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Regulating groundwater use: The challenges of policy implementation in Guanajuato, Central Mexico

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ABSTRACT

Around the world it has proven very difficult to develop policies and interventions that ensure socio-environmentally sustainable groundwater use and exploitation. In the state of Guanajuato, Central Mexico, both the national government and the decentralized state government have pursued to regulate groundwater use through direct state control, groundwater markets, energy pricing, and user self-regulation. We present and analyze these regulatory mechanisms and their outcomes in the field. We argue that the close interdependencies of these regulatory mechanisms have pre-empted the effectiveness of these policy instruments as well as that of other measures aimed at reducing groundwater use in order to advance towards sustainable exploitation levels.

1. Introduction

Groundwater has become the mainstay of many societies around the world. In many regions of the world, it is the primary source of water for domestic, urban, agricultural and industrial use (Burke and Moench, 2000; Shah et al., 2003, 2007). Vast quantitates of high quality fresh water is stored in aquifers and is usually easy to access with tubewell technologies. Users located above an aquifer can by-and-large sink and operate wells autonomously of each other over a significant areal extensions (Kemper, 2007). This makes groundwater a reliable source of water. According to Shah et al. (2007: 409), groundwater is often available on site; it has an important inter-annual storage buffer that is highly reliable; and it is highly flexible, providing its users with on-demand, just-in-time water when they need it. Therefore it is not surprising that for urban and rural domestic water provision as well as for industrial uses and agriculture, when available, groundwater is the preferred source of water. This has led to intensive and unsustainable groundwater use in many areas of the world with dire socio-environmental impacts (Hoogesteger and Wester, 2015).

In most countries, despite attempts to regulate groundwater use no significant reductions in groundwater extractions have been achieved. Common mechanisms include drilling bans, regulatory control through rights systems with assigned volumes, electricity pricing, and the regulation of drilling companies. Yet, in nearly all areas of intensive groundwater use, water users continue to have nearly unconstrained control over their pumps (Shah, 2009; Giordano, 2009; De Stefano and Lopez-Gunn 2012; Frija et al., 2014).

In this context the state of Guanajuato, located in Central Mexico (see Fig. 1), offers and interesting case to analyze the challenges that groundwater regulation and governance pose. Mexico has for years been an international show model in terms of water policies; including groundwater (Mukherji and Shah, 2005). Within Mexico, Guanajuato spearheaded the decentralization policies of the 1990s and as part of it started to work with Aquifer Management Councils (Wester et al., 2009). At present in the state all industrial and 99% of urban water supply is groundwater based; and a vibrant groundwater irrigated agricultural sector that consumes 84% of all extracted groundwater occupies over 260,000 ha (CEAG, 2016). According to official data the extracted volume oscillates around 3900 Million Cubic Meters (MCM) per year and recharge is estimated at just below 2800 MCM/year; the annual deficit surpasses 1000 MCM/year (CEAG, 2016). Aquifer levels are dropping on average between 2 and 3 m a year (Wester et al., 2011), land subsidence has become a problem in many regions of the state (Hoogesteger, 2004), tubewells dry up and need to be deepened or replaced and extensive pockets of arsenic and fluoride contamination have appeared in the north and center of the state forming a threat to public health (Gevaert et al., 2012; Ortega-Guerrero, 2009).

State initiatives to regulate groundwater use have been in place since the early 1950s (Wester, 2008). In 1992 a new national water use permit system was implemented that importantly included the possibility of groundwater rights transmissions (Reis, 2014). Energy pricing mechanisms have also been used (Scott and Shah, 2004). Inspired by ideas of user self-regulation, in the 1990s the state government of Guanajuato created Aquifer Management Councils. In parallel subsidies

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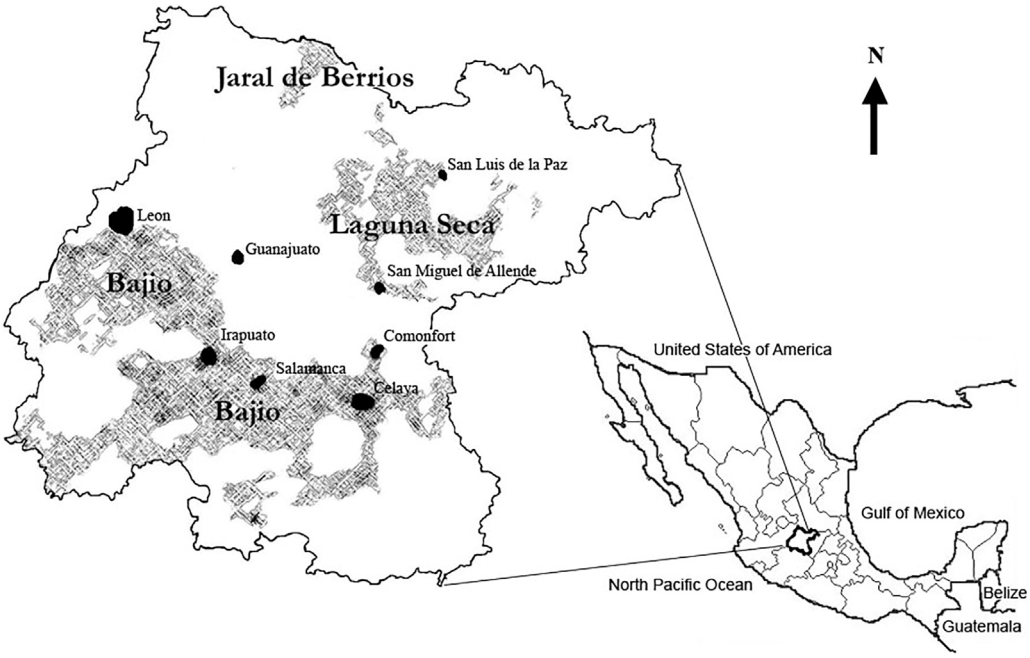

Fig. 1. State of Guanajuato, Mexico with areas of intensive groundwater use (Bajío, Laguna Seca and Jaral de Berrios) (adapted from Wester et al., 2011).

were put in place to stimulate the modernization of irrigation systems. These aimed to reduce groundwater use in the agricultural sector. In this contribution we analyze these policy interventions through the analytical lens of normative structures (Reimer et al., 2008). Based on our analysis we show the interrelatedness of these measures and discuss the challenges there are for achieving equity and sustainability in groundwater use in Guanajuato as elsewhere.

This article is based on fieldwork of both authors over the past 20 years. Data collection consisted of literature review, grey literature collection, structured and semi-structured interviews with farmers, staff of non-governmental organizations, state agencies, the Aquifer Management Councils, agro-export companies, drilling companies and policy makers. Several meetings and events which brought these actors together were attended and observed. Data collected from these different sources was triangulated to ensure their validity (Mason, 2002).

2. Normative structures and groundwater regulation

Groundwater is very often characterized by the basic resource features identified by Ostrom (1990) as Common Pool Resources (CPR) (see also Knegt and Vincent, 2001). Common pool problems or dilemmas arise when individually rational resource decisions bring about a result that is not optimal when considered from the perspective of the group; thus CPR are public goods with finite, or subtractive benefits (Ostrom, 1990). In the case of groundwater, when one user uses more, less remains for the others. When no regulatory frameworks exist users have neither carrot nor stick that incentivizes them to restrain or reduce their resource use; the self-interest of the individual users then easily leads to over-exploitation.

According to Ostrom (1990), the policy solutions that emerge mostly fall under: state control; market regulation or the creation of institutions for self-regulation (see also Agrawal, 2014; Araral, 2014; Lejano et al., 2014; Lejano and Fernandez de Castro, 2014). The basis for these different policy instruments is the creation of a normative framework that regulates the behavior of individuals for the benefit of the collective interest. A normative framework establishes a set of rules about rights, obligations and sanctions that create reciprocal expectations about the behavior in and amongst the resource users and the institutions responsible for its implementation; that is social capital.

The term social capital was developed as a way to better understand how and why individuals benefit from social relations (Bourdieu, 1977; Coleman, 1990). Today social capital has become a framework for 'analysing the functional value of social relations and organizational networks, as well as their influence on economic outcomes and state accountability' (Perreault, 2004:329). The term has been widely used in the analysis of natural resources management arrangements including groundwater (López-Gunn, 2012; Nenadovic and Epstein, 2016; Rica et al., 2012).

Social capital is engrained in the structure of relationships and can be defined as 'the ability of actors to secure benefits by virtue of membership in social networks or other social structures' (Portes 1998:6). The presence of reciprocity in networks (which often goes paired with trust) forms the basis for people to engage in actions that are of mutual benefit. Normative structures maintain and organize the connections in these networks by establishing 'reasonable' expectations concerning what others will do through 'systems of sanctions and incentives that ensure consistency in those actions' (Reimer et al., 2008: 259). These same authors identify four different kinds of normative structures that organize and guide the social relations through which people accomplish tasks, legitimize their actions, structure their institutions and distribute resources. These are (p. 261–263):

- Bureaucratic relations: These are legal relationships established by nation states at different levels. They are based on generally applied laws and legal decrees that are implemented through state based institutions and administrative systems to guarantee 'order' within society. The granting of entitlements, the protection of the rights that are imbued in these entitlements and the control over the fulfilment of the responsibilities that accompany this grant to groups and individuals is the responsibility of designated state agencies.
- Market relations: These revolve around the exchange of goods and services among people that relate to each other as free actors. For these relations to function trust among the engaged actors must exist with regards to the agreed upon exchanges as well as its terms and conditions.
- Associative relations: Associative relations emerge among people that come together for achieving a shared goal for which collaboration is required. Associative relations build on a set of normative frameworks (formal or intensely socialized) that establishe what people are expected to contribute and with what benefits to them

through the association.
- Communal relations: These are based on a strong sense of shared identity based on, for instance, location, birth, ethnicity, intensely shared socialization. The rights and obligations are closely linked to this identity and to the place and geographical space which the group of people share and use.

These relations are interdependent and can enforce and/or weaken and undermine each other. Once relations of reciprocity are established these can, according to Portes (1998), have three different yet complementary functions which are: a) a source of social control and enforcement of the shared normative framework, b) a source of support from other members of a defined and bounded group, and c) a source of benefits through broader extra-group networks. Yet, the existence of these relations does not mean that these are also mobilized for the purpose for which these were initially developed (Anthias, 2007). Thus, although networks might exist it does not mean that they are automatically translated into an advantage for the common interest.

From a perspective of groundwater regulation the aim of normative structures is to achieve socio-environmentally sustainable levels of resource use (Agrawal, 2014). To achieve this goal a set of rules and regulations that ensure sustained and equitable access to water to the population as a whole and to individual right holders in particular needs to be established (Kemper, 2001; Schlager, 2007). Yet, as is explored below the implementation of normative frameworks is fraught with challenges especially given their close interrelatedness.

3. Normative structures in Guanajuato's groundwater use sector

3.1. Bureaucratic relations

In Mexico, state involvement in water resources development received a legal push with the promulgation of the Water Law (*Ley de Aguas*) of 1910 that states that all waters are public property for common use. Article 27 of the Constitution of 1917 made it explicit that 'land and water property belong to the Nation', but the Nation has the right to transmit these property rights to individuals. At the same time it recognized the right of the owner of a piece of land to prospect for and use the water underlying his land as established in the civil code of 1884 (Sánchez-Rodriguez, 1998). This right was reaffirmed in the Law of Water of National Property of 1929 and that of 1934. In 1945 groundwater was made national property through amendments to paragraph 5 of Article 27 of the Mexican Constitution, which states that:

Groundwater may be freely brought to the surface through artificial works and appropriated by the owner of the land, but, when it is in the public interest or if it affects the supply of other users the Federal Government may regulate its extraction and utilization, and even establish prohibited areas, in accordance with that which applies for other waters of national property (Delgado Moya, 1999:49).

This amendment was further adapted in 1948 and 1956 to increase the legal faculties of the federal government in relation to groundwater. The Federal Water Law of 1972 specified that the national government has to regulate groundwater use through the issuing of groundwater use permits and by establishing rules and regulations for areas placed under *veda*. In an area placed under *veda* it is prohibited to sink new (tube) wells without the prior consent of the national water authority. Nonetheless Peña and Arreguín (1999) argue that the formulation of these regulations were rarely drawn up amongst others because until at least the 1970's little was known about how to determine aquifer boundaries and safe yields. Ten *veda* decrees were issued in the Bajío and northern areas of the state of Guanajuato between 1948 and 1964; and in 1983 the entire state was placed under a strict *veda*; yet the number of tubewells and extracted volumes kept increasing relentlessly (Wester, 2008).

The 1992 National Water Law introduced private concession titles (*título de concesión*) granted through the National Water Authority (CONAGUA) and registered in the Public Registry of Water Rights (REPDA). Groundwater remains the property of the state that is responsible for registry in REPDA. The granting of new concession titles replaced the precarious permits that had been granted before (Reis, 2014). The concession title allows the owner/user to extract a certain volume of water per year for a given number of years (between minimally five and maximally fifty; but usually ten years) after which the concession title expires and needs to be renewed. Based on extracted volumes users pay a volumetric water fee (charge according to the type of use; agricultural water use is exempt from this fee). The procedures, rights and obligations attached to the concession title are established in detail in Articles 20 to 29 of the National Water Law and its amendments (LAN, 1992). Officially, the user is obliged to have a working water meter on his (tube)well and submit a form with extracted water volumes every three months to CONAGUA. Failure to do so is officially penalized with high fines.

Yet despite subsidy programs that paid for the installation of flow meters on agricultural tubewells there is a very large number of users with a concession title that still don't have a meter installed. Of the installed meters a large number do not function properly making control over extracted volumes well-nigh impossible. As put by a former director of CONAGUA: 'there exist no flow meters that are Mexican proof'.

Though on paper the bureaucratic normative framework is well established, up to date insufficient effort has been put into restricting unauthorized groundwater abstractions. The preferred option of the state has been to 'legalize' irregular pumps. This process has been enabled and legally supported by regular amnesties decreed by Mexican presidents which allow 'illegal' pumps to legally register. Moreover several interviewees confirm that there are too few inspectors to implement regulations (4 inspectors in 2003 and 10 inspectors in 2016 for the whole state) and bribing inspectors is a widespread practice. Cases have also been reported of field inspectors that were abducted by angry farmers while on duty. Consequently the number of (tube)wells has increased from some 2000 in 1960 to more than 16,500 in 1997 (Guerrero-Reynoso, 2000) and over 17,300 officially registered wells in December 2015 (REPDA, 2015). At present the actual number of wells according to well informed estimates exceeds 20,000 and counting. As summarized by a water user in spring 2016:

I have not seen that the authorities limit the water use of anybody. If you have a pumping permit, a concession title, you have the right to pump a specific amount of cubic meters per year. If someone exceeds the granted concession, I up until now, have not seen that the National Water Authority or any other authority limits it. I do know that the National Water Authority is after illegal wells. I also know that the efforts to control are insufficient and that there are illegal wells everywhere.

Though legally (on paper) the bureaucratic normative framework to regulate groundwater use in Mexico is well established, its implementation (in the field) is difficult, incomplete and fraught with legal and administrative inconsistencies. Uncontrolled extraction of groundwater and the drilling of new (tube)wells sustains aquifer overexploitation in Guanajuato and Mexico at large. This is reflected in the 106 officially overexploited aquifers in Mexico (of the 653) (CONAGUA, 2014).

This does not mean that the legal system does not play a regulatory role. As pointed out by Reis (2014) based on the case of the Valley of Toluca and confirmed by fieldwork in Guanajuato, the control of the National Water Authority on the industrial sector and to a lesser degree the domestic water supply sector is much tighter than on the agricultural sector. For the agricultural sector the legal system (and its incomplete implementation) has constantly adapted to incorporate an ever increasing number of users without applying real restrictions to extracted volumes. This situation has also greatly undermined the effectiveness of other normative frameworks to regulate groundwater use

(especially by the agricultural sector) in the state, as is further explored below.

3.2. Market relations

3.2.1. Groundwater markets

Once the regularization of wells in REPDA closed (in Guanajuato CONAGUA did this in 2006) new concessions in overexploited aquifers can only be acquired through concession transmissions. The system of concession transmissions was introduced with the 1992 National Water Law (LAN, 1992). It enables the legal acquisition of concession titles by new users who can get a specific annual volume of groundwater from existing users. The system of concession title transmissions is regulated by Articles 33 to 37 of the National Water Law. It establishes amongst others that concession titles can be permanently transferred to other users either in their totality (the entire conceded water volume) or partially (only a part of the conceded water volume) (Art. 30). It also establishes that water transfers can only take place within the confines of the boundaries of hydrologic systems (aquifers and river basins as defined and delimited by CONAGUA). The transferred water volumes can change in its type of use (agricultural, industrial, potable) and can be extracted from a well at another location within the aquifer pending prior consent of CONAGUA; and as long as it meets the technical requirements established by this same authority. As water remains the property of the nation and may as such not be sold, water rights transmissions are in legal terms free of charge and only involve an administrative fee to CONAGUA. In the context of a growing economy, demand for groundwater concession titles is high, leading to a vibrant market for water rights[1] in many *veda* zones in Mexico (Reis, 2014), including Guanajuato.

Obtaining new legal water concession titles has become extremely important for the industrial and housing sectors as these need to show to the municipal authorities that they own sufficient water rights (volume in m^3/year) to guarantee that their production processes or potable water demands are met. Also within the agricultural sector it has become increasingly important to have the concession titles regularized in order to be able to access state subsidies and to comply with the increasing regulatory demands of certification companies and agro-exporters.

In Guanajuato, with many wells drying up because of aquifer drawdown there has been an increased number of agricultural users eager to sell part of −or their whole water concession. Usually the first ones to sell have been small farmers whose wells dried out and have no possibilities to replace or deepen these. This economic water scarcity of smallholders (Namara et al., 2010)[2] is leading to processes of increased social differentiation and capitalist accumulation of groundwater. In a context of no control over extracted volumes users that sell part of their concession often-times sustain their extractions or use the economic resources to deepen/replace their tubewell, while within the aquifer a new 'legal' tubewell can be installed. This 'market' mechanism has as such enabled to 'legally' sustain the growing demand for groundwater by those that can economically afford it at the cost of increased social differentiation and sustained groundwater overexploitation.

3.2.2. Energy pricing

In a context where because of dwindling groundwater tables energy to pump extracted volumes has increased, another market mechanism at play in the regulation of groundwater use is energy pricing. Most tubewells (usually between 75 and 150 horse power (hp)) are electricity powered. In Mexico a special subsidized tariff is applied for agricultural electricity, termed tariff 9. To be able to access this tariff users need amongst others a valid concession title and prove that their water use is for agriculture. Though the exact amounts have fluctuated over the years costs are substantially lower than for domestic and industrial use (Scott and Shah, 2004).

A raise in electricity tariffs in the early 1990s went paired with a substantial reduction of agricultural electricity consumption from 72 GWh in 1989 to 57 GWh in 1992 (Palacios, 1999). Nonetheless further raises to the electricity tariff 9 and its variations 9CU, 9N and 9 M have not been substantial as initiatives to do so have regularly been blocked by Congress (Wester, 2008). Tariff 9-CU, which was introduced in 2003 and has a lower tariff than 9 and 9 M, is linked to groundwater draft and establishes an Annual Energy Limit (AEL) in kWh/year per well. Energy use that surpasses the AEL is to be billed at the regular agricultural 9 and 9 M tariffs which are substantially higher (Scott and Shah, 2004).

However, despite a consistent (paper) normative framework that could potentially serve to regulate groundwater extractions, application of the regulations by the Federal Electricity Commission (CFE) is weak. In fact for CFE it is a great challenge to bill the payments for the energy consumed in the agricultural sector. Lack of trust in the CFE, power struggles and the inconsistency of governmental policies underlie this challenge.

Alongside the reduction of subsidies for electricity, in 2000 a large group of farmers in Guanajuato united in the *Comité Pro-Mejoramiento del Agro Nacional Guanajuatense* (CPANG) which is part of a broader national movement. Agricultural users adhered to this movement do not pay their agricultural energy consumption. This group of users have gained important political clout both in Guanajuato as well as in other parts of the country. Their main argument is that energy costs should be further reduced for the agricultural sector. The debts of some of the partaking users to CFE are on paper higher than the net value of their production system. Nonetheless CFE has little power to intervene. Though CFE inspectors regularly disconnect the tubewells from the power grid, these are easily re-connected and CFE has little power against the organized users as sketched by a user:

> 'To a rancher they [CFE] went to take away three electricity posts with all the cables because he had not paid. They [the user] called […] and we all went. Here in San Miguel at the entrance [of the CFE office] we had everything blocked… and the manager was trembling. […he was threatened…] and right away he ordered the posts to be reinstalled. (Pers. comm. December 2014)

The lack of trust in CFE has further ignited the reluctance of farmers to pay:

> "I have a 150 hp engine [on the well]. On average I consume 18–20 thousand pesos a month. […] I have a neighbour that has an engine of 250 hp at the same depth as mine [and irrigates more land]… he pays 5 thousand pesos monthly for energy. So how is this? There is an arrangement.". (pers. comm. October 2015)

On top of these local problems with the implementation of the existing normative framework for energy pricing, the federal government has extended amnesties that condoned up to 90% of the debts users had with CFE. One such amnesty was in 2003–2004 and ten years later a new amnesty regulation was being negotiated. Moreover CPANG lawyers are exploring a legal loophole which establishes that after a defined number of years a debt can no longer be claimed. The overall lack of consistency in the implementation of the (paper) normative framework established around energy pricing at local, regional and national level has led to an increasing number of farmers adhering to CPANG; undermining the ability of energy pricing to play a significant role in the regulation of groundwater use in the agricultural sector.

[1] Although legally the transactions are not market transactions but a water rights transmission, in practice market mechanisms are at play with higher costs per m^3 in aquifers were demand is high (ranging from 8 to 20+ pesos/m^3).

[2] For the same process in the Comarca Lagunera in northern Mexico see Ahlers (2010) for examples in North Africa see Ameur et al. (2015).

3.3. Associative relations

Users based groundwater self-regulation, which rests on the notion of establishing an associative normative framework to regulate groundwater extractions at aquifer level is increasingly advocated as a complement to state regulation (Lopez-Gunn, 2003; Steenbergen, 2006; Wester et al., 2009). To stimulate self-regulation, since 1996 the State Water Commission of Guanajuato (CEAG) developed an integrated groundwater management policy consisting of groundwater-modelling studies and a groundwater monitoring network to generate the necessary knowledge about aquifer behavior. In parallel a communication/capacity building program was implemented and users based Aquifer Management Councils (COTAS) were created (Sandoval, 2004). By 2000, in all 14 aquifers of the state a COTAS was in place (see Wester et al., 2011). COTAS are user based civil society associations financially supported by the state government of Guanajuato. CEAG finances an office, operational costs and the salary of a manager, a technician and a secretary. COTAS are to: propose aquifer rules and regulations; propose local working plans for aquifer management and participate in the CEAG State Water Resources Plan (Guerrero-Reynoso, 2000). COTAS were also eager to participate in the granting of water concessions; the monitoring of extracted groundwater volumes and the implementation of aquifer rules and regulations. However these ambitions were blocked by CONAGUA and the existing legal framework for groundwater management. In 2004 COTAS were recognized by the law, but only as auxiliary to the CONAGUA (LAN 1992, Art. 13 BIS 1). Based on these provisions, CONAGUA delegated programs to the COTAS and recognized these as intermediaries between users and CONAGUA in the administrative procedures related to groundwater-use permits.

Under CEAG guidance, COTAS initiated a working process with the users in pilot areas to identify measures to reduce groundwater extractions on a voluntary basis and reach agreements on its implementation (Montoya et al., 2004). This program aimed to channel the different government support programs for irrigation modernization through COTAS to these pilot zones. Once the measures had been agreed on and funded, users were requested to form committees to monitor groundwater levels and evaluate the results of the interventions. Users were asked to register pumping hours and electricity use. On the long-run these pilot zones were to gradually expand. Only then would the work start on drawing up the rules and regulations of the aquifers. These initiatives though promising stranded in most COTAS because of a lack of user engagement.

With the sustained support of CEAG, COTAS continue working on awareness raising, small scale water saving projects and many have become service windows that support users with the administrative procedures in dealing with CONAGUA, CFE and in getting subsidies from the Ministry of Agriculture for irrigation modernization programs. In some COTAS staff serve as brokers in groundwater concession title transmissions. Some COTAS have managed to get project funding from other governmental instances and collaborate with CONAGUA on monitoring tubewells and extracted volumes. However none have established self-regulating mechanisms for the stabilization of aquifers.

López-Gunn and Martinez Cortina (2006) show, based on the case of groundwater user associations in Spain that self-regulation by groundwater users associations requires a strong and efficient water administration, a common understanding among users, autonomy, trust, and local leadership. In Guanajuato, through the sustained support of the state government of Guanajuato these associations are operational and have come to play a lot of different roles in the groundwater governance domain. However the capacity of COTAS to engage users in self-regulation remains pre-empted on the lack of autonomy, legal faculties and support by CONAGUA in the groundwater regulation domain (see also Wester et al., 2009, 2011).

3.4. Communal relations

In Guanajuato communal relations exist around the use of groundwater. This mostly concerns *ejidos* where several users share access to groundwater through communal wells. Though the ties that bind these users together are strong they mostly revolve around ensuring groundwater access to the individual through the collective (Massink, 2016). As part of their efforts to optimize resource use and make due with dropping well yields, most *ejidos* have, with state subsidies, switched from open earthen conduction canals to piped water distribution systems. Efforts to reduce groundwater use at this scale are mainly coupled to controlling and keeping the increasing energy costs at bay while ensuring sufficient access to groundwater to its members. However with no control over extracted volumes by CONAGUA and with the increased number of *ejido* groups joining CPANG this economic incentive to reduce groundwater use has been shattered.

Moreover, given the large spatial extent of the aquifers in Guanajuato the individual community efforts to reduce groundwater use have little impact on total extractions in a context in which at broader scales there is no consistency in the implementation of other bureaucratic, market based and/or associative normative frameworks across the whole aquifer.

4. Discussion and conclusions

Taming groundwater exploitation in intensively used aquifers to ensure long term sustainability is urgent in many areas of the world (Hoogesteger and Wester, 2015). Yet it is only when problems of serious aquifer drawdown become apparent and start to imperil socio-economic development that regulatory responses are set in place (Mukherji and Shah, 2005; Shah et al., 2003). Our analysis of the regulatory measures that have been implemented in the state of Guanajuato to control groundwater overdraft shows the deep interrelatedness of the bureaucratic, market, associative and communal structures for groundwater regulation and the challenges this poses in terms of groundwater governance.

Although bureaucratic regulatory measures to control groundwater overdraft have been in place since the 1950s their effect on the ground is limited. The lack of capacity of the state agencies responsible for the implementation of the advanced bureaucratic (legal) framework (as reflected in the internationally acclaimed LAN (1992) and REPDA) have undermined the effectiveness of state regulation up to date. In 1992, LAN introduced tradable groundwater concessions through REPDA. This led to the development of groundwater permit markets, especially in overexploited aquifers. In a context of an incomplete implementation of the bureaucratic regulatory system these groundwater markets have become a new mechanism to 'regularize' illegal wells and enable the legal perforation of new ones. Its' effects on groundwater extractions have been adverse while leading to processes of groundwater accumulation and capitalist expansion (see also Ahlers, 2010; Hoogesteger and Wester, 2015).

Energy pricing which was expected to economically motivate farmers to reduce water use to limit energy consumption has by and large failed. The difficulty to homologate electricity connections with REPDA made implementation of preferential tariffs incomplete. The increased political power of the organized non-paying users at local and national level coupled to the lack of trust in the transparent functioning of CFE, has made it almost impossible for CFE to take tubewells of the electricity grid. Furthermore there are no mechanisms in place to force farmers to pay their debts. At national level the political amnesties to non-payers that have recurrently been issued by the government have further demoralized this regulatory mechanism as well as the salience of bureaucratic regulation.

The creation of COTAS as self-regulatory mechanisms to complement state regulation has up to date been disappointing. Despite the long-term commitment of the Guanajuato state government to COTAS

and their legal recognition in LAN since 2004 their self-regulating capacity remains scant. The lack of legal faculties of COTAS in the groundwater governance domain (all legal faculties to regulate groundwater are centralized at CONAGUA) has undermined their effectiveness and salience. This results in low levels of adherence, trust and reciprocity by users. As associative organizations they have created new networks amongst users and worked towards creating a common understanding of the groundwater problems; but these have not necessarily led to collective action aimed at curbing groundwater extractions. Rather they have become support windows for users in dealing with CONAGUA and in accessing subsidies (see also Wester et al., 2011).

Finally, in this context, in which at broader scales (aquifers and basins) bureaucratic, market and associative relations have by-and-large failed to regulate groundwater overdraft, there are few economic and regulatory incentives for local groundwater use collectives (of *ejidatarios*) that share the use of a tubewell to reduce their groundwater use.

The interrelated failure of the different existing regulatory frameworks in place also pre-empts the effectiveness of other initiatives such as irrigation modernization. The state government through its Secretary of Agriculture has subsidized the modernization of groundwater irrigation systems since 1996 to a total of 30,000 ha of drip irrigation, 18,000 ha sprinkler and 146,000 ha piped conduction systems (SDAyR, 2014) with a potential 'saved' volume of 440 MCM/year (*idem*). Yet these figures are not reflected in the aquifer balances nor in a reduction in aquifer drawdown as users have used the new irrigation technologies to intensify production rather than to reduce extracted volumes (see Hoogesteger, 2017).

Our analysis highlights the challenges of devising policies that lead to groundwater socio-environmental sustainability (see also Giordano, 2009). Though in Mexico and especially in the state of Guanajuato important advances have been made in terms of establishing regulatory efforts, these have up to the moment been insufficient. It is clear that for advancing toward effective groundwater regulation cooperation between higher levels of authority, user associations and individual water users is necessary. The case of Guanajuato shows that for this autonomy and different forms of trust and reciprocity between the regulator and the regulated are needed. Integrated efforts towards the consistent implementation of state regulations and a delegation of responsibilities to user based associations is important to facilitate self-regulation (see Lopez-Gunn and Martinez Cortina, 2006). Finally special attention has to be given to the socio-economically marginalized populations which are often the first to suffer the consequences of sustained groundwater overdraft and the resulting economic water scarcity (Hoogesteger and Wester, 2015).

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