Region - Water Conservancy, 2024 , Volume7, Issue1
DOI: 10.32629/rwc.v7i1.2283
ISSN Online: 2630-4902

The crisis under our feet: a preliminary analysis of groundwater in the municipalities of the Paranapanema basin (SP/PR)

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Abstract: Groundwater, unseen by humanity, is a strategic resource for dealing with droughts caused by climate change, a problem exacerbated by a lack of governance and monitoring. This study consulted the SIAGAS (Groundwater Information System) database for the municipalities in the Paranapanema basin (SP and PR) to assess the number of licensed wells and their characteristics (monitoring, exploitation and maintenance). The aim was to analyze the Paranapanema basin and the occurrence of wells in the municipalities, since not knowing about them leads to misuse and increases the risk of contamination. The clandestine condition masks the environmental value of groundwater, since it is not known exactly how much is extracted or whether there is contamination. This work therefore advocates integrated management of the hydrological cycle, i.e. studying the two types of associated reservoirs.

Key words: Paranapanema basin; tube wells; wells and municipalities; planning and wells

1 Introduction

The water that is invisible to humanity is under our feet, in the rocks, in the soil, and is called aquifers. It is a resource used by billions of people around the world. In agriculture, it is widely used to supply and irrigate crops. In urban areas, it is used to supply homes, industries, etc. However, there is a lack of governance, i.e. proper management and monitoring, which is causing the levels of aquifers around the world to drop to alarming levels, and there may even be a risk that they will dry up (Jasechko and Perrone, 2021).

The studies by Richey et al. (2015) and Famiglietti and Ferguson (2021), using the GRACE (Gravity Recovered and Climate Experiment) mathematical model, pointed to the depletion of large aquifers, including the Guarani. The model compares the simulations and identifies the depletion as anthropogenic pumping (Hua et al., 2020). The conclusion is that pumping exceeds natural recharge and that the future supply will not be governed by precipitation, but by other hydrological processes, such as recharge, and it is essential to deepen studies and monitoring so that future economic development can be sustainable.

So what are the factors that must be observed for effective management? First of all, it is necessary to understand water as a system, circulating through the terrestrial environment (atmosphere, biosphere, soil and rocks), that stores and interacts with each other, since hydrology is the science that studies "the occurrence, circulation and distribution, as well as the chemical and physical properties, its reaction with the surrounding environment (which includes living beings)" (Vasconcelos, 2017, pg 1580). It is the totality of the earth's history.

The development of the Paranapanema basin region has led to an increase in water demand, both in urban centers and in rural areas (irrigation), and this process has generated a need for governance to mediate conflicts and to plan the sustainable use of water resources, influencing management policies such as: water balance, aquifer recharge, piston effect, seasonal effects, safety flow and sustainable flow.

One aspect of the motto *save our rivers* involves maintaining the riparian vegetation and the surroundings of the springs (mines and springs). This is also part of the popular observation that the rivers are drying up, which makes it difficult to separate the silting up of their beds from the hydrological fact of the reduction in the river's flow. But this interpretation hides the concept of the water balance, i.e. an accounting of inflows and outflows from soils, rocks and surface waters, reaching deeper aquifers (Balek, 1988).

On the other hand, changes in land use (deforestation, increase in pasture, crops and urban areas) separate the infiltration flow from surface runoff, reducing the hydraulic properties and decreasing the flow to aquifers and rivers. There are also cases in which there is a reversal of flow, i.e. the river begins to supply its water to the aquifer.

2 Methodology

The methodology used to carry out this work was bibliographical research (ZANELLO, 2013). Scientific articles obtained from various research sites were used, such as: Google Scholar, Scielo, Scopus Science Direct, among others. The data analyzed was collected from the hydrogeological database of the CPRM (National Geological Service), at SIAGAS - Groundwater Information System (HTTP://siagasweb.cprm.gov.br/layout/index.php).

3 Theoretical foundations

3.1 Lack of management/monitoring

According to Fretwell et al. (2006, p.7), there are three main categories of monitoring:

Strategic: to obtain baseline information on quality, which can be used to determine the classification of the water, the trend of diffuse pollution or problems and changes in this quality;

Preventive: taken as part of a current or potential problem, used to provide information on the impact of a suspected or known source of contamination. It can also indicate the progress of the clean-up (decontamination) of a region;

Investigative: used to improve a conceptual understanding of a site, it can detect contaminants or problems and identify interactions between groundwater and the environment (surface water, habitat, among others).

The main objective is to represent the different objectives, which will influence some process that will need to know its concentrations, substances of interest or even knowledge of physical behavior. This process must guarantee its safety and quality control (data reproducibility) through the use of standards and rules, both for analysis methods (geostatistics) and technical and operating procedures (ISO, ABNT, NBR).

These assessments and proposed solutions require geological data that are called "baselines" and, in part, vary over time. This data collection comprises the collection, analysis and storage of this variation on a regular and accessible basis, according to the circumstances and predetermined objectives.

There are exploration wells and observation wells. All these elements are called a monitoring network. The wells can be for:

· General actions detected in the flow and trend of groundwater;

· Primary systems, which is reference monitoring, generally known, for recharge, diffuse contamination or changes resulting from changes in land use, climatic variations, etc;

· Evaluating and controlling changes in risks. Secondary systems are those for protection against potential changes, strategic resources, supply for public use, urban infrastructure and groundwater-dependent ecosystems.

· Tertiary systems, for knowledge of already contaminated areas, such as: intensive agricultural sites, industrial districts, landfills, dumps and mining areas, whether in operation or abandoned.

Its importance is clear in the National Water Resources Policy (PNRH, BRASIL, 1997), which states that future generations have the right to the availability of water necessary to maintain the quality standards appropriate to their respective uses. It plays an important role in protecting groundwater.

4 Exploitation and flows

It is the first and main goal of aquifer management. It is essential for planning its use. It controls abstracted flows and exploitation by wells, and is therefore the basis for developing a policy and planning a monitoring network. (Dutra, 2016)

The abstraction of water is regulated by the granting of rights of use, an instrument of administrative control, through which the federal, state (by delegation from the federal government) or municipal (in agreement with the state government) authorities allow one or more users to withdraw a certain amount of water for various uses, but limiting the maximum volume that each user can use of the resource.

The flow granted is known by means of a test, in which the characteristics of the aquifer are known. The main parameters that must be obtained in order to know the aquifer's potential are the definitions that, based on historical data, must guide minimum flows, which are difficult to determine, as they are based on the volume contained in the aquifer, the area of contribution, recharge and the flows obtained.

One of the criteria is the average flow rate of the aquifer, a simple arithmetic average, or obtained from a weighted average that takes into account the depth, diameter, length of the filter section or other constructive parameter. It can be applied to isotropic and homogeneous aquifers, which have low spatial variability of flows for continuous abstractions. It is a characteristic associated with the average specific capacity, from which flows can be added according to the depth of the wells in relation to their drawdown. The percentage that each well is entitled to is related to the aquifer's hydraulic parameters (hydraulic conductivity, saturated thickness, effective porosity and storage coefficient). Grantable flows should be conservative, especially in cases where the aquifer is poorly known (Campos; Correa, 2013).

Another technique is one that uses a fraction of the flow rate obtained by stabilizing the dynamic level with a 24-hour test. This percentage will vary depending on the degree of impairment of the region and the degree of circulation (recharge and discharge) for the aquifer. It must therefore take into account the conditions of over-exploitation, risks of contamination, i.e. qualitative and quantitative limitations. These are characteristics of aquifers that are anisotropic and heterogeneous, where flows vary enormously.

Flow rates are determined by tests that can be carried out with a constant flow rate, staggered with or without level recovery. For an assessment of the behavior of aquifers and their specific capacity, the stepped test is recommended, although its application requires a good assessment of the quality of the data presented.

The surface drainage base flow technique recommends that all surface water flow in critical periods and underground flow indicates that the grant should be released at up to 30% of this base flow (in the long period). To do this, it is necessary to determine its unit hydrograph and separate surface flow, internal flow and base flow. This technique has limitations for semi-arid regions (where the base flow is zero) or in places where there is historical flow data, or extensive modification of recession flows due to a high number of releases or abstractions, or major changes in land use, or in areas with many dams (Campos et al., 2007).

Using the available drawdown technique, the number is obtained through a mathematical analysis of the staggered pumping test (in three stages, with increasing flow rates). It starts with the well's characteristic equation. The drawdown can be the maximum value that the dynamic level has reached. The safety flow technique is the spatialization of exploitable reserves per unit area, obtained from the sum of the renewable reserve and a percentage of the aquifer's permanent reserve. Thus, the allocation is based on the area of the aquifer available to each user (Sofhocleus, 1997; Bredehoef, 1997).

In all tests, the specific capacity is used (ratio of drawdown to flow rate), as well as information such as the depth of the pump's sieve, the pump's power, the pressure drop curve and the recovery of the level after pumping stops.

Chemical monitoring is an attribute of quality assessment, not only for diagnosis and control, but mainly for prognosis, involving monitoring programs, which are made up of planning, execution and interpretation, evaluation of the results and re-evaluation of the program. Quality is defined by its composition and interaction with the rocks in the aquifer, which makes it possible to establish patterns in the evolution of this quality.

Other factors are also involved in these analyses (climate, recharge composition, contamination time/medium, rock types and land uses). These studies must be defined according to need (potability, irrigation, animal watering, industry, recreation, commercial use, environmental contamination, scientific research and geochemical prospecting). These are physico-chemical and bacteriological analyses, all of which focus on major, minor and trace constituents, with the exception of strontium (Conicelli et al., 2021).

Pattern classification techniques are shown through graphs of various types and for various uses (agriculture, industry, livestock, recreation, fish farming, or even environmental quality benchmarks). The graphic technique is a powerful aid in the diagnosis and prognosis of actions, (Mestrinho, 2013).

5 Maintenance and operation

It is the main catalyst for the volume of water extracted from the aquifer. In practically all the guidelines for obtaining the right of use, the maintenance and operation characteristics are cited as necessary. It is a fundamental part that is not taken into account when evaluating the efficiency of systems.

The operation of a well must obtain and store information for its best use over time. The only equipment used is the pump (most of the time submerged), with information on power and depth (sieve). Exploration is carried out in the way that seems most convenient and according to needs, for 24 hours a day, 30 days a month and 365 days a year, a real absurdity for those who work with sanitation systems.

Maintenance is a permanent objective, a systematic program to guarantee the functioning of the equipment and the opportunity to exploit the well (Mariano, 1997).

Maintenance can be preventive and/or corrective. Preventive maintenance is carried out at regular intervals, with systematic records of information such as: water level behavior, hydraulic losses, efficiency and durability of equipment. This leads to the standardization of materials and equipment.

Corrective maintenance is the correction of problems as they occur, without studying the causes. They are partial resolutions, with momentary attention paid to mechanical and equipment failures, while neglecting the body of the well.

Due to the difficulty of observation, what happens in a well is not easily detectable. It is a slow and gradual process, up to a point where it becomes observable and shows a collapse. There are many problems that can be avoided with an annual disinfection of the well for the quality of the consumable water, or even a flow test to observe the hydraulic behavior of the well.

There are no old wells. There is a lack of maintenance. Obstruction of the filter section, sand production, deterioration of the well structure, defects in pumping, hydraulic problems, scaling, drop in flow, everything is perfectly predictable and remediable. (Hirata et al. 2019)

Preventive maintenance services must be efficient and agile, both in the office and in the field, as they involve routine and periodic inspections to check that the system is working properly and is clean, as well as the processing of control data (daily, monthly and annual collections). (Silveira et al., 2020)

6 Excess and drilled wells: interference between wells

Aquifer overexploitation is a situation in which abstraction exceeds recharge within a certain area and over a period of time. It is a reflection of physical-environmental and socio-economic complexity, among other factors. This phenomenon occurs mainly in large urban centers, where growth is faster and, more often than not, disorganized. Cities in fractured aquifers have even greater problems, such as depletion and pollution.

At a glance, it seems that population and number of wells have a direct relationship, from which a vicious circle develops, as shown in Figure 1.

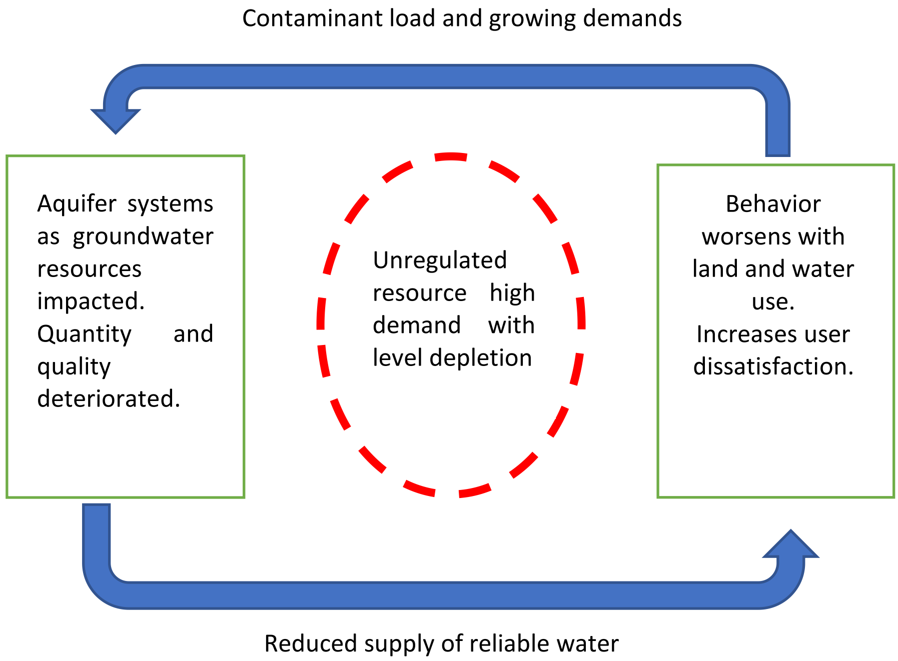

Figure 1. Vicious circle of lack of governance towards groundwater

Source: Tuinhof et al. (2006)

Figure 1 shows the relationship between contaminant load and reduced water supply and user dissatisfaction, in which water supply is deteriorated by unregulated land use. However, through governance, this circle must be transformed to meet socio-economic (demand management) and technical (supply management) needs. It is therefore necessary to understand the susceptibility to negative impacts caused by increased extraction and the interactions between surface water and groundwater (base flow, for example) and the effects of reduced recharge (altered flow from river to aquifer).

7 Downgrading - NA

Continuing with the observations related to the use of groundwater as a public supply, the main one is the lowering of the level in the wells (potentiometric surface).

· All water extraction causes negative physical effects, especially when there is excessive withdrawal. But this concept is still under discussion. On this issue, Margat (1992, p. 148) offers some comments:

· It is a state of imbalance or the cause of a need;

· Diversity of hydrogeological characteristics and management planning;

· As a consequence of abstraction, a problem arises;

· Interruption of the hydrodynamic balance, physical/quantitative criterion;

· Degradation of quality due to withdrawal, qualitative criterion;

· Withdrawal costs exceed the value offered by the resource, or direct costs are lower than external costs and collective advantages;

· Conflicts of use between different categories of users, with an effect on third parties, social criterion;

· Damage to the aquatic ecosystem, ecological criterion.

These are criteria related to the use made of the aquifer or its management plan. In this way, preserving the conditions of an exploited aquifer means maintaining a dynamic balance, perpetuating the average annual water production (Margat, 1992).

In a condition where extraction exceeds average recharge, the exploitation index (abstraction/average recharge) is greater than 1 (or 100%). It is an unbalanced and excessive regime. It is always based on observations of continuous lowering of the potentiometric surface.

Although this decrease does not imply an excess (greater than the average natural recharge), it does reflect local conditions of increase, or that the effects of flows at the edges of the system are not fully known. Based on this reality, two interesting properties to analyze are resistance and resilience (Monteiro, 2003).

When water withdrawal begins, a disturbance is caused. The system seeks an equilibrium condition, which becomes dynamic as abstraction continues. Withdrawal increases as the number of wells drilled grows. Dynamic stability is broken and the aquifer will respond. There will be greater resistance to extraction by the aquifer and it will respond with a slight lowering depending on its dimensions, porosity/permeability, among other properties.

Resilience, on the other hand, refers to the aquifer's ability to return to its original piezometric levels (or very close to it). These are essential characteristics, which should be the subject of aquifer testing and studies that provide subsidies for the management and governance of an aquifer.

8 Results and discussions: an approach for the Paranapanema basin

When you look at the municipalities that make up the Paranapanema basin, you can see the breadth of the area analyzed. It is possible to analyze the land use and economy of the region bathed by the river and served by the aquifers. Another observation is that the aquifer will not obey the area of the river basin, because this is where much more care must be taken because the use of these waters can affect other regions, other river basins. In the state of São Paulo there are three major basins: the Alto Paranapanema, the Médio and the Pontal. In the state of Paraná there is the Tibagi, the Cinzas, Itararé and Paranapanema I and II, plus the Paranapanema III and IV and Pirapó.

How does groundwater behave? This behavior is not properly explained in the basin reports and, just to put the concern into context, data was collected from the federal database, the geological service of Brazil, the CPRM, and from it was collected the number of wells that are granted to each municipality in each basin of CBH Paranapanema. The literature shows that only 30 to 40% of wells are licensed, or rather legalized (Conicelli et al., 2021).

As shown in Table 1, a total of 32 municipalities with licensed wells are listed in the Pontal do Paranapanema Basin.

Table 1. Municipalities in the Pontal do Paranapanema Basin and the number of licensed wells

Municipality	Wells	Municipality	Wells
Alfredo Marcondes	08	Presidente Epitácio	49
Alvares Machado	31	Presidente Prudente	258
Anhumas	04	Presidente Venceslau	51
Caiabú	08	Quatá	28
Caiuá	19	Rancharia	23

Emilianópolis	02	Ribeirão dos Índios	04
Estrela do Norte	05	Rosana	136
Euclides da Cunha	209	Sandovalina	07
Iepê	07	Santo Expedito	57
Indiana	05	Taciba	06
João Ramalho	10	Tarabaí	20
Marabá Paulista	04	Narandiba	20
Martinópolis	28	Piquerobi	10
Mirante do Paranapanema	37	Pirapozinho	45
Nantes	07	Presidente Bernardes	30
TOTAL: 1.185 Wells			

Source: SIAGAS - Consultation carried out by the authors in June 2021

Table 2 shows a total of 33 municipalities with licensed wells in the Middle Paranapanema basin.

Table 2. Municipalities in the middle Paranapanema basin and number of licensed wells

Municipality	Wells	Municipality	Wells
Agudos	56	Ourinhos	48
Assis	64	Palmital	19
Borá	05	Paraguaçu Paulista	45
Cabrália Paulista	12	Piratininga	23
Campos Novos Paulista	05	Pedrinhas Paulista	17
Cândido Mota	37	Platina	03
Canitar	04	Paulistânia	02
Chavantes	08	Ribeirão do Sul	08
Cruzália	15	Salto Grande	04
Duartina	18	Santa Cruz do Rio Pardo	42
Echaporã	10	São Pedro do Turvo	13
Espírito Santo do Turvo	10	Tarumã	42
Fernão	05	Ubirajara	02
Florínia	24	Lucianópolis	04
Ibirarema	08	Letícia	11
Gália	23	Maracaí	50
Oscar Bressane	07		
TOTAL: 664 wells			

Source: SIAGAS - Consultation carried out by the authors in June 2021

There are a total of 42 licensed wells in the Alto Paranapanema basin (Table 3).

Table 3. Municipalities in the Alto Paranapanema Basin and the number of wells licensed

Municipality	Wells	Municipality	Wells
Itabira	07	Cerqueira César	21

Itapeva	16	Pirajuí	21
Taquariaiva	03	Sarutaiá	21
Buri	09	Timburi	04
Campina do Monte Alegre	06	Fartura	01
Itapetininga	110	Tejupá	01
Sarapuí	21	Itatinga	17
Pilar do Sul	14	Pardinho	12
Piedade	13	Bofete	16
Tapiraí	00	Guareí	11
São Miguel Arcanjo	17	Itai	22
Capão Bonito	12	Taquarituba	11
Ribeirão Grande	02	Taguaí	07
Guapiara	05	Barão de Antonina	09
Ribeirão Branco	02	Itaporanga	05
Apiaí	04	Coronel Macedo	04
Nova Campina	04	Riversul	06
Bom Sucesso de Itaboraí	00	Itararé	13
Ipaussu	13	Paranapanema	17
Bernardino de Campos	20	Avaré	91
Manduri	06		
TOTAL: 591 wells			

Source: SIAGAS - Consultation carried out by the authors in June 2021

On the Paraná side of the basin there are three large groupings of municipalities, the Cinzas, Itararé, Paranapanema I and II committees (Table 4); the Tibagi committee (Table 5) and the Paranapanema III and IV and Pirapó committees (Table 6).

Tabela 4. Municipalities in the Cinzas, Itararé and Paranapanema I and II basin and the number of wells licensed

Municipality	Well	Municipality	Wells
Jaguariaíva	22	Sertaneja	18
Arapoti	72	Leópolis	24
São José da Boa Vista	08	Itambaracá	67
Santana do Itararé	11	Jandaia dom Sul	64
Wenceslau Braz	13	Guapirama	20
Ventania	29	Joaquim Távora	17
Curiúva	24	Carlópolis	15
Sapopema	07	Nova Fátima	16
Figueira	10	Cornélio Procópio	50
Ibaiti	44	Santa Amélia	18
Japurá	43	Abatiá	21
Jaboti	15	Santo Antônio da	42

		Platina	
Pinhalão	15	Ribeirão Claro	18
Tomazina	09	Jacarezinho	60
Siqueira Campos	27	Santa Amélia	18
Salto do Itararé	13	Cambara	48
Quatiguá	17	Andirá	33
Conselheiro Mairinck	05	Barra do Jacaré	28
Congoinhas	10	Santa Mariana	22
Ribeirão do Pinhal	17	Bandeirantes	90
TOTAL: 1.103 wells			

Source: SIAGAS - Consultation carried out by the authors in June 2021

There are 18 municipalities in the Tibagi basin group (Table 5).

Table 5. Municipalities in the Tibagi basin and the number of wells licensed

Municipality	Well	Municipality	Wells
Palmeira	109	São Jeronimo da Serra	22
Campo Largo	103	Assaí	100
Ponta Grossa	277	Ibiporã	73
Teixeira Soares	43	Jataizinho	27
Ipiranga	41	Rancho Alegre	23
Tibagi	88	Sertaneja	18
Telêmaco Borba	57	Sertanópolis	40
Ortigueira	60	Primeiro de Maio	51
Tamarana	24	Londrina	733
TOTAL: 1.889 wells			

Source: SIAGAS - Consultation carried out by the authors in June 2021

Finally, there are 44 municipalities in the Paranapanema III and IV and Pirapó basins (Table 6).

Table 6. Municipalities in the Paranapanema III and IV and Pirapó basins and the number of wells licensed

Municipality	Wells	Municipality	Wells
Alvorada do Sul	34	Terra Rica	92
Bela Vista do Paraiso	18	Guairaçá	58
Cambé	151	Diamante do Norte	25
Prado Ferreira	08	Itaúna do Sul	23
Florestópolis	22	Nova Londrina	34
Porecatu	24	Marilena	57
Miraselva	11	Maringá	1.394
Jaguapitã	83	Uniflor	18
Rolândia	176	Alto Paraná	96
Pitangueiras	17	São João do Caiuá	45

Astorga	138	Santo Antônio do Caiuá	37
Munhoz de Melo	43	Jardim Olinda	03
Guaraci	39	Inajá	15
Centenário do Sul	29	Cruzeiro do Sul	60
Lupionópolis	26	Paranapanema	04
Santo Inácio	37	Nova Esperança	128
Cafeara	30	Uniflor	18
Nossa Senhora das Graças	11	Colorado	87
Santa Fé	97	Santa Inês	14
Iguaraçu	56	Itaguajé	21
Ângulo	25	Mandaguaçu	124
Atalaia	30	Presidente Castelo Branco	36
TOTAL: 3.494 wells			

Source: SIAGAS - Consultation carried out by the authors in June 2021

9 Results and discussion

There are 8,906 licensed wells in total (data as of June 2022) in 124 municipalities, an average of 19.5 wells per municipality in São Paulo (with 2,420 wells); and 6,486 wells in 102 municipalities, or 63.5 wells per municipality in the state of Paraná. A small statistical calculation shows us how far we are from monitoring the basin's aquifers. It's hard to believe that any municipality doesn't have licensed wells, but we have two in the state of São Paulo, in the Alto Paranapanema Basin. On the other hand, it is also quite strange that we have less than 10 licensed wells in one municipality. Table 7 shows, by river basin, the percentage of municipalities that have between 1 and 9 wells.

Table 7. Number of municipalities per river basin that have between 1 and 9 wells in their territory

Watershed	Number of municipalities	% in relation to thenumber of wells in the municipality
Pontal do Paranapanema	12	37,5
Médio Paranapanema	13	39,5
Alto Paranapanema	18	42,8
Cinza, Itararé, Paranapanema I e II	5	12,5
Tibagi	1	5,5
Pirapó	2	4,5

Source: Prepared by the authors based on SIAGAS data from June 2021

10 Final considerations

It's hard to believe that 30% of the municipalities on the São Paulo side have less than 10 wells in their territory. Just as it's hard to believe that Londrina, whose population is larger than Maringá's and whose industrial production is stronger, has only 733 licensed wells, while Maringá has 1,394 wells in the Pirapó basin alone.

From observations in the field, it was noted that the wells in Paraná do not have the equipment (hour meter and flow meter) required by the permits, i.e. there are no objective conditions for monitoring them. In the São Paulo wells, this reality is similar.

This hidden nature doesn't allow us to understand the importance of groundwater, but preliminary data reveals the reality. Ignorance leads to misuse and increases the risk of contamination. It is interesting to remember that water is of a category of property different from that private and that public. It belongs to everyone and it is up to the federal and state authorities to manage it, and to the municipal authorities to monitor it (because of health, sanitation, environmental and land use zoning issues, which are the responsibility of the municipality under the 1988 *Federal Constitution*).

This clandestine condition masks the environmental value of groundwater. The exact quantity extracted is unknown and the quality (whether it is maintained or contaminated) is not monitored (Foster et al., 2019; Oviedo and Czeresnia, 2015).

How many cities in the basin are supplied by wells, carry out monitoring and leave their hydraulic knowledge in the open? How many cities have water policies (*Municipal Water Resources Plan*, *Municipal Sanitation Plan* or *Master Plan for Urban Development*) that effectively take into account the supply of the population by wells, either strategically or as a primary source?

Groundwater is closely linked to the quality of sanitation in municipalities. It is important resources for dealing with climate change. It is important for maintaining the ecological balance of various areas in our region. Without groundwater, there would be no rivers, reservoirs or marshy environments.

Groundwater is the largest reservoir for human use, as well as being a strategic source for the future of the region, especially during periods of drought. Therefore, integrated management of the hydrological cycle is necessary. It is therefore necessary to study the three types of reservoirs together, integrated.

Acknowledgments

To CNPq (310.608/2017) and the Araucária Foundation of the State of Paraná, Brazil, for financial support through the CNPq/Araucária Foundation Agreement: 61.0088/06-8 and Araucária Foundation/UEL Agreement: 063/08. Also the Araucária Foundation of the State of Paraná projects 15.880, 19.733 and 25.247.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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