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GEOSCIENCES

Groundwater governance: The illegality of exploitation and ways to minimize the problem

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Abstract: In Brazil, there are about 2.5 million tubular wells in which 88% of them are illegal, extracting more than 17,580 Mm^3/yr. This irregular use may cause sustainability issues that may be economic, social, or environmental (overexploitation, well losses and associated increases of water conflicts; aquifer contamination; and land subsidence). This paper aims to address the illegal wells in Brazil and discuss measures to minimize it. Conclusions indicate that users do not understand the aquifer dynamic and, therefore, do not have a proper understanding of problems such as loss of water quality and quantity caused by the excess of groundwater exploitation. This creates a false idea that there are no water conflicts among users, which causes a lack of engagement by society. Without groundwater users and stakeholder pressure, the government does not aim to control or close illegal wells, and the "vicious cycle" persists. The one way to break this "vicious cycle" would be programs of social communication and users' participation, coupled with improvements to the control apparatus and inspection from State institutions, making sure that there is correct management and not only legislations that are not applied.

Key words: illegal well, participation, stakeholder engagement, sustainability, water governance, water resources.

INTRODUCTION

Groundwater is a globally vital resource that has always contributed to a safe water supply for domestic, industrial, and agricultural activities. However, its importance for socio-economic development for the Brazilian population contrasts with limitations in the knowledge of its potential uses and about its exploitation. Additionally, the increasing number of illegal wells, that is, those who do not have a license or registration for pumping, may compromise effective groundwater management. Although the population supplied by groundwater represents a smaller portion compared to surface water, the numbers of groundwater users call attention. According to Hirata et al. (2019), it is estimated that the total water pumped (both public and private water supply) coming from more than 2.5 million tubular wells, surplus 17,580 Mm^3/yr (or 557 m^3/s), which represents sufficient volume to supply the current Brazilian population or 10 Metropolitan Regions of São Paulo size, which means 217 million people per year.

In populational terms, of the 172 million Brazilians who have access to the public water supply, 30.4 million (17.7%) are groundwater users; the remaining 141.6 million (82.3%) are surface water users. This proportion exists because the largest cities are primarily supplied by surface water (just 2% of municipalities with more than 500 thousand inhabitants use groundwater to fully supply their demands) (Hirata et al. 2019). On the other hand, according to ANA (2012), 52% of the 5,570 Brazilian municipalities are totally (36%) or partially (16%) supplied by groundwater. This regime is particularly crucial for small municipalities and is the only option for 48% of cities with less than 10,000 inhabitants and 30% of those between 10,000 and 50,000 inhabitants.

It is estimated that most of the existing wells in Brazil (over 88%) are illegal (Hirata et al. 2019). This situation has led to a “statistical iceberg”, where groundwater has a significant share in the city’s water supply but does not appear in the official statistics. In other words, it is statistically hidden. In several metropolises, such as São Paulo, Recife, Brasília, and Fortaleza, for instance, private complementary water supply maintains equilibrium between water supply and demand (Hirata et al. 2015). Thus, the security of water supply in these cities is dependent indirectly on illegal wells.

The illegal exploitation indicates potential problems of groundwater overexploitation (primarily for use in the urban public water supply) and conflicts among users, causing resource loss, increased operational costs, and contamination of aquifers by degradation induced by unplanned pumping (Hirata & Suhogusoff 2019, Galvão et al. 2020). One of the reasons for an illegal well operation is that users and decision-makers are unaware of problems and consequences in the absence of legal compliance. Besides, users are not informed of the obligation to observe the correct procedure to drill a well, and society’s perception is that groundwater laws do not need to be enforced and improved (Berger et al. 2017).

Additionally, the groundwater extraction license process in Brazil is time-consuming, costly, and with dubious returns, which further contributes to the illegal operation of wells. Moreover, water resource legislation is based on the principles of “command and control”; however, the existing government structure is not equipped to detect and combat irregularities (Porto & Lobato 2004a, b). Unfortunately, there is no movement to change this scenario in the short-term because there is not, on the part of the government, the “will” to enforce these regulations. Paradoxically, conflict-involving groundwater that becomes public is rare, giving the false impression of no management or sustainability-related problems, and, consequently, there is no need for more stringent measures to control the water utilization by the state.

Control actions for surface water management, when applied to groundwater, have been ineffective worldwide, and this scenario is particularly characteristic in Brazil (Foster et al. 2004, Hirata et al. 2015). Thus, actions, such as water use licensing and concession processes, need to rely on social communication and participation mechanisms involving the entire stakeholder group and the institutions responsible for the management of water resources.

While indispensable to the management of all water resources, knowledge is particularly imperative when dealing with groundwater. In contrast to surface waters, users, as well as many authorities, poorly understand groundwater dynamics. Therefore, the challenge is to manage groundwater utilized by users who share the same resources but have different vested interests. Thus, this paper will discuss how the lack of public and political attention, and therefore, the consequences of not having a proper understanding of problems about aquifer exploitation could be related to the illegality of exploitation of Brazilian groundwater.

Groundwater governance

Groundwater governance is distinguished in various aspects from that of surface water (Hirata & Conicelli 2012). Due to its reduced initial and operational investments, the participation of private users, especially in urban areas, is much higher than that observed for surface water. Control through groundwater exploitation licenses has been used as a model in Europe for regulating resource usage. Thus, successful governance is associated with the capacity of government agencies and commitment on the part of civil society and the private sector (Mechlem 2016). In the European countries, respect for the inspection agency is a tradition, and the State's presence is not merely formal (United Nations 2006, European Commission 2008). In developing countries, government agencies are just getting structured, and the imposition of regulations by traditional control mechanisms has not been effective (Tuinhof et al. 2006). Thus, many illegal wells in countries that do have legislation reflect this phenomenon.

Recent experiments in groundwater governance (Mechlem 2016, van Steenbergen & Shah 2003, Sandoval 2004, Wester et al. 2011) have indicated participatory management can be a success (GWP 2000, Smith 2003, Garduño et al. 2006a, b, Foster et al. 2011). However, these have generally been assessed in agricultural areas where the landowners know one another and can control what happens in neighboring regions (Rathore & Mathur 1999, Govardhan Das 2000, van Steenbergen & Shah 2003); or in areas of substantial water scarcity such as deserts. However, this is not the case in cities where anonymity prevails.

According to Kemper (2007), groundwater users who are not familiar with the concepts of this resource are less concerned with the depletion of the aquifer despite potential issues related to overexploitation soon. Therefore, easily understandable and reliable information is required to raise awareness among these users. Furthermore, it is essential to note that technical studies are often limited in demonstrating losses at the individual level, and therefore, the users are unable to play their role in the problem.

Users are only recognized as real actors when they have the right to information about the resources they depend on (Kemper 2007). For many water management agencies, this will imply a significant change, especially in their culture, where the centralization of information about water availability allows decisions to be taken without the stakeholders' participation (Megdal et al. 2017). Information dissemination among all stakeholders is essential during decision-making. This aids long-term planning considerations about decisions of economic measures, resource investment, and the nature of services that must be demanded from the water agencies and other government authorities.

Groundwater: A common-pool resource

The success of the management of common-pool resource, already explained conceptually by Ostrom (2002), is intrinsically related to the effective governance of these resources. Fenny (2001) states that common-pool resources share two fundamental characteristics. The first refers to exclusivity in access control, which elicits costs by not allowing others to have access to natural resources. The other feature is subtraction, where the use of a resource by a person results in diminishing the total resource available to other potential users (Olson 1965, Hardin 1968).

Historically, water resource management has been centralized in hierarchical systems, where problems primarily concerned water availability and were resolved by increasing supply by building infrastructure. Presently, water management involves a broader range of issues, such as water's role in the environment; diffuse pollution in agricultural areas; and climate change and its impact on the public water supply (Megdal et al. 2017, Ross & Martinez-Santos 2009). Given the complexity of water management in the face of uncertainty, Gunderson & Holling (2001) proposed that administrators should apply adaptive management. The process of adaptive management includes program planning based on social learning through experiences, analysis, and the comparison of selected policies and practices (Megdal et al. 2017, Varady et al. 2016, Pahl-Wostl 2007).

Young (2002) suggested that an aquifer directly connected to a surface water resource or crossing many localities with different laws and actors will require a more sophisticated and legitimate management system. Also, adaptive management requires information sharing and accountability between governments, water providers, users, and other stakeholders, such as environmental groups (Varady et al. 2016, Falkenmark et al. 2004). Under such circumstances, it is unlikely that collective management by the users will be successful without the collaboration of governmental authorities and vice-versa (Megdal et al. 2017, Ross & Martinez-Santos 2009).

Ostrom (2005) recognized that local appropriators face particular difficulties in regulating just one part of a resource (surface water, groundwater) at the regional scale without having access to the legal apparatus for that scale. Therefore, its principles require complex administrative mechanisms where authorities at higher level address problems that exceed the capacity of units at the lower levels by providing reliable information and mechanisms for conflict resolution. Ostrom makes a theoretical argument for polycentric management systems, where the various government authorities, at different scales, can enforce and obtain compliance with the rules of a specific geographical area within the domain of one local authority. In a polycentric system, some of the units will be governments, with general interests, while others, like water basin authorities or associations of water users, will be highly specific (Ostrom 2005). In practice, while polycentric governance demonstrates its willingness to deal with resource management problems across scales, high-level governmental authorities are often reluctant to hand over decision-making power or build capacity at lower levels to confront the challenges of complex resource management (Megdal et al. 2017, Varady et al. 2016, Marshall 2008, Ross & Dovers 2008, Ross & Martinez-Santos 2009).

User heterogeneity increases the complexity of implementing aquifer self-management. This complexity brings increased costs of reaching an agreement between the interested parties. Further analysis in this regard revealed a complicated relationship between heterogeneity and users' capacity to organize themselves (Ross & Martinez-Santos 2009). Balland & Platteau (1996) and Ostrom (2002) distinguished between cultural differences and user perceptions, interests, and aptitudes. Balland & Platteau (1996) argued that differences in user aptitudes do not impede uniformity of interests in collective agreements; however, both Balland & Platteau (1996) and Ostrom (2002) noted that the economic power of users strongly influenced the consolidation of collective action, i.e., the more economic power the user has, the higher the possibility of collective action. The impact of this action on the sustainability of the resources depends on the position and the strategic interests of users with many resources. Nevertheless, users with a common perception of their situation and interests, such as the cost of not dealing with the lowering of water levels in an aquifer, may be prepared to collaborate even if their cultural beliefs and aptitudes differ (Ross & Martinez-Santos 2009).

Furthermore, Ostrom observed that users with strong ties to their land were more apt to seek long-term sustainability while landowners who managed their properties as an investment were more interested in short-term profitability. The divergence of values and interests among owners is, therefore, a factor that may not be neglected. Such neglect may explain some of the failures in negotiations among water users in implementing collective agreements (Ross & Martinez-Santos 2009).

Challenges in groundwater governance in Brazil

The groundwater should always be considered in territorial management and infrastructure investments, as well as in urban planning policies. For an evaluation of the role of groundwater and the opportunities it provides, it is necessary to distinguish between two different scenarios (Foster et al. 2010, Hirata et al. 2015):

- Cities in which public water supply is mainly derived from surface sources, with groundwater intensely exploited by private wells (most illegal), without which there could even be water shortages. In such cases, the drilling of private wells generally occurs due to the inadequate supply of water or as a strategy to escape from the high price of publicly supplied water.
- Cities where a substantial part of the municipal water supply is derived from groundwater sources; however, often, a significant number of private wells exist too, depending on the hydrogeological conditions, the cost of wells, confidence in the public water system, the price of water, among other factors.

The lack of integration of groundwater into urban development policy in Brazil, mainly in certain Brazilian cities, has caused sustainability problems (Foster et al. 2011), including the following:

- Overexploitation: intensive extraction of groundwater, which generates one or more of the following impacts: a) localized reduction of aquifer levels which may lead to exhaustion (for instance, city of Ribeirão Preto) (GEOWATER 2017); b) reduction of base flows of surface water bodies influencing its hydraulic and ecological system (Urucuia Aquifer - Bahia) (Cunha 2017, Hirata & Conicelli 2012); c) increasing costs of water exploitation due to reduction of the dynamic water levels in wells and/or readjustment of abstraction work (city of São José do Rio Preto) (Simonato 2013); d) induction due to pumping of contaminants and saline waters (city of Recife) (Cary et al. 2013, Petelet-Giraud et al. 2017); e) land subsidence issues (city of Sete Lagoas) (Galvão et al. 2015); and f) problems of social equity among users caused by unfair competition between owners of small and large wells (city of São José do Rio Preto) (Conicelli & Hirata 2011, DAEE 2012a).
- Pollution of aquifers: this results from poorly operated anthropic activities, especially those related to improper final disposal of liquid effluents and solid residues generated during industrial processes, municipal solid waste landfills and change in land use (Santos Filho et al. 2017, Aranda et al. 2019). This scenario is common in cities such as São Paulo (Bertolo et al. 2015, Conicelli 2014, DAEE 2012b), Recife (Cary et al. 2013, Petelet-Giraud et al. 2017), and Urânia (Hirata et

al. 2015). It is estimated that the country's subsoil receives 4,329 Mm^3/yr of sewage, which corresponds to the sum of the sewage from the lack of networks (3,747 Mm^3/yr) and that resulting from lack of maintenance (582 Mm^3/yr). This volume is equivalent to the launch of 1.8 million Olympic swimming pools per year or almost 5,000 swimming pools/day (Hirata et al. 2019).

- Inappropriate water resources management: the characteristics of surface water and groundwater are not considered in an integrated manner, and the two resources are not optimally balanced to reduce expenses and increase hydric security (integrated water resource management) (Hirata & Conicelli 2012). This situation occurs in the north semi-arid region of the state of Minas Gerais, within what is known as the "drought polygon", in the Verde Grande water basin, where conflicts between groundwater users are frequent. Due to the significant increase in agricultural activity between the 1970s and early 1980s, the conflicts increased due to the higher demand and consequent reduction in water availability (ANA 2013).
- Poor construction or inadequate design of wells: results in contamination of abstracted waters or deeper aquifers (Bertolo et al. 2015, Conicelli 2014, DAEE 2012b).

All these issues have been anticipated in the water legislation (Water Law N° 9.433) for almost all the Brazilian states. However, the legislation has not been (properly) applied, and as a result, there is practically no groundwater management. Additionally, the granting process, which is the basis for control of demand and proper adaptation of aquifer production, is virtually non-existent. The exploitation license process is a mere formality in most of the Brazilian states, and administrative agencies do not evaluate requests for licenses considering the real (and current) conditions of the aquifer.

In Brazil, the administrative agencies that control groundwater use rarely penalized those who do not comply with the resolutions, i.e., those without licenses to drill or operate wells. The identification of groundwater usage often occurs through complaints. Therefore, the number of wells with license represents a small number vis-à-vis the existing wells. When licenses are approved, they are done without considering the situation of the aquifer and are only a legal requirement where little or no attention is paid to the sustainable management of the underground basin, except in a few cases (such as in the region of Ribeirão Preto, and some areas of the Piracicaba water basin and the region of Jurubatuba, São Paulo) (Hirata et al. 2015, Bertolo et al. 2015, Conicelli 2014, DAEE 2012b). In some other cities, such as Recife, Ribeirão Preto and region of Jurubatuba (São Paulo) (Lappicirela et al. 2009, Carvalho et al. 2009, Cary et al. 2013, Petelet-Giraud et al. 2017, GEOWATER 2017), and Sete Lagoas (Minas Gerais) (IGAM 2004) there are restrictions for new drilling, but these have not resulted in reductions in a large number of illegal wells. Also, in the north semi-arid region of the state of Minas Gerais, to encourage legal wells, rural areas with wells pumping up to 14 m^3/d, a license is not required (SEMAD/IGAM 2015). Even so, the number of illegal wells in the drought polygon remains high.

In fact, the societal response when the numbers of restrictions are increased has been to reduce consultation with the government and seek illegality solutions.

The traditional behavior for solving this problem, as anticipated in the latest water resource plans, would be a joint initiative on the part of different institutions that are, in some way, involved in groundwater resource governance. In the state of São Paulo, for instance, the Department of Waters and Electrical Power (DAEE), the Environmental Company of the State of São Paulo (CETESB), and the Health Secretariat would defend the interests of the state government. The likely actions would be as follows: a) strengthening supervision, seeking compliance with the resolution; b) registration of wells; and c) studies about aquifers with regards to their overexploitation in critical areas, greater exploitation or density of abstraction.

A classic case of a joint initiative on the part of different institutions that are involved in groundwater resource management in Brazil is the city of São José do Rio Preto (SJRP), where 70% of the total public supply is made through the exploitation of groundwater (DAEE 2012a, Conicelli & Hirata 2011). DAEE (2012a) identified in the area more than 340 wells with a license. On the other hand, were identified by the Municipal Water and Sewage Service (SEMAE), by Brazilian Geological Survey (CPRM), and the Institute for Technological Research (IPT) 1,700 wells without a license (clandestine). Therefore, the city has about 2,000 tubular wells. (Figure 1).

Although the database does not include all existing wells in the urban area of SJRP, it is estimated that it represents over 80% of existing wells (Simonato 2013). The scenario of high disobedience to regulations made it difficult for the management of groundwater resources. The dimension of this problem is illustrated in Figure 1, where the total number of wells and the density of wells can be observed. In some locations, the density is 47 wells over an area of 500 m x 500 m. This density has negative consequences, such as increased groundwater exploration costs, contamination of deeper aquifer levels, rearrangement of grains in the aquifer matrix, which may lead to decreased storage capacity and land collapse, among other issues (DAEE 2012a, Conicelli & Hirata 2011). It should be noted that the elaboration of this database was a pioneer work in Brazil and represents an advance in groundwater management; however, it was only the first step (Simonato 2013).

Essentially, groundwater is a local resource, and its management must include the participation of end water users (Varady et al. 2016, Burchi & Nanni 2003). The foundation of mechanisms that provide a basis for water resource management in Brazil is “command and control,” where a vigilant State maintains the regularity of extraction (its sustainability) through its executive forces (police power) (Porto & Lobato 2004a, b, Mukherji & Shah 2005). However, these mechanisms of control are more effective and common for surface water than groundwater. These mechanisms require, on the one hand, that the State can enforce the resolutions, and on the other that users accept and respect these mechanisms. However, users take advantage of the difficulties in locating illegal wells, especially in urban areas.

Besides, users contest the groundwater water right system. They argue that ownership of the territory where the resource is located permits the exploitation of the aquifer with minimum control (Mechlem 2016, Ross & Martinez-Santos 2009). In this regard, the intervention by the public authorities to mitigate problems related to overexploitation and quality problems may provoke social conflict (Garrido et al. 2006). This phenomenon was observed by Llamas & Custodio (2003) in various arid and semi-arid regions of the world. Monitoring, control of exploitation, and groundwater use also present a unique characteristic where the diffuse nature of the users spread over a determined territory makes it difficult for the government authorities

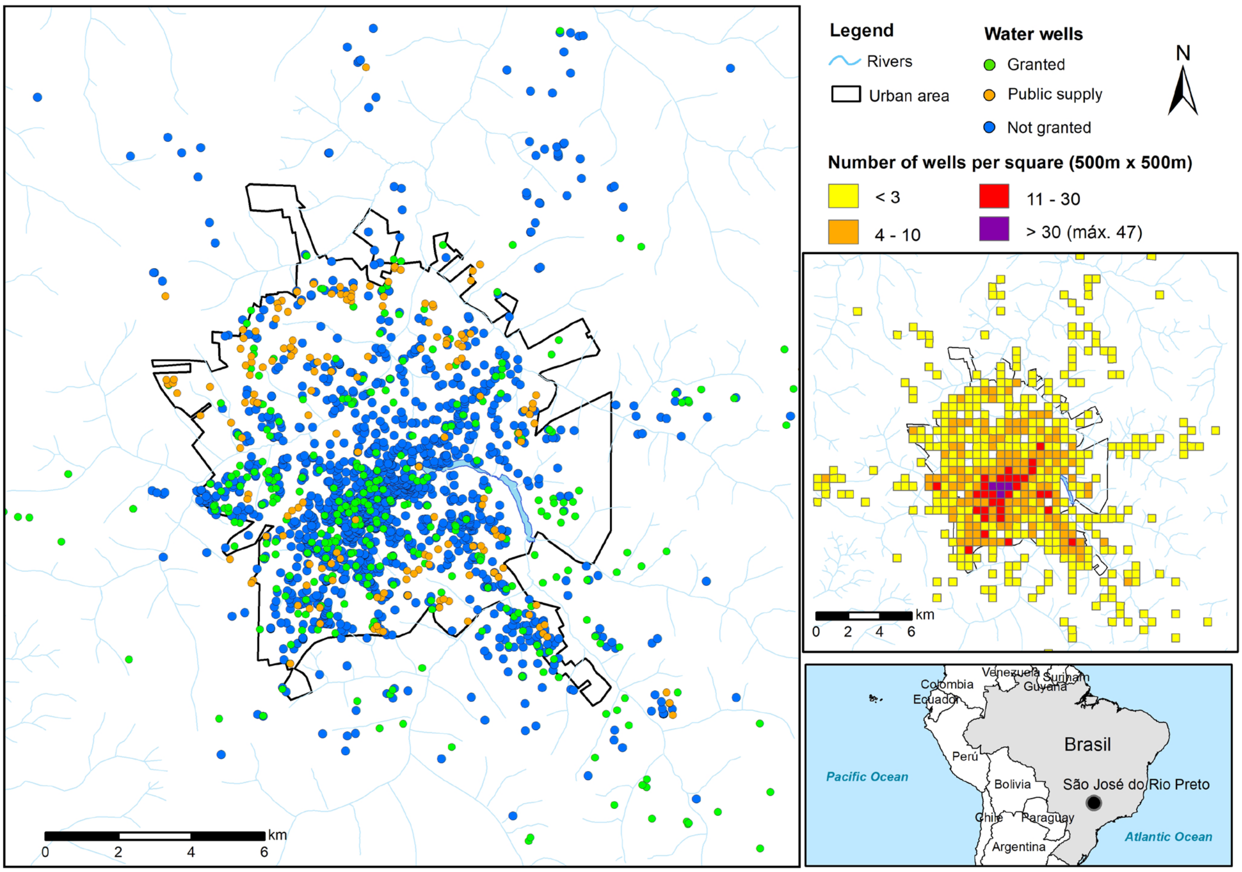

Figure 1. Total wells and well density in the city of São José do Rio Preto (Modified from Conicelli & Hirata 2011).

to control the users and prevent possible cheating near their abstractions.

Due to the limited effectiveness of these actions, other more innovative ways are needed focusing on a shift in the locus of control and the mechanisms for social communication, raising more awareness and allowing them to act more efficiently in this regard. Such an initiative, which would be complemented by traditional methods of inspection of new wells and response to public complaints, would possibly provide better management of groundwater resources. The rational and controlled use of groundwater and its conservation and protection are in the interest of society.

The vicious and virtuous cycles in groundwater management

Non-engagement of users and the State in question regarding groundwater is associated with a lack of perception of the problem and its causes on the part of affected users. This constitutes a severe roadblock to groundwater management. The impacts on groundwater are not visually apparent (confusing cause-effect correlation in space and time), which impedes the perception of the problem by users, society, and government bodies. Conflicts over groundwater (overexploitation and pollution) occur, however, mainly in urban areas, where they are invisible. This lack of "apparent" conflict does not engage the society for more control, and without such pressures, the State does not enforce the laws or monitor the users. Therefore, it turns into a vicious cycle (Figure 2).

This lack of perception is even more significant when society does not have a clear understanding of the economic value of groundwater and how it contributes to the functioning of the city's economy (Llamas & Custodio 2003). Therefore, the government must take a stance to overcome this problem. A reality that corroborates this thesis is the comparison between the cities of Mexico and São Paulo. In Mexico City, illegal wells are practically non-existent, in contrast to the town of São Paulo where more than 70% of the wells are illegal (Hirata & Escolero 2017). According to the authors, this is due, among other things, to the high demand in Mexico, making conflicts very clear among all (soil subsidence is a common consequence of groundwater overexploitation in Mexico City; therefore, a well-developed water resource management with more mechanisms to control the use of water is needed). In São Paulo, despite the last major drought that hit the city occurred from 2014 to 2016 and forced the water company to adopt several actions aimed to increase water production, there was no change in the groundwater management structure explicitly motivated by this water crisis (Hirata et al. 2015, Bertolo et al. 2015). In São Paulo,

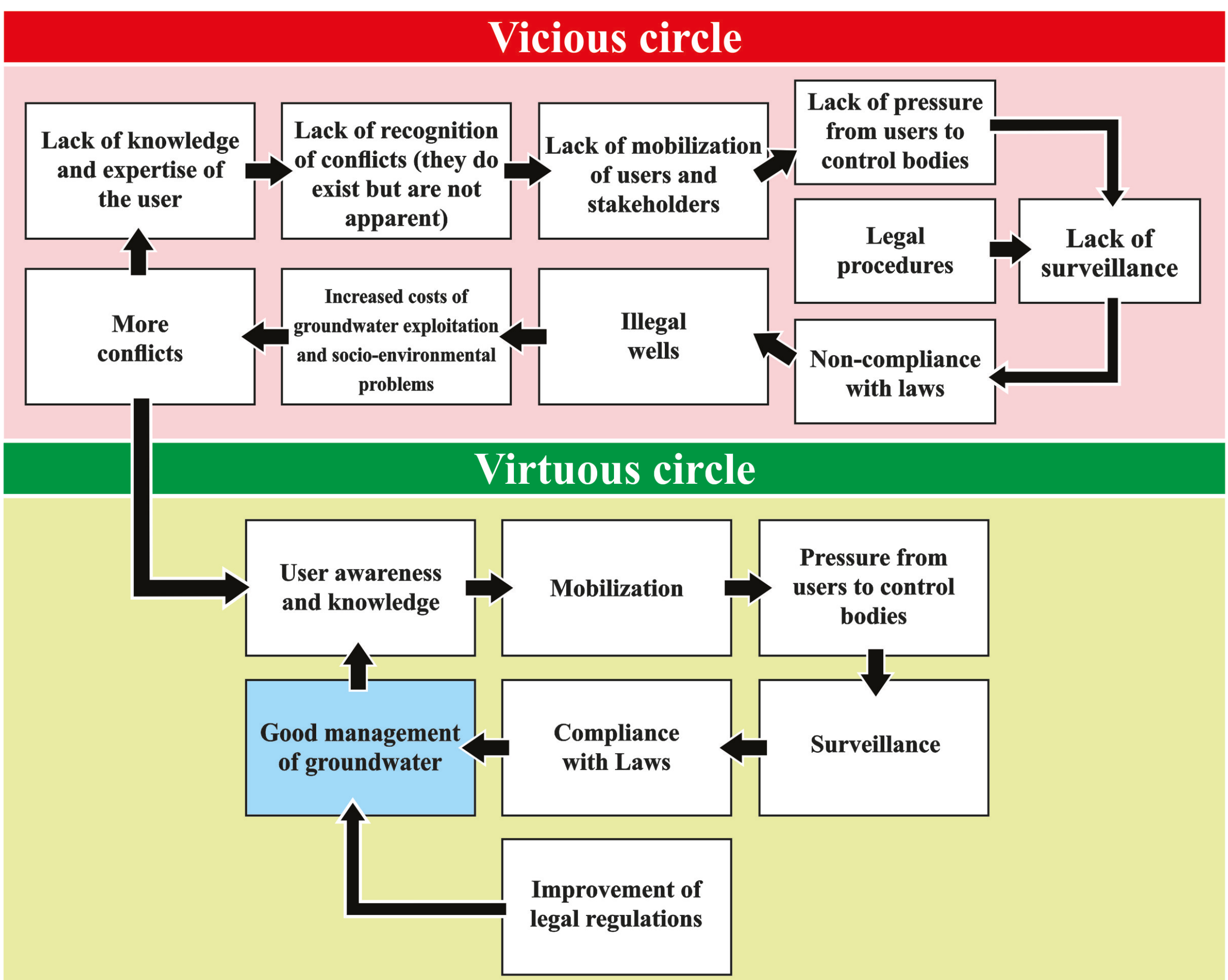

Figure 2. The illegality of wells as a result of unapparent conflicts (vicious cycle) and proper management based on user cooperation (virtuous cycle).

groundwater is entirely marginal, operated by private wells.

To minimize this problem, it is necessary instruments of social communication to engage and persuade users by disseminating information and awareness creation of economic, ecological, and social benefits of groundwater management. This type of communication is distinct from early childhood education. The two communication processes are essential, but they are not similar. Such initiatives, associated with more useful and incisive action on the part of the State in surveillance of incorrect practices of well drillings (particularly with the drilling companies), will be necessary to the regularization of the sector.

Thus, a virtuous cycle (Figure 2) must be created with user participation (Castro 2007). The mechanisms of engagement would involve showing users, based on their situation, that their well could have better performance (lower cost or higher flow), or would not be contaminated, if not for the illegal behavior of their neighbors or the lack of control of potential local contaminators. One important aspect is for users to have access to appropriate information directed at them, so that knowledge may be transformed into awareness (and vice-versa), and that in turn, this awareness-raising may lead to knowledge-generating action. Therefore, easily understandable and reliable information is required to ensure such "awareness" (Kemper 2007, Sarkki et al. 2014, Kunseler et al. 2015, Van Enst et al. 2016, Rose et al. 2017). Users who see their resources being lost because of misuse by other illegal users may pressure the responsible authorities to end irregularity and see the losses on their investments restituted.

A program based on rewards could be one alternative to reach the users and make them aware that legal wells offer security to their investment and a guarantee given by the government of a certain quantity of water for a given period. A voluntary program would be based on offering users support regarding how to correctly operate their wells, in exchange for the legalization of their abstraction. The information provided would permit users to have a notion of the costs of their exploitation and lost income, which is essential, as it makes it possible for them to understand the value of water and the impacts to which it is subjected (Lopez-Gunn & Cortina 2006).

Broad and harmonic networking with various actors, as well as with the interacting policies within the urban space, is also required (Hirata et al. 2015). Therefore, it is necessary to shape a policy where the role of the institutions and their interrelationships are critically evaluated, contemplating all bodies responsible for the water resources, including utilities and municipal governments (which are responsible for decisions regarding land use and occupation) as well as other spheres (responsible for the effluent release, management of contaminated areas, and health surveillance) (Varady et al. 2016, Kooiman & Bavinck 2005). Furthermore, mechanisms for stakeholder participation are usually much less well defined in urban than in rural areas (Burke 2003), where the groups tend to converge around common interests (Shah 1993, 2000, Garduño et al. 2006a).

Raising groundwater users' awareness

The primary motivation of the users for regularizing their abstraction lies in showing that only through the identification of wells and observance of authorized flow rates is proper resource management made possible. Otherwise, significant environmental and economic losses are likely to occur to the users and society. Therefore, awareness of the importance of this resource needs to be raised among the users with regards to the especially following:

- Groundwater resources as a strategic reserve: issues related to water shortage in a water basin may be minimized by using groundwater, especially during dry seasons (Hirata & Conicelli 2012). Therefore, exhaustion of the aquifer (because of uncontrolled exploitation) will result in forfeiture of user investments in abstraction and distribution facilities.
- Optimal groundwater utilization minimizes extraction costs: knowing well the characteristics of an aquifer, such as hydraulic parameters (storativity, transmissivity, and hydraulic conductivity) as well as recharge (Galvão et al. 2018) and discharge areas and their rates, may bring exploitation into line with the potential of the aquifer, principally through reducing expenditures on power for running the pumps and obviating the need to deepen the well.
- The right of access to groundwater and government supports for those with authorized wells: in conflict cases due to hydraulic interference between proximal abstractions, regularized users will receive legal preference. Therefore, it is in the users' interest to denounce illegal wells because new abstraction in the proximity of their wells may cause interference, overexploitation, an increase in abstraction costs, and even exhaustion of the aquifer, with loss of their investment as a result.
- Water quality and quantity in the aquifers: the findings of studies conducted by the managerial bodies must be provided to the users to highlight not only the actions of the government in maintaining the resource but also the utility of these studies for users. One way to communicate these findings to the population may be a small monthly notification in the users' water bill.

Additionally, it is crucial for water companies (public and private) to identify users and preserve the aquifer reserves because:

- The registration of users will make it possible to charge for sewage removal.
- A lack of control of extraction results in loss of aquifer resources due to overexploitation. This makes users abandon their wells and migrate to the public utility, which is often not able to absorb the additional demand.
- The identification of the aquifer potential concerning present and future demands will help increase the utilization of groundwater, reduce consumption in the public system, and optimize its use.

Along these lines, an idea that is still little explored would be to form partnerships between individual water users-producers in specific areas with significant problems regarding the adequate water supply. User loyalty to such partnerships could be grounded in the technical support that the utility could provide, such services as periodical chemical analyses. This strategy would increase water supply in the localities and increase the resilience of the cities vis-à-vis water supply crises.

CONCLUSIONS

The presence of over 88% irregular wells is one of the severe issues interfering with proper groundwater governance in Brazil. Thus, the control of extraction and user identification are of importance in allowing the State to manage and adequately administer the water resource. The lack of knowledge amongst the society and users of groundwater regarding the available forms of management, control, and protection, as well as the costs and deadlines required in authorization processes, favors clandestine practices.

There is an urgent need to encourage users to legalize their abstraction by sharing knowledge regarding the resource and the advantages of its utilization vis-à-vis other sources of water, simplifying the authorization process, and making it easy and inexpensive to implement. A permanent social media program should be created and demonstrate that the lack of water management can cause severe problems and represent significant financial losses to the water-well owner and society. Conflicts between users should become apparent and visible to everyone. This will undoubtedly improve the management of this resource by reducing the interference between legal and illegal wells in water exploitation.

It is indispensable to explain to users, society, and water companies that the regularization of the wells is beneficial to all. Groundwater governance requires a new paradigm, and this change must be grounded in user participation and directed information. Persuasion, based on an approach of demonstrating complex hydrogeological results as well as showing users the societal and individual benefits of collectivization of the management process, must be the starting point in breaking the vicious cycle prevailing in groundwater governance.

Governance must, therefore, provide inputs and information directed mainly to all stakeholders involved with groundwater resources. The process starts with the government, with its legal and institutional structure, and continues through the private user, civil society, well drillers, and water supply utilities. All actors have different and specific motivations, such as consumption and the provision of services or supervision, but they must address the same goal of protection of the quality and quantity of available groundwater resources.

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