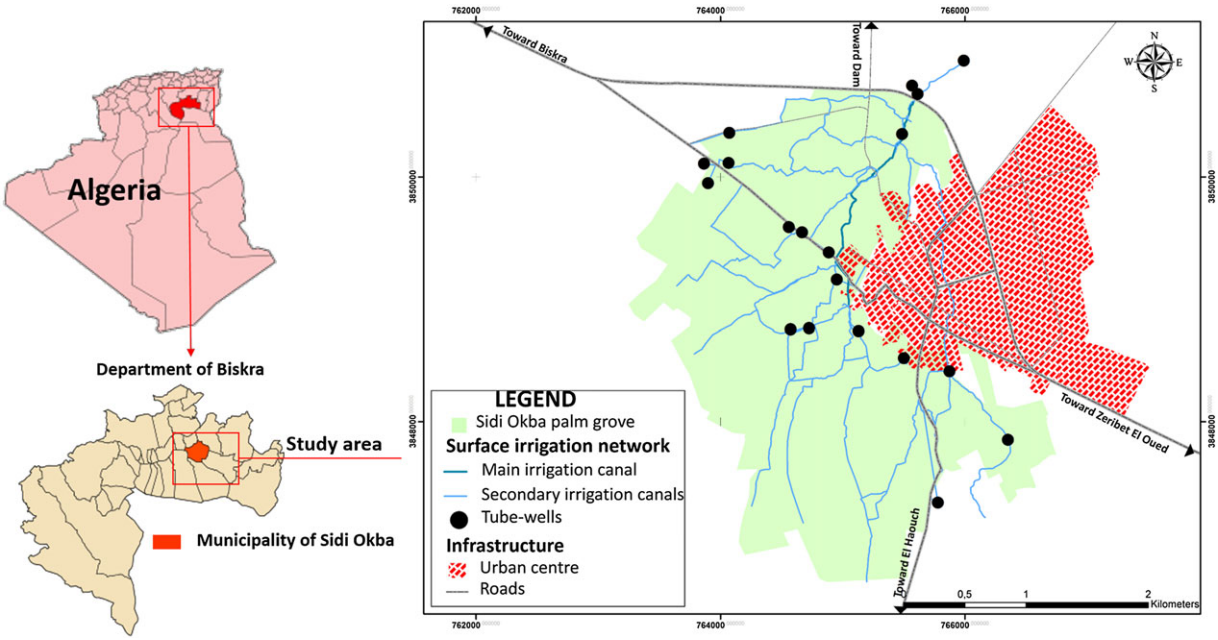

Figure 1. The study area. [Colour figure can be viewed at wileyonlinelibrary.com]

foothills of the Aures Mountains in the Algerian Sahara (Figure 1).

The centuries-old irrigation system in the Sidi Okba palm grove is a complex hybrid system with several layers. Before 1950, the palm grove was irrigated by a community-managed spate irrigation system, completed by private shallow wells. The distribution of irrigation water was based on proportional water rights according to the physical effort provided by the lineage to divert water from Wadi Biraz (name of the non-perennial stream upstream of the gorge of Foum El Gherza). However, this system was profoundly disturbed in 1950 when the Foum El Gherza dam was built by the state on Wadi El Abiod (name of the same stream downstream of the gorge), which was intended to supply the palm grove and nearby land used for annual crops up to six times a year. Water rights were then distributed proportionally to the number of palm trees per garden. After the dam came into service, a new and unexpected water resource emerged: dam leakages of about 180–480 m^3 h^{-1} (Hamamouche *et al*., 2017). This resource was integrated into the surface irrigation system of the four palm groves (Seriana, Gharta, T'Houda and Sidi Okba). However, the physical characteristics of this resource (low water discharge in continuous flow) were very different from the high discharge rates during the limited periods provided by the dam, and very different from the previous spate irrigation. As a result, the irrigation community in Sidi Okba created new institutions to better manage these water leakages, mainly through water service markets. Then, in the late 1970s, the state introduced deep tube-wells to irrigate the palm grove and to mitigate water scarcity, followed by several subsidized and private collective or individual tube-wells. Today, the palm grove is irrigated by several water resources, all water being distributed through the existing surface irrigation system.

Broadly speaking, the Sidi Okba palm grove is dominated by two socio-ethnic groups: (i) noble families who enjoy a higher status within the oasis community, and who own large gardens inside the palm grove. Their gardens are mainly located in the upstream and central parts of the palm grove; (ii) descendants of former sharecroppers who, since the 1960s, have gradually acquired access to land, palm trees and water (first surface water then groundwater). This socio-ethnic group own small gardens scattered throughout the palm grove (Hamamouche *et al*., 2015).

Research approach

To analyse the way state interventions and power games shaped groundwater markets in Sidi Okba, we sought inspiration from some of the works on groundwater markets in South Asia (Shah, 1993; Mukherji, 2004; Prakash, 2005). In these works, the term 'groundwater market' was used 'to describe a localized, village level institutional set-up through which owners of modern water extraction mechanisms supply water to other members of the community at a price' (Shah, 1993). However, many researchers contested the use of this term, because the pumped water is not a private property and the owners of the tube-wells rather sell the services of their pump (Saleth, 1994). Hence, Shah and

Ballabh (1997) proposed the term of 'pump irrigation service markets' defined as 'an informal arrangement through which owners of wells and pumpsets sell irrigation services to other farmers for a consideration'.

We analysed the emergence and dynamics of 'groundwater services markets' in the Sidi Okba palm grove over the last four decades, through three main components: the resource base, the actors involved (owners of tube-wells and water buyers), and the institutional arrangements (formal and informal groundwater service markets).

We first studied how different surface and groundwater resources were progressively integrated into the irrigation system through different formal and informal institutional arrangements. The entire irrigation infrastructure, including tube-wells and the surface irrigation network, and the distribution of irrigation water were then characterized. The discharge of all water resources (dam releases, dam leakages and groundwater) was measured using micro-reel and flow meters. Next, we analysed the interactions between different water sellers and water buyers, their relations with the state, and the institutional arrangements governing the groundwater service markets, through field observations and 50 semi-structured interviews with local actors (water users and groundwater providers). The interviews focused on the management of groundwater providers and their status, the history of their services, state interventions, and on the coexistence of different groundwater service markets in the same irrigated area. Following this, a second series of interviews was conducted with all different groundwater providers, this time focused on the operation of tube-wells (command area, groundwater pricing, electrical connection and consumption in kW, costs of groundwater pumping), and operations and sales strategies used by different groundwater providers. Interviews were also conducted with representatives of state administrations (the manager of the dam, water agency staff and staff of the electric distribution agency). These interviews enabled us to access official documents such as electricity bills for the tube-wells and reports on studies carried out in our study area.

RESULTS

In this section, we will first show that the chronological emergence of the different groups of groundwater providers coincides with the agricultural subsidies granted by the state. Underlying their emergence are the social power struggles with the persistent ambition of countering the possible control of groundwater access by a single socio-ethnic group. We will then analyse the nature of the groundwater service markets by showing that their functioning depends on the social logic of groundwater providers, but also —increasingly—on their economic interests. Finally, we will show that the absence of a monopoly in groundwater supply gradually resulted in economic competition between groundwater providers, which in turn led some groundwater providers to design sales strategies around the price of groundwater and the quality of service.

The underlying power games of extending the resource base by different groups of groundwater providers

Dam water releases and the water leakages from the dam, which depend on the water stored in the reservoir, have notably decreased over the last four decades due to droughts and the reduced capacity of the reservoir. From the end of the 1970s onwards, groundwater thus progressively became the main water resource proposed by different water providers. The multi-layered structure of the groundwater service markets is the result of the combination of state interventions through regulation and agricultural subsidies and the socio-economic ambitions of the different socio-ethnic groups present in the palm grove.

The chronological emergence of the different groups of groundwater providers. The sequence of the emergence of the different groups of groundwater providers was most often linked to state interventions, as the state was able to mobilize financial resources and technical expertise to tap into new water resources (Figure 2). However, the local community played an active role in mobilizing the different state agencies or political bodies. The emergence of different groups of groundwater providers thus revealed ongoing power games in the access to irrigation water.

State tube-wells conceded to an agricultural cooperative. To mitigate the surface water crisis in the 1970s, the Communal Peoples' Assembly (CPA) of Sidi Okba provided a budget to drill five large tube-wells (to depths ranging from 275 to 807 m) between 1979 and 1984. The tube-wells were equipped with submerged pumps to tap the confined Mio-Pliocene aquifer. The tube-wells were distributed throughout the surface irrigation system of the palm grove, one in the upstream part, one in the central part, and three in the downstream part, with the aim of covering as much irrigated area as possible. Groundwater is pumped and then transported through the existing surface irrigation network. The management of these five state tube-wells was granted to groups of 10–15 garden owners grouped in formal tube-well associations, as they are called locally in Arabic. The majority of the beneficiaries of the state tube-wells were owners of small gardens (former sharecroppers), as the wells were drilled during the period of political transition after the socialist era when marginalized small-scale farmers were strongly supported by the state.

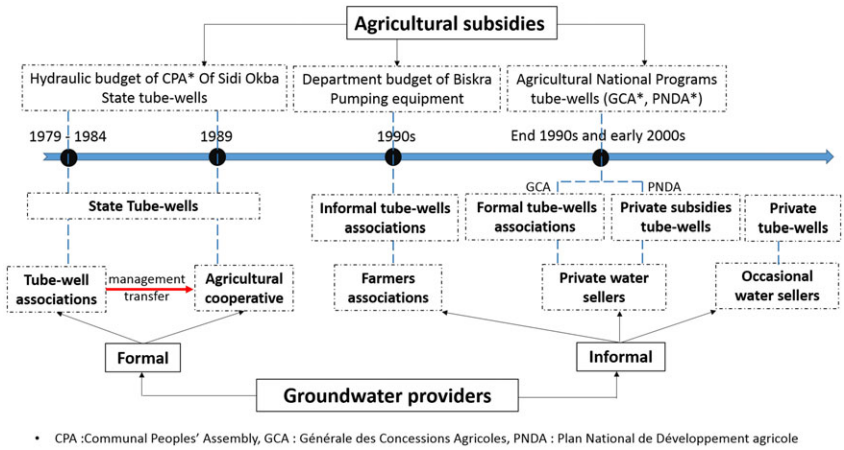

Figure 2. Relationship between state interventions and the emergence of different groups of groundwater providers. [Colour figure can be viewed at wileyonlinelibrary.com]

However, the transfer of the management of tube-wells led to intra-community conflicts between the beneficiaries —the former sharecroppers—and the non-beneficiaries— the large garden owners and local notables—of the state tube-wells. Groundwater was available only to certain small garden owners, whereas the irrigation community of the palm grove comprised 4000 water users, owners of small and large gardens. To solve this conflict, the state and the irrigation community began negotiations to find a compromise that would be acceptable to the different socio-ethnic groups. These negotiations resulted in the creation of an agricultural cooperative in 1989. This hybrid management structure involved the irrigation community through the active membership of the two socio-ethnic groups as well as the state, since the cooperative was directly under the authority of the Ministry of Agriculture. The agricultural cooperative was made responsible for the management of the distribution of surface water (dam releases and dam leakages), which was previously state-operated, and for the maintenance of the main irrigation canal. The secondary irrigation canals were considered by the state to be the property of the water users, and water distribution and maintenance were, therefore, not the responsibility of the cooperative. The agricultural cooperative was also made responsible for the management of four out of the five state tube-wells. After convincing their respective presidents to join the agricultural cooperative as the tube-well water guards, with a salary and all the benefits connected with public service, four of the tube-well associations were dissolved. The fifth state tube-well remained independent of the others, as its president systematically refused to join the agricultural cooperative despite several attempts using social and legal pressure. The president informally appropriated this tube-well and became a private water seller. The community explained the president's behaviour by the fact that he was not promoted to be the head of the agricultural cooperative, even though he was also a main water guard of dam releases. Almost four decades later, the irrigation community had still not forgotten this long-lived conflict. At the time we conducted our field study, the president of the fifth state tube-well had accumulated unpaid electricity bills and was under scrutiny by the administration. He had even been imprisoned on other charges. Nevertheless, the water users did not rely on this tube-well, which was well known for its unpredictable and erratic functioning.

Informal farmers' associations. A few years after the creation of the agricultural cooperative, some large garden owners decided to drill collective tube-wells to be managed by informal farmers' associations. They thought that the agricultural cooperative tube-wells could not cover all their palm trees' water requirements, and did not allow them access to irrigation water at the time they needed it and in the quantity desired. In addition, these large garden owners wanted to control their own water resource by developing a 'club good', outside the sphere of the agricultural cooperative. These associations recall the Indian 'tube-well companies' described by Shah and Bhattacharya (1992). Three farmers' associations were created between 1992 and 1998, each with 33–62 rights-holders per tube-well. Access to groundwater via these tube-wells was based on the financial contribution of each shareholder. Given the high cost of the submerged pump and of the generator at that time, the group of garden owners called on the administrative department of Biskra to finance the equipment of these collective tube-wells. After the collective tube-wells were completed, informal water service markets developed for non-rights-holders outside peak periods, who pay a slightly higher price (2.25 € h^{-1}) than the shareholders (2 € h^{-1}). In India, Shah (1993) called this situation 'seasonal groundwater markets'.

State subsidies of collective and private tube-wells: A way for small garden owners to gain access to groundwater. While large garden owners solved their problem of access to groundwater in the 1990s, small garden owners did not have the financial means to invest collectively in tube-wells and thus create informal farmers' associations. Their access to groundwater through the formal (agricultural cooperative) and informal (farmers' associations) groundwater service markets was insufficient in some parts of the palm grove and resulted in inequities in access to water. They had to wait a decade before they could correct these inequities. Some seized the opportunities offered by the state at the end of the 1990s to kick-start agricultural development through two major agricultural programmes: the General Agricultural Concessions (GCA) in 1997 and the National Agricultural Development Programme (PNDA) in 2001. In this framework, collective (GCA) and individual (PNDA) tube-wells were subsidized. The collective tube-wells were placed in sectors where state agents had previously identified water supply problems. The official beneficiaries of these tube-wells were those whose gardens were located in the command areas of the tube-wells. All of these collective tube-wells were informally privatized by their presidents. The main reason given to justify privatization was incomplete subsidies: 'we were allocated a tube-well with no pumping equipment' (a beneficiary). The exploitation of these tube-wells required further collective investment by their beneficiaries, who refused, and preferred to withdraw from the association. After having equipped the tube-wells, their respective presidents turned them into commercial tube-wells. This was partly inspired by the example of the fifth state tube-well, which had previously been privatized informally by its president, who engaged in water service markets. The second attempt by the state to create formal tube-well associations thus also failed.

As regards the private tube-wells granted under the PNDA programme, the beneficiaries were selected based on the submission of a grant file. Only two small farmers obtained this subsidy due to the complicated criteria required by the state, including a minimum distance to existing tube-wells (700 m) and the size of the farm. While large landowners mainly used these individual subsidies to extend agriculture outside the traditional palm grove (Hamamouche *et al*., 2015), these two small garden owners obtained subsidies to install tube-wells inside the palm grove with the intention of selling water. A new group of five private water sellers thus emerged, supplying water mainly to small garden owners through informal groundwater service markets. These tube-wells had all been subsidized by the state, three under the GCA collective tube-well programme and two under the PNDA individual tube-well programme.

Private tube-wells. Finally, between 2000 and 2015, some large garden owners invested in individual tube-wells, which were no longer subsidized; their aim was to become independent of groundwater providers and their power games. Some occasionally offer water for sale to their neighbours. The local name given to this group of groundwater providers is 'occasional water sellers'. We identified six occasional water sellers, each of whom had an individual tube-well.

The chronology of state interventions and local initiatives between 1979 and 2015 gave rise to four parallel groups of groundwater providers in the irrigation system of Sidi Okba palm grove: (i) the agricultural cooperative managing four large-scale tube-wells; (ii) three farmers' associations, each managing one tube-well; (iii) six private water sellers each managing one tube-well; (iv) six occasional water sellers each having one tube-well.

The overlapping and juxtaposition of the command areas of different groundwater service markets. Figure 3 shows the command areas covered by each group of groundwater providers. These groups emerged in the chronology described in the previous section. The partial overlapping and the juxtaposition of the command areas can originally be explained by the underlying power games in the irrigation community in close interaction with the state, but obeys increasingly an economic logic of private water sellers reaching out to clients.

The command area of the four state tube-wells managed by the agricultural cooperative (Figure 3) represented the starting point and the reference on which future groundwater providers based the choice of the location of their tube-wells. The large garden owners, organized in farmers' associations, installed three collective tube-wells near two state tube-wells, one managed by the agricultural cooperative and the other by a private water seller in the upstream and central parts of the palm grove. The collective tube-wells belonging to the farmers' associations cover 47% of the palm grove. The choice of the location of the tube-wells was purely strategic: (i) to extend the command area not covered by the tube-wells of the agricultural cooperative; (ii) to add one more resource to the command area already covered by the state tube-wells. Three reasons were given to justify strategy (ii). First, the state tube-well managed by the cooperative in the upstream part had a low water discharge (19 $m^3 h^{-1}$), and alone, could not cover the irrigation needs in the upstream part of the palm grove. Second, the private water seller who informally appropriated the fifth state tube-well in the central part of the palm grove bore a personal grudge against the members of the agricultural cooperative and access to his tube-well turned out to be difficult. Third, most shareholders of the farmers' associations wanted to gain control over an alternative water

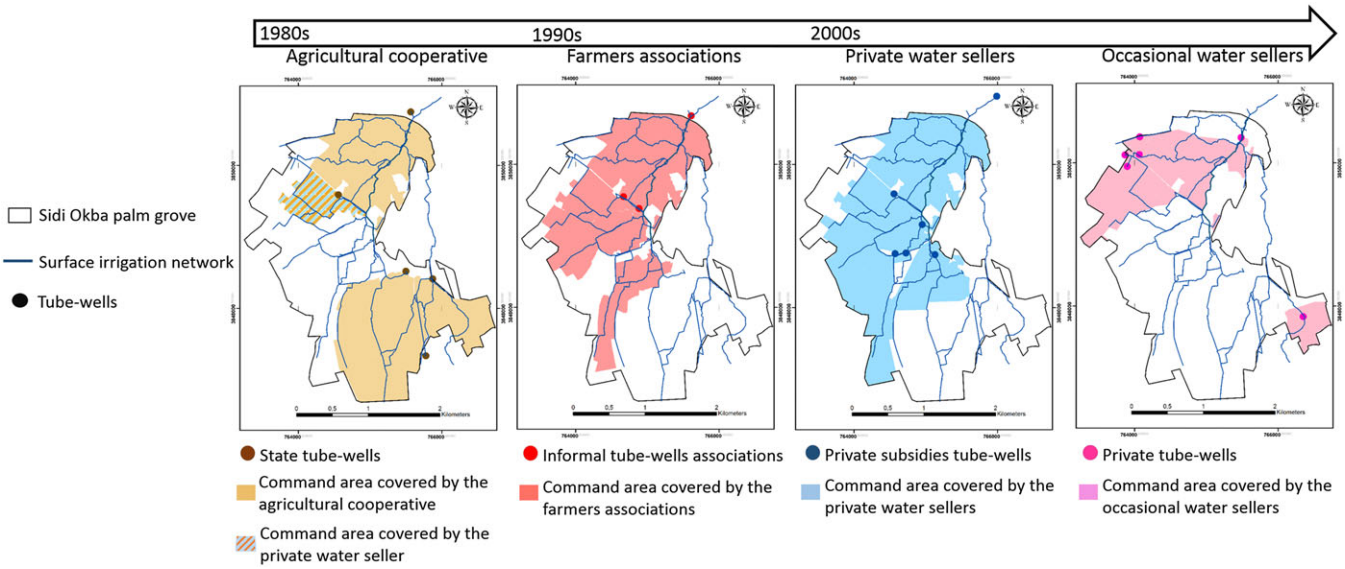

Figure 3. The overlapping and juxtaposition of the command areas of the different groups of groundwater providers. [Colour figure can be viewed at wileyonlinelibrary.com]

resource to water their gardens in the upstream and central parts of the palm grove.

The small garden owners had difficulty obtaining access to groundwater, particularly in the central part of the palm grove. They were at the mercy of the large garden owners for any water they required in addition to the water they received from the agricultural cooperative, which was either insufficient or not available when they needed it. They consequently installed four tube-wells in the central part of the palm grove and one in the upstream part. The command area of these tube-wells generally overlapped with the command areas of collective tube-wells of the large garden owners. In this way, they prevented the farmers' associations from obtaining a monopoly of the supply of groundwater in these two parts of the palm grove. However, these private water sellers also had the ambition to cover the maximum command area to be able to serve a large number of clients. They now cover more than 59% of the palm grove.

Finally, some large garden owners who were not shareholders of farmers' associations and not members of the agricultural cooperative decided to invest in private individual tube-wells in their respective gardens. These tube-wells cover the smallest area irrigated (28% of the palm grove), as their choice of location was based on the location of their own gardens. They sell water only occasionally and only to farmers located along the 'way', that is, on the secondary canal they use to irrigate their own gardens. The command areas of these tube-wells are mostly juxtaposed with the command area of other water providers, but partly overlap the command area of the agricultural cooperative.

The nature of the different groundwater service markets

The way in which the different groundwater service markets function varies with the group of groundwater providers, their economic interests and social logic (Table I).

Two main types of groundwater service market were identified in the irrigation system of the Sidi Okba palm grove. Two 'permanent' groundwater service markets concern the agricultural cooperative and the private water sellers. In both cases most of the pumped water is sold to water buyers, as each provider has more than 1000

Table I. Properties of groundwater irrigation

Groups of groundwater providers	Number of tube-wells	Types of groundwater service markets	Net irrigation surplus		Water sales surplus	Approximate number of gardens irrigated		Likely trend in income gain
			Tube-well owners	Water buyers		Tube-well owners	Water buyers	
Agricultural cooperative	4	Permanent		+++++	+++++		1330	Minimum gains
3 Farmers' associations	3	Irregular	+++	++	++	170	290	Moderate gains
6 Private water sellers	6	Permanent		++++	+++++	10	1440	Maximum gains
6 Occasional water sellers	6	Irregular	+++	++	++	170	30	Moderate gains

This table was inspired by the work of Shah (1993): from the smallest (+) to the largest (+++++).

customers (Table I). However, the two management structures can be distinguished by their strategic interests. The agricultural cooperative must provide water to the highest possible number of water users for social and community reasons. In theory, all 4000 garden owners have the right to buy groundwater, but half cannot physically be served as they are located upstream of the tube-wells. To be able to serve all water users regardless of their socio-ethnic affiliation, the cooperative established a supply-driven water turn between three secondary irrigation canals for each state tube-well. Groundwater pumped by each tube-well flows into a secondary irrigation canal for a period of 30 days (720 h). During this period, a groundwater service market is open for garden owners who have a water intake from this canal. Once the quota of 720 h is reached, the agricultural cooperative stops selling the water in this canal. Groundwater is then distributed to another secondary canal covering another area. In the next supply turn, the agricultural cooperative favours the garden owners who were unable to buy water during the last supply turn. On average, four water turns are available from a given secondary irrigation canal per year.

In contrast, the focus of the group of private water sellers, which was originally based on a socio-ethnic claim to obtain access to groundwater, rapidly turned to more economic reasons. In the first period after they emerged, this group only sold water to the disadvantaged former sharecroppers, small owners whose gardens were located in the upstream and central parts of the palm grove. Then they discovered the economic interest of selling the groundwater (Table I). They extended their groundwater sales to all water users who owned gardens within the command area of their tube-wells. The water sales and the supply of groundwater to secondary irrigation canals by these service providers are consequently now mostly governed by water demand.

The 'irregular' groundwater service markets concern the two remaining groups of groundwater providers: farmers' associations and occasional water sellers. Their main aim is to cover their own collective or private needs for irrigation water, thus only surplus water is available for purchase and only outside peak periods (Table I). A distinction can be made between the two management structures concerning the value of water. For the farmers' associations, the water is a club good, but they consider off-season water sales to be an excellent way to pay for the maintenance and repair of the tube-wells. The groundwater distribution proposed by farmers' associations follows a water turn between the shareholders. A supply turn is applied to secondary irrigation canals, since the shareholders are located along various canals. The water rights, expressed as a period of irrigation, are counted once water enters a garden. Two prerequisites determine the sale of water to non-shareholders: (i) the gardens of water buyers must be located between gardens of shareholders on the same secondary irrigation canal, and (ii) the shareholders do not want to use their water rights for one reason or another at a specific point in time.

For the occasional private water sellers, the water is a private good but which for reasons of social relations is shared with small-scale neighbours. For these occasional private water sellers, the financial gains are of secondary importance. They sell groundwater services to neighbouring garden owners who share the same secondary irrigation canal. In so doing, they (i) reduce water transport time and hence consumption of electricity, (ii) make a profit to cover the cost of pumping and pay for mechanical repairs, and (iii) maintain good relations with their neighbours.

The coexistence of rival groundwater service markets

The coexistence of four groups of groundwater providers in the same irrigated area with the original social objective of avoiding the emergence of a monopoly gradually resulted in economic competition for the water supply, and hence to the beginning of rivalry between the groundwater service markets. This in turn led some groundwater providers to design strategies around the price of groundwater and the quality of service.

Groundwater pricing strategies around the reference price of the agricultural cooperative. The informal groundwater providers use the groundwater pricing of the agricultural cooperative, expressed as an average cost per hour (€2.25 h^{-1}, see Table II), as the benchmark for their water sales. No water seller ever exceeds this hourly price. Competition in the groundwater service markets imposes a price which ranges from €1.5 to 2.25 h^{-1}. However, when the price of water of € h^{-1} is converted into € m^{-3}, it is clear that the price of water from all the other water providers is from one-third higher to even double the price proposed by the agricultural cooperative (Table II).

Groundwater pricing is not a function of water discharge or of the consumption of electricity: the price per volume of groundwater (in m^3) is higher, the lower the discharge. For example, the agricultural cooperative sells groundwater for €0.03 m^{-3} at an average discharge of 72 m^3 h^{-1}. The price of groundwater supplied by the other informal groundwater providers is much higher for lower water discharges: the farmers' associations sell it for €0.04 m^{-3} (at a discharge of 54 m^3 h^{-1}), private water sellers sell it for €0.06 m^{-3} (34 m^3 h^{-1}) and occasional water sellers sell it for €0.05 m^{-3} (30 m^3 h^{-1}).

The price of groundwater (€ h^{-1}) sold by the groundwater providers is chosen to ensure a profit over and above the cost of water extraction (electricity), the monitoring service (water guards) and the cost of maintenance and spare parts. The depreciation cost of the investments (about €20 000 for

Table II. Technical and economic indicators of groundwater irrigation (empirical data for 2014)

Groups of groundwater providers	Characteristics of the tube-wells				Groundwater pricing			
	Number	Average power of the pump (A)	Average discharge (m^3 h^{-1})	Volume pumped (Mm^3 yr^{-1})	Average (€ h^{-1})		Average (€ m^{-3})	
					Tube-well owners	Water buyers	Tube-well owners	Water buyers
Agricultural cooperative	4	69	72	1.7		2.25		0.03
3 Farmers' associations	3	47	54	1.0	2	2.25	0.04	0.04
6 Private water sellers	6	31	34	1.3		1.80		0.06
6 Occasional water sellers	6	24	30	0.5		1.50		0.05

a tube-well, equipped with a pump and electrical engine) is not taken into account by any of the four categories of water providers. This is all the more so since the majority of these tube-wells were subsidized by the state.

The economic gains generated by the sale of groundwater and the operational costs of the tube-wells vary depending on the group of groundwater providers (Table III).

The agricultural cooperative makes the least profit per tube-well (€970 yr^{-1}). This is because of the social objectives of the cooperative, as discussed above. Despite the stated objective of the farmers' associations to make some profit on the sale of groundwater services, they only manage to do so to a certain extent (€3750 yr^{-1}). This is because shareholders of the collective tube-wells have priority, meaning groundwater is only available for sale at limited times. In addition, most tube-wells belonging to the agricultural cooperative (3/4) and the farmers' associations (2/3) are equipped with the most powerful submersible pumps in the palm grove and pump water at high discharges. They are connected to the electricity supply at medium power; the electrical transformer can support up to 50 kVA per tube-well. Therefore, their electricity consumption and bills are very high (€8000–8470 yr^{-1} per tube-well) including a subscription for the electrical transformer (€50 $month^{-1}$). This type of electrical connection does not benefit from state subsidies.

The farmers' associations generate four times more profit (€3750 versus €970 yr^{-1}) than the agricultural cooperative, while the revenues and costs of electricity are almost the same. This difference in profit is relative to the cost of the water guard. The services of the water guard are much cheaper in the farmers' associations than in the agricultural cooperative (€940 versus €3000 yr^{-1}). In the farmers' associations, the services of the water guard are paid at a rate of €0.15 h^{-1} of water sold, whereas in the agricultural cooperative, the water guards are public service employees who receive a monthly fee of €250. The high costs of electricity and of the water guards have a direct impact on the management of the agricultural cooperative. Despite several attempts to raise the price of groundwater, the majority of the official members (who are also water buyers) opposed this, as 'the objective of the cooperative is to ensure the water supply and not to make a profit' (official of the agricultural cooperative).

In contrast, most tube-wells belonging to the private and occasional water sellers are smaller and are connected to the agricultural electrical line at low power (34 A), only making it possible to operate a pump at a maximum of 36 m^3 h^{-1}. All owners of connections to this type of electrical line in the Algerian Sahara benefit from a 50% reduction in their electricity bills. The low cost of electricity (€2190 yr^{-1} per tube-well) and the absence of water guards meant private water sellers could make very high profits on the groundwater irrigation water services markets (€9650 yr^{-1} per tube-well). The sales of groundwater became their main agricultural activity, especially as the majority only have small gardens (less than 0.5 ha) that are hardly or not at all profitable. As private seller of groundwater said: 'my tube-well is more profitable than my small inherited garden'. However, as stated above, the reference price of the agricultural cooperative means that, for the time being, these private water sellers cannot increase the price per hour.

Table III. Costs and gains of groundwater pumped (empirical data for 2014)

Groups of groundwater providers	Average economic (€ yr^{-1} per tube-well)					
	Revenues	Costs of electricity	Electricity subsidies	Costs of guard	Total costs	Gains
Agricultural cooperative	12 400	8 470	No	3 000	11 500	970
Farmers' associations	12 700	8 000	No	940	8 940	3 750
Private water sellers	11 800	2 190	Yes (50%)	0	2 190	9 650
Occasional water sellers	5 000	1 100	Yes (50%)	0	1 100	3 900

Playing on the quality of services to attract more water buyers. The price of water is not the only criterion of differentiation between the different groups of groundwater providers. Most propose a quality service to attract more water buyers, in particular in the 60% of the palm grove where there is no monopoly of water supply in the upstream and central parts (Figure 4).

The group of private water sellers came up with strategies to increase the command area for their tube-wells as much as possible (59% for a pumped volume of 1.3 $Mm^3\ yr^{-1}$) to attract more water buyers and hours of water sold. Their strategy is to combine two to three low-discharge tube-wells (34 $m^3\ h^{-1}$ from each tube-well), and guarantee that supply to the same secondary irrigation canal simultaneously. This case is most common during peak periods (from May to September). It makes it possible to increase the distance travelled by the water in the earthen canal up to 2.5 km. Likewise, private water sellers sell their water 24 h a day during peak periods, whereas the agricultural cooperative and farmers' associations shut off the supply from their tube-wells for 4 h a day, when the price of electricity is high. In this way, the private water sellers cover the largest command area with their tube-wells (59% of the palm grove), compared to that of the agricultural cooperative (72 $m^3\ h^{-1}$ for a command area of 55%), and farmers' associations (54 $m^3\ h^{-1}$ for a command area of 47%).

The non-shareholders of collective tube-wells and the non-owners of individual tube-wells depend on purchased irrigation. Originally, they chose from whom they purchased water based on their social relations with one or more water providers, or on the hydraulic characteristics (discharges, the distance between tube-wells and their garden, etc.). However, things have changed, as some private water sellers offer facilities, or have introduced new rules to help achieve their commercial objective, depending on the balance of power in the different parts of the palm grove. First, they facilitated payment for irrigation by allowing the farmers to pay at the end of the agricultural campaign or in several instalments. Second, they provided a maintenance service of secondary irrigation canals, which they supply with water. Third, they provided a monitoring service of groundwater purchased from tube-wells up to the entrance of the garden. Fourth, they did not charge for water transport time when the gardens are located near the tube-well (i.e. involving less than 1 h of transport). Otherwise, 1–2 h are subtracted per irrigation turn. Fifth, to ensure regular water sales all year round, especially in winter when the demand for water is lower, the private sellers introduced a rule that obliges their customers to purchase five or six irrigation turns per year: 'buying water in winter ensures you have priority in the peak period' (a private water seller). Despite the increased rivalry, the social dimension of water was not completely absent, even for the private water sellers. Some of them sell water at a lower price to their family and close friends, for instance.

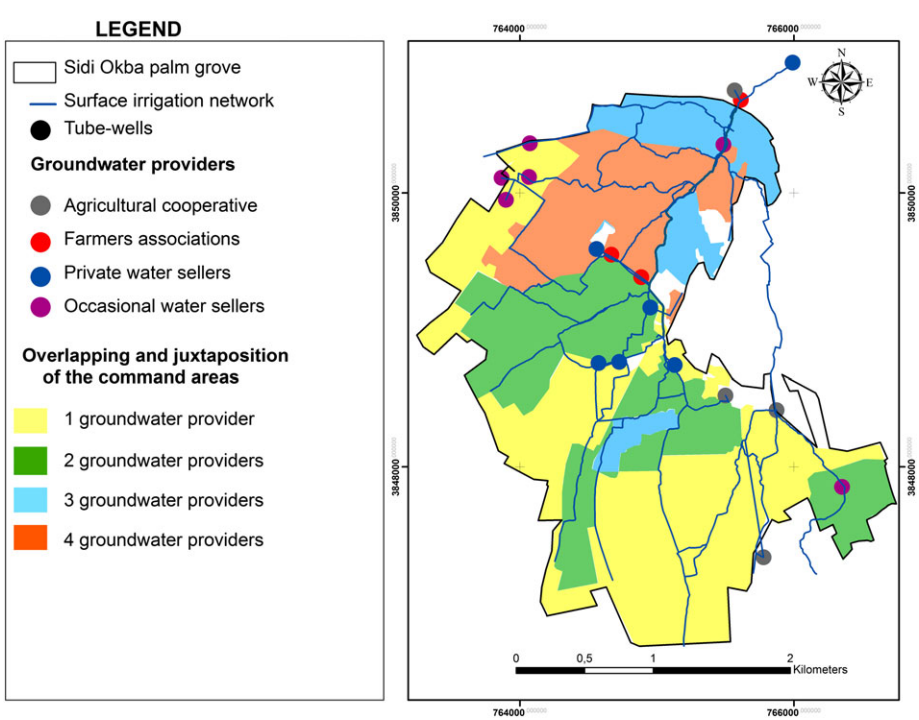

Figure 4. The current distribution of groundwater in the Sidi Okba palm grove. [Colour figure can be viewed at wileyonlinelibrary.com]

DISCUSSION

Complex power relations underlying the development of the groundwater service markets

This study showed how over a period of four decades, four formal and informal often overlapping groundwater service markets emerged in Sidi Okba, which still coexist today and cater to different date palm growers. These markets were progressively shaped by antagonistic socio-ethnic exchanges and negotiations, interventions by the state (particularly through subsidy programmes) and increasingly by economic competition between water sellers. The formal institutional arrangements around groundwater proposed by the state were systematically transformed to fit the existing social relations and balance of power. This emphasizes the interest in using a historical perspective when studying the emergence and development of groundwater institutions, and confirms the analysis of Dubash (1998, 2000), who reported that groundwater markets are socially and ecologically embedded with a path-dependent history. We showed that the 'question of power in rural society' is important, which raises the question why so few studies have focused on this question to date (Mukherji, 2004).

Interestingly, in the case study, state interventions played a key role in the emergence of the different formal and informal groundwater institutions. These interventions did not only take place at the initiative of the state. The different socio-ethnic groups called on the state whenever the opportunity or necessity arose, underlining the ambivalent relation local communities have with the state (Boelens, 2008). In Sidi Okba, the state originally favoured small garden owners, who had been their allies since the struggle for independence (Hamamouche *et al*., 2015). In parallel, noble families, who possessed the largest gardens and were the 'water lords' of the palm grove at the time of the spate irrigation system before 1950, gradually lost control over irrigation water as a result of several state interventions. The creation of informal farmers' associations by these large garden owners in the 1990s can thus be understood as a way of countering this gradual shift in the power balance by obtaining control over their own supply of groundwater in the upstream and central parts of the palm grove. They had the financial means to make the initial investment (drilling the boreholes) and the networks needed to obtain additional funding from the state, but also the organizational capacity for collective action. Thanks to the (relatively) large size of their gardens, three informal associations of 33–62 garden owners were able to install a collective tube-well. In the case of small garden owners, this would have required at least five times this number, which made this option not feasible. However, this initiative encouraged small garden owners, who were water buyers, to retaliate as soon as the opportunity arose. This became possible a decade later when agricultural subsidies became available for smaller and less costly tube-wells in the 2000s. According to Lewis (1991) the originally disadvantaged water buyers were then able to redefine or reverse the power game in favour of the water sellers, which is exactly what the different socio-ethnic groups did.

In the Sidi Okba palm grove, some water buyers belonging to the group of small garden owners consequently drilled small private tube-wells, subsidized by the state, either to extend the command area irrigated by groundwater (juxtaposition of groundwater service markets) or in the same command area as that of the collective tube-wells belonging to farmers' associations, to prevent a monopoly in the supply of groundwater, thereby destroying the status of the water lords and countering inequities in access to groundwater. In contrast to reports by Fujita and Hossain (1995) but in agreement with a report by Ballabh *et al*. (2002), in India, different social categories of farmers thus gained access to groundwater through tube-wells and proposed their services to sell groundwater to other farmers. For the irrigation community, this meant a long process of mutual observation, intricate negotiations and mobilizing the state whenever this was possible.

Rivalry, competition and mutual influence between coexisting groups of groundwater providers

According to Swyngedouw *et al*. (2002), social power relations 'decide who will have access to or control over, and who will be excluded from access to or control over, resources or other components of the environment'. Interestingly, even in case of formal water markets, as in Chile, empirical evidence shows the importance of the social and environmental dimensions of these markets, which are often analysed solely for their economic dimension (Bauer, 2004). In the case of Sidi Okba, the power games and the desire of each socio-ethnic group to have its own access to groundwater and not to depend on another group finally prevented the emergence of a power monopoly in 60% of the palm grove. This also explains the coexistence of several groups of groundwater providers. This is in line with Palanisami and Easter (1991), who stated that the best way to destabilize a monopoly position in the supply of groundwater is to increase competition by encouraging the development of community and private tube-wells. Indeed, in the case of the Sidi Okba palm grove, the private water sellers installed their subsidized tube-wells near the collective tube-wells, belonging to the farmers' associations created by large-scale garden owners of higher status, to cover the same command area, and thus break the monopoly power of these large garden owners and the dependence of small garden owners on them.

However, once groundwater had become accessible to all the garden owners who wanted to buy water, the private water sellers became aware of the economic opportunity represented by the sale of water. Our study proves that water markets are very dynamic, which pleads—once again—for a historic perspective when analysing institutional arrangements. Along the way, groundwater service markets enabled their protagonists to make money and introduced a clear economic dimension to these markets. Today, in the Sidi Okba palm grove, water sales are consequently less influenced by belonging to a socio-ethnic group. Shah and Ballabh (1997) also pointed out that when several socio-ethnic groups are water sellers in the same area, 'there was smooth, trouble-free water trade which seemed to be least influenced by the caste and class of either the buyer or seller'. The coexistence of four groups of water providers created competition for the supply of groundwater, economic rivalry between groundwater sellers, but also mutual influence between groundwater providers. For instance, the private water sellers could not increase their prices (per hour of irrigation service) beyond the official price of the agricultural cooperative (see Mukherji, 2004, for similar observations in water service markets in India). However, in our case, private water sellers got round this constraint by selling water at the same price per hour but with lower discharges, thus making the unit of water more expensive. To justify this difference in price, they provided more flexible water delivery to their 'clients'. Several authors have analysed such 'oligopoly models' of groundwater service markets in South Asia (Dubash, 1998; Palmer-Jones, 2001; Prakash, 2005), where each water buyer had access to two or three alternative groundwater providers belonging to different social groups. Shah (1993) showed that in the competitive groundwater service markets, 'sellers are under pressure to "delight" their clients' by offering facilities to attract more customers. According to Shah and Ballabh (1997), such sales strategies include the reduction 'of prices to the minimum', the provision of 'dependable, high quality irrigation service', and the offer of 'non-price inducements such as credit up to harvest time, water supply through rubber pipes or 'pucca' channels'. In the case of Sidi Okba, the private water sellers used two types of strategy. First, the water providers jointly agreed to accumulate low water discharges from their respective tube-wells in order to transport groundwater as far as possible, and consequently be able to serve more customers. Each customer would then get a share of the combined discharge. Second, individually, they offered different advantages to differentiate themselves from the others, but also imposed, whenever possible, some rules, for instance the obligation to buy water during winter (when demand is low) in order to ensure access to groundwater during the peak summer season. These empirical results reveal the limits of the reduction in the monopoly of power of the water sellers as groundwater markets develop and become more competitive. In our case study, the balance of power between private water sellers and water buyers is dynamic, for instance prompting the emergence of new water sellers, and differs depending on the water situation in different parts of the palm grove. This also explains why the community maintains distribution of groundwater by the agricultural cooperative as a way to check the advance of private water sellers. The economic dimension of water service markets consequently remains embedded in the wider social structure of the irrigation community.

CONCLUSION

This study shows how, over time, different groups of water buyers gained access to groundwater, often as water buyers, but also—whenever possible—by becoming water sellers themselves. These different groups were very much aware of the importance of gaining control over part of the resource base, possibly because of their long-standing experience in dealing with water issues in this community-managed irrigation system. Despite this fascinating tale, it should not be forgotten that sometimes brutal social power games underlie such strife, in which some lose out. For example, some garden owners stopped irrigating their gardens due to the difficulty in accessing groundwater, often combined with other problems such as the sharing of inherited land. Finally, the institutional arrangements set up by the irrigation community in close interaction with the state, focused on dealing with the social, economic and physical constraints to gain access to and use groundwater, to the detriment of the (declining) groundwater resource. However, the proven capacity of the irrigation community to ensure these complex groundwater service markets function should encourage public actors to mobilize this capacity to deal also with the decline in water tables, which is one adverse outcome of the 'success' of these markets in furnishing groundwater to all users.

REFERENCES

Adnan S. 1999. Agrarian structure and agricultural growth trends in Bangladesh: the political economy of technological change and policy interventions. In Rogaly B, Harriss-White B, Bose S (eds). *Sonar Bangla? Agricultural Growth and Agrarian Change in West Bengal and Bangladesh*. Sage: New Delhi, India.

Ballabh V, Choudhary K, Pandey S, Mishra S. 2002. Groundwater development and agricultural production: a comparative study of eastern Uttar Pradesh, Bihar and West Bengal. Paper submitted to IWMI-Tata Water Policy Programme, Anand, Gujarat, India.

Bauer CJ. 2004. Results of Chilean water markets: empirical research since 1990. *Water Resources Research* **40**(9): 1–11.

Boelens RA. 2008. Water rights arenas in the Andes: upscaling networks to strengthen local water control. *Water Alternatives* **1**(1): 48–65.

Bouarfa S, Kuper M. 2012. Groundwater in irrigation systems: from menace to mainstay. *Irrigation and Drainage* **61**: 1–13.

Dubash NK. 1998. The 'instituted process' of groundwater exchange in Gujarat, India. In *Proceedings of the Crossing Boundaries' Seventh Annual Conference of the International Association for the Study of Common Property*: Vancouver, British Columbia, Canada; p 10–14.

Dubash NK. 2002. *Tubewell Capitalism: Groundwater Development and Agrarian Change in Gujarat*. Oxford University Press: Oxford, UK.

Easter KW, Rosegrant MW, Dinar A. 1999. Formal and informal markets for water: institutions, performance, and constraints. *The World Bank Research Observer* **14**(1): 99–116. https://doi.org/10.1093/wbro/14.1.99.

Frija A, Chebil A, Speelman S. 2016. Farmers' adaptation to groundwater shortage in the dry areas: improving appropriation or enhancing accommodation? *Irrigation and Drainage* . https://doi.org/10.1002/ird.1986.

Fujita K. 2004. *Transformation of groundwater market in Bengal: implications to efficiency and income distribution. Centre for Southeast Asian Studies*. Kyoto University: Kyoto, Japan.

Fujita K, Hossain F. 1995. Role of the groundwater market in agricultural development and income distribution: a case study in a northwest Bangladesh village. *The Developing Economies* **33**(4): 442–463. https://doi.org/10.1111/j.1746-1049.1995.tb00725.x.

Hamamouche MF, Kuper M, Lejars C. 2015. Émancipation des jeunes des oasis du Sahara algérien par le déverrouillage de l'accès à la terre et à l'eau. *Cahiers Agricultures* **24**(6): 412–419. https://doi.org/10.1684/agr.2015.0777.

Hamamouche MF, Kuper M, Riaux J, Leduc C. 2017. Conjunctive use of surface and ground water resources in a community-managed irrigation system—the case of the Sidi Okba palm grove in the Algerian Sahara. *Agricultural Water Management* **193**: 116–130 Retrieved from DOI: https://doi.org/10.1016/j.agwat.2017.08.005.

Janakarajan S. 1994. Trading in groundwater: a source of power and accumulation. In Moench M (ed). *Selling Water: Conceptual and Policy Debates over Groundwater Markets in India*. VIKSAT: Ahmedabad, India; p 47–58.

Kuper M, Dionnet M, Hammani A, Bekkar Y, Garin P, Bluemling B. 2009. Supporting the shift from state water to community water: lessons from a social learning approach to designing joint irrigation projects in Morocco. *Ecology and Society* **14**(1): 19.

Lewis DJ. 1991. *Technologies and transactions: a Study of the Interaction between New Technology and Agrarian Structure in Bangladesh*. CABI, Centre for Social Studies: Dhaka, Bangladesh.

Llamas MR, Custodio E. 2002. *Intensive Use of Groundwater: Challenges and Opportunities*. A.A. Balkema Publishers: Lisse, the Netherlands.

Margat J, Van der Gun J. 2013. *Groundwater around the World: a Geographic Synopsis*. CRC Press: Boca Raton, Fla, USA.

Meinzen-Dick RS. 1998. Groundwater markets in Pakistan: institutional development and productivity impacts. In Easter K, Rosegrant M, Dinar A (eds). *Markets for Water*. Kluwer Academic Publishers: Boston, USA; p 207–222.

Mukherji A. 2004. Groundwater markets in Ganga–Meghna–Brahmaputra basin: theory and evidence. *Economic and Political Weekly* **31**: 3514–3520.

Mukherji A. 2007. Implications of alternative institutional arrangements in groundwater sharing: evidence from West Bengal. *Economic and Political Weekly* **42**(26): 2543–2551.

Palanisami K, Easter KW. 1991. Hydro-economic interaction between tank storage and groundwater recharge. *Indian Journal of Agricultural Economics* **46**(2): 174–179.

Palmer-Jones R. 2001. Irrigation service markets in Bangladesh: private provision of local public goods and community regulation. In *Symposium on Managing Common Resources: What Is the Solution?* Lund University: Sweden; p 10–11.

Prakash A. 2005. *The Dark Zone: Groundwater Irrigation, Politics and Social Power in North Gujarat*. **7**. Hyderabad, India: Orient Blackswan.

Rica M, López-Gunn E, Llamas R. 2012. Analysis of the emergence and evolution of collective action: an empirical case of Spanish groundwater user associations. *Irrigation and Drainage* **61**(S1): 115–125. https://doi.org/10.1002/ird.1663.

Saleth RM. 1994. Groundwater markets in India: a legal and institutional perspective. *Indian Economic Review* **29**(2): 157–176.

Schlager E. 2007. Community management of groundwater. In *The Agricultural Groundwater Revolution: Opportunities and Threats to Development*. **3**. CABI: Wallingford, UK; p 131–152.

Shah T. 1985. Transforming ground water markets into powerful instruments of small farmer development: lessons from Punjab, Uttar Pradesh and Gujarat. Mimeo, Institute of Rural Management, Anand, India.

Shah T. 1993. *Groundwater Markets and Irrigation Development*. Oxford University Press: Oxford, UK.

Shah T, Ballabh V. 1997. Water markets in north Bihar: Six village studies in Muzaffarpur District. *Economic and Political Weekly* A183–A190.

Shah T, Bhattacharya S. 1992. *Farmer organisation for lift irrigation: irrigation companies and tubewell co-operatives of Gujarat*. ODI/IIMI Irrigation Management Network Paper: London, UK.

Shah T, Singh OP, Mukherji A. 2006. Some aspects of South Asia's groundwater irrigation economy: analyses from a survey in India, Pakistan, Nepal Terai and Bangladesh. *Hydrogeology Journal* **14**(3): 286–309. https://doi.org/10.1007/s10040-005-0004-1.

Swyngedouw E, Kaika M, Castro E. 2002. Urban water: a political-ecology perspective. *Built Environment* (**1978-**) 124–137.

Zhang L, Wang J, Huang J, Rozelle S. 2008. Development of groundwater markets in China: a glimpse into progress to date. *World Development* **36**(4): 706–726.

