Chapter 3
Groundwater Management Instruments and Induced Second-Order Conflicts: The Case of the Paraíba River Basin, Brazil

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Abstract Management measures addressing water scarcity are often pointed out as resolution alternatives for first-order conflicts; however, failures in introducing such measures or their unforeseen consequences can transform them into sources for second-order conflicts caused by social resource scarcity. Hence, implications of their adoption should be analyzed. Considering unsustainable groundwater use in the Paraíba River Basin—the most important basin in the state of Paraíba, Northeastern Brazil—and focusing on water quality guidelines, water permits, and bulk water charges, this paper analyzes thirteen criteria for applying these management instruments with regard to their potential for inducing second-order conflicts, and identifies the possible consequences of their adoption. Then, utilizing the Graph Model for Conflict Resolution (GMCR), these consequences are introduced as management outcomes to model the conflict over groundwater residential supply in João Pessoa, the state's capital. The analysis/modeling results can support decision-making on options to avoid/minimize second-order conflicts over groundwater management.

Keywords Management criteria · Graph model for conflict resolution (GMCR) · Water permits · Bulk water charges

3.1 Introduction

In Brazil, the National Water Policy (Federal Water Law 9433/1997) establishes water management that is *integrated*, considering all the phases of the hydrological cycle, *decentralized*, where the river basin is the territory unit for water planning and management, and *participatory*, in which decision-making involves water

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users, civil society, and the governmental sector. The policy should be implemented through the application of five management instruments, namely: (1) *water plans*, which are developed to guide future decisions, establishing priorities and general mechanisms for water allocation and water pricing; (2) *water quality guidelines*, which intend to guarantee that water quality is compatible with the target use of each water body; (3) *water permits*, which seek to balance supply and demand sides through water use authorization; (4) *bulk water charges*, which recognize water as an economic good, encouraging responsible and rational water use and for collecting revenues to improve the basin's conditions; and (5) *water information system*, a database on water availability, uses, users, and so on, to support decision-making. These five instruments are complementary and their relationship can be summarized as follows: based on the water information system, the water plan defines the goals in relation to water quality and quantity; therefore, water quality guidelines, water permits, and bulk water charges constitute "operative instruments", since it is their implementation that may induce the necessary changes in water use patterns for achieving the water plan goals. Besides, bulk water charges can only be applied to the water uses granted by water permits, and water permits must consider the standards established by water quality guidelines; evidently, reliable information is necessary to guarantee the effectiveness of these instruments.

After seventeen years of the Water Law promulgation, although the Brazilian Water Policy has already achieved several effective advances, there is a clear emphasis on surface water management. As a result, the management instruments fail to consider groundwater specificities, and that hinders integrated management from being accomplished (Ribeiro et al. 2012). This gap in relation to groundwater management allows unsustainable groundwater use patterns, causing problems like aquifer depletion, salt water intrusion, and groundwater contamination/pollution, among others. Thus, the increasing competition for groundwater resources creates the so-called "first-order conflicts", which are related to demand-induced water scarcity, in the absence/inadequacy of norms and regulations (Ohlsson 1999). Such conflicts call for the application of adequate management instruments.

However, since the application of management instruments demands a societal adaptation effort, "second-order conflicts", which are connected to scarcity of social resources, may be induced by the very means societies employ to overcome the first-order scarcity (Ohlson 1999). Hence, second-order conflicts are likely to occur from the inadequate or unmonitored implementation of water demand mechanisms that seek to achieve a more equitable water distribution (e.g., water permits) or even spring from the use of economic tools which may infringe on traditional values or privileges of previous users (e.g., bulk water charges). In this context, the current gap in relation to groundwater management implies not only in the need to address the adequacy of water management instruments to groundwater specificities, but also the evaluation of such instruments from the point of view of their potential for inducing second-order conflicts.

Thus, this paper adopts as study area the coastal region of the Paraíba River basin, the most important basin in the state of Paraíba, Northeastern Brazil, and where conflicts over groundwater use have been observed. Thirteen criteria for applying water quality guidelines, water permits, and bulk water charges to groundwater management are analyzed. The objectives of this paper are to identify the consequences of the adoption of these criteria, classify their potential for inducing second-order conflicts, and suggest mitigating measures to avoid/minimize such conflicts.

3.2 Conceptualizing Second-Order Conflicts

Literature on water conflicts presents two main approaches. The first, based on classic environmental researches (Homer-Dixon 1994; Bächler et al. 1996; Gleditsch 1997), links water conflicts to water scarcity, both the scarcity caused by the heterogeneous spatial-temporal distribution of water (arid and semi-arid climates, periodic droughts) and the scarcity motivated by human activity impact on water resources (desertification, increasing demands, inadequate use patterns, pollution). The second, followed by authors like Glachant (1999), Rogers and Hall (2003), Ravnborg (2004), among others, considers that, more than to water scarcity, water conflicts are related to water governance, that is, the set of political, social, economic and administrative systems for developing and managing water resources at different societal levels (GWP 2002).

Ohlsson (1999) synthesizes these two different approaches. Although still considering water scarcity as the basic source for water conflicts, this author links it to water governance by introducing an important conceptual distinction between first- and second-order scarcities. The former results from hydrological conditions and/or the increasing pressures on available water and can be: (1) induced by demand, due to population growth and its justified demands and/or inadequate use patterns; (2) induced by supply, as a result of quantitative and/or qualitative unavailability of water to meet existing demands; and (3) structurally induced, due to water resources appropriation by powerful social segments. The latter indicates a societal incapacity in finding adequate social tools to deal with the social consequences of a first-order scarcity. Consequently, he distinguishes between "first-order conflicts", which are originated from the competition for scarce water resources (first-order scarcity) in the absence/inadequacy of norms and regulations for managing that scarcity, and "second-order conflicts", which are related to scarcity of social resources (second-order scarcity) and caused by failures in introducing the correct kind/sufficient amount of management measures to overcome the first-order scarcity, or by unforeseen consequences of such measures.

Even in the context of a relatively high level of water availability as is, in general, the case of groundwater resources, first-order scarcity/conflict can occur due to inadequate use patterns which may result in interference among wells, aquifer depletion and groundwater pollution. The effectiveness of management measures to discipline water use and solve first-order conflicts depends on the societal ability to mobilize a sufficient amount of social resources, i.e., institutional capability, economic incentives/disincentives, users' acceptability, etc. (Ohlsson and Turton 2000). For example, the implementation of water permits may change the balance of power among different user sectors, by considering multiple uses; the implementation of bulk water charges can reduce the level of economic activity of given user groups; in both cases, mitigating measures are necessary to minimize these negative consequences and avoid the occurrence of second-order conflicts. However, the feasibility of such measures is related to the availability and correct application of social resources.

3.3 The Brazilian Groundwater Management Legal Framework

The Brazilian National Water Resources Council (NWRC) is responsible for regulating the application of Water Policy instruments. Thus, at federal level, and in relation to groundwater management, the NWRC establishes general criteria to implement water permits (Resolution 16/2001), bulk water charges (Resolution 48/2005), and water quality guidelines (Resolution 91/2008), considering surface water and groundwater conjointly.

Brazil is a Federative Republic, and federal regulations act as general norms to be followed by all its members. On the other hand, the country is very large (more than 8.5 million km^2) and its five geographic regions (comprising twenty-six states and the Federal District) present great hydrological, economic and social differences. So, the NWRC Resolutions cannot be specific and the states can choose the aspects they will adopt.

Thus, in the state of Paraíba:

- Water quality guidelines are not explicitly considered as a management instrument, although the State Water Law authorizes the State Water Resources Council to define water quality targets to be achieved by the state water bodies;
- The Decree 19260/1997 establishes that water permits should adopt, as reference for groundwater withdrawal, the well's nominal flow rate test or the aquifer recharge capacity; when this flow rate is less than 2 $m^3\ h^{-1}$, the use is considered insignificant and no water permit is needed. With this approach, however, the state water permit system doesn't take into account aspects such as the risk of interference among wells, or the proximity of potential pollutant sources;
- In relation to bulk water charges, the Decree 33613/2012 defines the values to be collected according to each water use, without distinguishing between surface and groundwater, and establishes annual volumes which are exempt from charges for each state river basin. For the Paraíba River basin these volumes are as follows: water supply and industrial uses: 200,000 $m^3\ year^{-1}$; agriculture and agricultural-industry: 350,000 $m^3\ year^{-1}$. As a result, the state bulk water charges system doesn't consider the differences between wet and dry seasons, or if high quality water is being destined to less noble uses, among other aspects.

3.4 The Study Area

The Paraíba River basin (Fig. 3.1) is the largest and most important basin under the domain of the state of Paraíba, since the main river and its tributaries lie solely within the state's borders. It covers an area close to 20,128 km^2, of which more than 80 % is inserted in Brazil's semi-arid region (AESA 2006), a drought prone area characterized by low average annual rainfall—concentrated into four months of the year and presenting high inter-annual and spatial variability—, high evaporation rates, intermittent rivers, and crystalline based aquifers which offer very low groundwater availability (Vieira and Ribeiro 2010).

As groundwater occurs mainly in the basin's coastal area, this paper focuses on the Paraíba River Lower Course Region and its sedimentary aquifers. The Region (area: 3,925.4 km^2) includes twenty-five municipalities—among which is João Pessoa, the state's capital—and presents a high urbanization rate (85.68 %) and a demographic density close to 293 $inhab.km^{-2}$ (ASUB 2010). Its Gross Domestic Product is predominantly formed by the service (55.6 %) and industrial (39.4 %) sectors, while the agricultural sector's contribution is very low (5.0 %); its Human Development Index is 0.711, indicating medium human development (IBGE—Instituto Brasileiro de Geografia e Estatística 2010).

The Coastal Sedimentary Basin comprises two distinct aquifer subsystems: a free subsystem, in Barreiras formation; and a confined subsystem, the most important, in Beberibe formation. Although groundwater potential by aquifer unit is not yet known, the entire system potential is 628.48 h m^3 $year^{-1}$. The State Water Plan defines the maximum groundwater availability as 60 % of this potential (AESA 2006), although current withdrawals sum up to 82.7 % of the potential, characterizing overexploitation in the study area, where there are more than 3,660 wells. Recent studies have revealed wells with negative static levels in relation to the sea

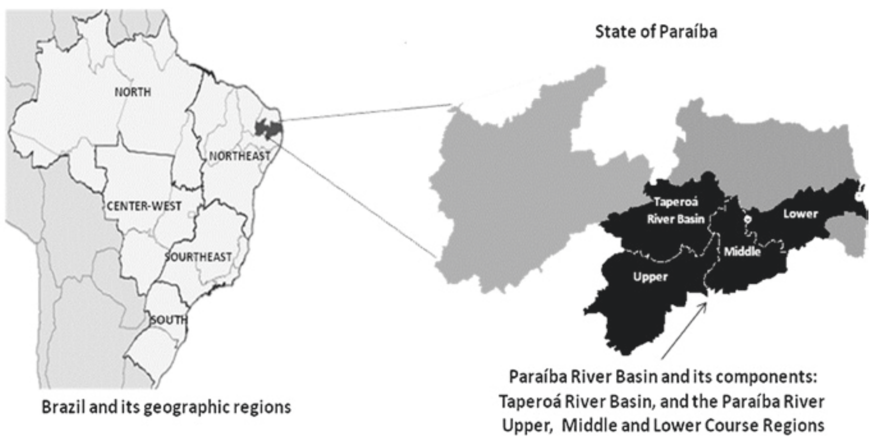

Fig. 3.1 Location and components of the Paraíba River Basin

level, and areas with excessive water table drawdown, especially in the industrial district of João Pessoa city; besides this, salt water intrusion has been detected in some coastal points (ASUB Project 2010).

In João Pessoa city, urban water supply is under the responsibility of CAGEPA (Water Supply Company of the State of Paraíba), the state public water supply company. High tariffs along with eventual failures in meeting demands have made it attractive to drill private wells, notably in residential apartment condominiums along the coastal area. The majority of these wells are clandestine; their water does not always meet quality standards for drinking water; and their concentration, in some areas, has given place to interference among wells and aquifer depletion has already been observed. All these detected problems, which are mainly allowed by the lack of monitoring/punishment actions (already foreseen by the state water legislation), highlight inadequate groundwater use patterns and the absence/inadequacy of groundwater management in the study area, and reveal the occurrence of first-order conflicts.

3.5 Criteria Definition and Analysis

This paper considers the criteria originally suggested by the ASUB Project (2006–2010), which was carried out by the research team on Integrated Water Resources Management of the Federal University of Campina Grande. The main goals of the ASUB Project were: (1) to acquire information (institutional, legal, hydrological, geological, economic, social, groundwater users and use patterns, etc.) about the Coastal Sedimentary Basin of the Paraíba River Lower Course Region; (2) to analyze the water policy's operative instruments (water quality guidelines, water permits, and bulk water charges) with regard to their adequacy to groundwater management; and (3) to indicate management measures/parameters/criteria to guarantee the integration/adequacy of these instruments to groundwater management. In the process of defining criteria for applying groundwater management instruments, three spatial levels were considered (ASUB Project 2010):

- Global, which considers the entire river basin, according to a systemic and integrative view;
- Regional, defined by groundwater recharge and discharge zones, i.e., according to the behavior of physical processes;
- Local, in which the main analysis object is the well and the consequences of its drilling in a given point in the basin.

Table 3.1 presents the thirteen suggested criteria, and indicates their respective spatial level, the management instrument(s) that can use them, the meaning of each criterion and the possible consequences of its application.

As Table 3.1 indicates, all the criteria for applying water quality guidelines and water permits can result in suspension or restriction of granted water permits and/or non-granting of new permits; for bulk water charges, charge values should increase in the context of low groundwater availability, dry season, and high water quality required by the current/intended groundwater use, or diminish in the event of high groundwater

Table 3.1 Criteria and their respective spatial levels, instruments, meanings and consequences

Criterion (Level)	I	Considerations	Possible consequences
1. Priority for using surface water (G)	WP	Groundwater is a strategic resource to be used only if there is no existing surface water supply alternative	Suspension/restriction and/or no new permit
2. Groundwater availability (G)	WP	Total groundwater abstraction should be inferior to 60 % of the potential	Suspension/restriction and/or no new permit
	BW	Differentiates charge values	Increased/decreased values
3. Hydrological seasonality (G)	BW	Differentiates charge values for wet and dry seasons	Increased/decreased values
4. Investments in the basin (G)	BW	User's structural investments in the basin can diminish charges up to 0 %	No investment and no changing in charges values
5.Water use priorities (R)	WQ	Water quality adequacy to each use	Suspension/restriction and/or no new permit
	WP	By law: human and animal supply > industry and commerce > agriculture	
6. Salt water intrusion (R)	WQ	Protection zones implementation in coastal areas can restrict water uses	Suspension/restriction and/or no new permit
	WP	Prevention of salt water advancing	
7. Aquifer vulnerability (R) +	WQ	Protection zones implementation for highly vulnerable aquifers can restrict water uses	Suspension/restriction and/or no new permit
8. Potentially pollutant sources (R)	WP	Prevention of water contamination	
9. Water quality (L) +	WQ	Well's water adequacy for water uses	Suspension/restriction and/or no new permit
10. Kind of use (L)	WP	Verification of current/intended uses	
11. Interference between wells (L)	WP	Based on the well's radius of influence and water table maximum drawdown	Suspension/restriction and/or no new permit
12. Demand man-agement measures (L)	WP	Need for users' actions that reduce waste and guarantee rational water use	Suspension/restriction and/or no new permit
13. Aquifer classification versus kind of use (L)	BW	Differentiates charge values based on the level of (high/low) water quality the use requires	Increased/decreased values

Obs. *Level* Spatial level [*G* Global, *R* Regional, *L* Local]; *Instr.* Instrument [*WQ* Water Quality Guidelines, *WP* Water Permits, *BW* Bulk Water Charges]; *Considerations* indicate the meaning of each criterion; *Possible Consequences* indicate the consequences from applying the instrument using the criterion availability, wet season, low water quality required by the current/intended groundwater use, and/or authorized and confirmed users' investments in the basin.

3.6 Criteria Potential for Inducing Second-Order Conflicts

The potential presented by each criterion for inducing second-order conflicts was classified into four categories, according to the following conditions:

- Low, if the criterion maintains current groundwater use patterns;
- Medium, if the criterion slightly modifies current groundwater use patterns, implying in the need for few restrictions in existent/new water permits and/or insignificant increases in bulk water charges values;
- High, if the criterion forcefully modifies current groundwater use patterns, implying in the need for many restrictions in existent/new water permits and/or significant increases in bulk water charges values;
- Very High, if the criterion prevents groundwater use, implying in the suspension of existent water permits and the no-granting of new ones, or important increases in bulk water charges values.[1]

Thus, in the light of current groundwater use patterns in the study area, analysis of consequences most likely to occur allowed the determination of the criteria potential for inducing second-order conflicts. Table 3.2 indicates the overall criteria analysis results. As an illustration, the summarized analysis performed for two global criteria and its results are presented below.

- Criterion #1. Priority for using surface water: the Paraíba River is perennial just in its Lower Course Region. Reservoirs located in other river basins are surface water sources for the major cities in the study area; all of these cities are already served by the water supply company, which utilizes both surface water and groundwater sources. In rural areas, on the other hand, there is no public water supply service and, in most cases, the distance between farms and surface water sources is very large. Hence, the costs of replacing groundwater with surface water in urban areas and using surface water instead of groundwater in rural areas would be very high. The application of this criterion to urban areas implies in the need for suspending water permits granted for private groundwater use and the non-granting of new water permits for such use. Considering the numerous private wells (including those clandestine ones) existent in the urban zones in the study area, the potential for inducing second-order conflicts is very high. Current groundwater users would be unlikely to submit to a command-and-control instrument implementation and clandestineness would very likely increase. Thus, the criterion potential for inducing second-order conflicts is Very High.

[1] Increases in bulk water charges values are considered insignificant (<3 %), significant (from 3 % up to 10 %), and important (>10 %), according to the economic conditions in the study area.

Table 3.2 Criteria's potential for inducing second-order conflicts

Criterion	Potential classification (observations)
1. Priority for using surface water	Very high (especially in urban areas)
2. Groundwater availability	High to very high (abstractions surpass 60 % of potentiality)
3. Hydrological seasonality	Low (wet seasons) or very high (dry seasons)
4. Investments in the basin	High (need for the users' own investments)
5. Water use priorities	Medium (a few changes required to attend specific areas)[a]
6. Salt water intrusion	High (in coastal areas and irrigated areas)
7. Aquifer vulnerability +	Low (confined aquifer, especially in rural areas) to
8. Potentially pollutant sources	Very high (free aquifer, especially in urban areas)
9. Water quality +	Low (water quality is adequate for the intended use) to Very
10. Kind of use	High (advanced water treatment is need for allowing the intended water use)
11. Interference between wells	Low to medium (in rural areas) and high to very high (in urban areas, especially in the study area's major cities)
12. Demand management measures	High (in the entire study area)
13. Aquifer classification versus kind of use	Low (low water quality and mean water uses) to very high (high water quality and noble water uses)[b]

[a]According to the municipalities' economic basis, irrigation can be more important than industry
[b]The higher the water quality the higher the charges to be paid

- Criterion #3. Hydrological seasonality: during dry seasons, the adoption of this criterion for applying bulk water charges would increase the total amount to be paid by users, with the desired effect of inducing groundwater rational use. On the other hand, during wet seasons the charge values would decrease. Although the latter situation would be welcome by the users, negative reactions to the former could be expected. Expressions include refusal to pay charges and clandestine abstraction attempts, since abstractions increase during dry seasons. Thus, this criterion presents a potential for inducing second-order conflicts which is either Low (wet seasons) or Very High (dry seasons).

3.7 Modeling the Residential Groundwater Supply Conflict

The conflict over residential groundwater supply in João Pessoa city (mentioned in Sect. 3.4) is the most expressive first-order conflict detected in the study area and demands the implementation of management instruments to discipline groundwater use. In order to evaluate the users' acceptability to this implementation and to verify the conditions that could support conflict resolution, the Decision Support

System GMCR II (Hipel et al. 1997; Fang et al. 2003a, b) is used to model the conflict. The GMCR II implements the Graph Model for Conflict Resolution (Fang et al. 1993), an abstract game model mathematically based on Game and Graph Theories, which furnishes a systematic structure for describing a conflict in terms of decision-makers, their options, and their preferences, and can point out the most likely resolution (equilibrium) to the conflict; besides, the interpretation of results can provide important information to assist in decision-making.

The conflict is modeled considering the consequences of adopting criteria, firstly, for applying water permits in order to reduce abstractions, and secondly, for applying bulk water charges to induce rational groundwater use. In both cases, the three decision-makers represent all the sectors involved in the conflict: (1) AESA—Water Management Agency of the State of Paraíba, the state water manager responsible for granting water permits, collecting bulk water charges, monitoring water uses, and punishing infringers, among other attributions; (2) CAGEPA—Water Supply Company of the State of Paraíba, to whose water distribution network all the city's apartment condominiums are connected; and SICON—Residential Condominiums Union of João Pessoa, an entity which represents a large number of residential apartment owners. Tables 3.3 and 3.4 indicate the decision-makers (DM) and their options, respectively for water permits and bulk water charges modeling. For water permits modeling, from the possible 64 (2^m) states, the states where AESA selects more than one option or doesn't select any option were excluded; thus, 20 feasible states remained. For bulk water

Table 3.3 Water permits modeling: decision-makers and options

Decision-makers (DM)	Options (m)
AESA (DM1)	1. Maintains its current water permits system but legalizes clandestine wells
	2. Applies restrictions to granted water permits and grants new restricted ones
	3. Maintains the existent water permits but does not grant new ones
	4. Suspends all the existent water permits and does not grant new ones
CAGEPA (DM2)	5. Accepts AESA's choice
SICON (DM3)	6. Accepts AESA's choice

Table 3.4 Bulk water charges modeling: decision-makers and options

Decision-makers (DM)	Options (m)
AESA (DM1)	1. Charges according to the state's current law
	2. Charges considering suggested criteria
CAGEPA (DM2)	3. Accepts AESA's choice
SICON (DM3)	4. Accepts AESA's choice

charges modeling, from the possible 16 states, the states where AESA selects more than one option were excluded; thus, 12 feasible states remained.

In order to determine the DM's preferences, the authors had interviews with key representatives of AESA (two directors and two technicians), CAGEPA (one director and two technicians), and SICON (one director and six members, all syndics and apartment owners in residential condominiums supplied by wells). The consequences of overexploitation and the suggested criteria were explained and AESA's options for both the conflict models were presented. Thus, the DM's preferences were attributed based on these interviewees' answers. For example, for water permits modeling, AESA is aware of its own organizational fragilities—which include an inadequate number of employees and the lack of financial/administrative autonomy in relation to the state government, and, consequently, hinder effective monitoring/punishing capacity—and its most preferable state is the one where option 1 is selected and accepted by all the other DMs; this is also SICON's most preferable state, since the status quo is just slightly modified; CAGEPA doesn't agree to the condominiums private groundwater supply and its most preferable states are those where option 4 is selected by AESA, independently of SICON's acceptance. For bulk water charges modeling, AESA's most preferable states are those where option 1 is selected and accepted by at least one of the other DMs, while its least preferable states are those where all the other DMs don't accept the option (1 or 2) selected and the status quo (where neither option 1 nor option 2 is selected[2]); CAGEPA's most preferable states are those where option 2 is selected, independently of SICON's acceptance, while all the other states are equally and less preferred; SICON's most preferable state is the status quo, followed by those states where options 1 and 4 are selected, and its least preferable states are those where option 2 is selected.

The results indicate that: (1) for water permits model the equilibria most likely to be maintained in the long run are state 1 (where AESA selects option 1 and CAGEPA and SICON accept) and state 5 (where AESA selects option 2, CAGEPA doesn't accept, but SICON accepts). Hence, the conflict solution demands, especially, SICON's acceptance in order to allow effectiveness for the criteria implementation; (2) for bulk water charges model, the equilibria most likely to be maintained in the long run are state 7 (where AESA selects option 1 and CAGEPA accepts, but SICON doesn't accept), state 9 (where AESA selects option 1, CAGEPA doesn't accept, but SICON accepts), and state 11 (where AESA selects option 1, and CAGEPA and SICON accept). Thus, the conflict solution hinders the criteria implementation; (3) in both cases the equilibria confirm the results obtained from criteria analysis (Sect. 3.6) and indicate that the criteria potential for inducing second-order conflicts ranges from High (for water permits) to Very High (for bulk water charges).

[2] Bulk water charges are not being applied yet, although the Decree 33613/2012 has been approved.

3.8 Mitigating Measures

By definition, mitigating measures to avoid or minimize second-order conflicts occurrence imply in the ability to eliminate the sources for failures in introducing water management measures. Groundwater use patterns currently observed in the study area constitute the major indicator of the state water manager's organizational fragility. For example, numerous clandestine wells, out of date water permits, unknown abstraction rates, among other distortions, highlight the urgent need for updating groundwater use information, renovating water permits, and taking wells out of clandestineness.

Hence, the first suggested mitigating measure is a reliable water information system to support the granting of water permits and the application of bulk water charges, facilitating the monitoring tasks. This means, in other words, the effective implementation of the fifth management instrument established by the Brazilian National Water Policy. The process of developing such an information system, in turn, requires the strengthening of the state water manager's organizational capacity, especially in terms of increasing the number of qualified employees/equipments to improve the agency's monitoring capacity.

Secondly, the attractiveness of public water supply in comparison to private wells could be augmented—if the state water supply company diminished the number of failures in meeting demands, minimized leakages and clandestine connections, and reviewed (and lowered) its tariffs—in order to stimulate its use and diminish groundwater exploitation.

Thirdly, as the use of the Decision Support System GMCR II pointed out, another aspect to be corrected is the high rejection the users present in relation to the suggested criteria, and, even, the very implementation of groundwater management instruments. The interviews made clear the users' lack of knowledge about groundwater specificities, the state water legal framework, and the role played by the components of the state water resources management system, among which is the state water manager (AESA). Publicity campaigns or education programs, among other tools, can enlarge the users' consciousness and increase the acceptability of groundwater management instruments and criteria.

3.9 Conclusions

This paper focused on groundwater management practiced in the Coastal Sedimentary Basin of the Paraíba River Lower Course Region. Unsustainable patterns of groundwater use are expressed by problems such as interference among wells, salt water intrusion, water contamination/pollution, among others, and reduce groundwater availability (first-order scarcity induced by demand). These problems occur more intensely in relation to residential groundwater supply in apartment condominiums along the coastal area of João Pessoa city, and characterize a first-order conflict over groundwater use.

The analysis of thirteen criteria, for applying water quality guidelines, water permits, and bulk water charges to groundwater management, indicated their high potential for inducing second order conflicts, due to the restrictions applied to existent/new water permits and/or the increases in bulk water charges values. Such conflicts are mainly expressed by the clandestine use of groundwater and the users' refusal in paying charges.

The Decision Support System GMCR II was used to model the conflict over residential groundwater supply in João Pessoa city. Besides confirming the results obtained from criteria analysis, the modeling/analysis process provided a better understanding on the decision-makers preferences, and the outputs indicated the importance of the users' acceptance to allow the criteria implementation.

Although the suggested criteria are very necessary for adequate management instruments to groundwater specificities, the results highlight the need for mitigating measures—which necessarily should support the state water manager's organizational strengthening, especially in relation to its monitoring/punishment capacity; public water supply attractiveness, by reducing supply failures and tariffs, in order to diminish groundwater exploitation rates; and the increasing of groundwater user's consciousness in order to augment criteria/management instruments acceptability—to allow the effective implementation of groundwater management in the Paraíba River basin, Brazil.

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