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The effectiveness of exploitable zoning in the Boa Viagem neighborhood, in Recife/PE

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ABSTRACT

This study aimed to analyze the effectiveness of exploitable zoning in the neighborhood of Boa Viagem, city of Recife/ PE. For this, the information present in the three editions of the Hydrogeological Study of the Metropolitan Region of Recife, known as HIDROREC I, II and III, was used as subsidy, as well as the database of groundwater allocation, provided by APAC. From the analyses performed, an improvement in the level of the Cabo aquifer was obtained in Zone A of Boa Viagem, which may be related to compliance with Resolution CRH no. 04/2003. It can also be concluded that this resolution was being complied with in zone B. Thus, the importance of the exploitable zoning map is highlighted as an important tool for promoting groundwater management and conservation.

KEYWORDS: Groundwater. Hydrogeological. Grant.

1 INTRODUTION

The Federal Constitution of 1988, in Article 26, I, treats groundwater as property of the federal units, which are responsible for its management through legal instruments. However, Souza-Pereira and Oliveira (2018) organized in study the laws specifically aimed at groundwater in the Brazilian states and noted that not all states follow, or, follow only in part what is provided in the aforementioned article of the Constitution.

With the objectives of ensuring the availability of water for different uses, aiming at future generations, in January 1997, the Union established the National Water Resources Policy (PNRH), seeking, through this, to potential imbalances between availability and demand (ANA, 2013). PNRH presents tools for management, they are: Water Resources Plan, classification of water bodies, granting of use rights, charging for water use, and information system on water resources (ANA, 2013). Although the PNRH does not exactly mention groundwater, the instruments described have validity for it as well as for surface water (SOUZA-PEREIRA, OLIVEIRA; 2018).

Souza-Fernandes and Oliveira (2018) found that, in Brazil, the 26 states and the Federal District have a State Water Resources Policy (PERH) and articles on aquifers or groundwater are present in them. However, only 14 federal units presented specific legislation for groundwater, which are presented in Table 1.

Table 1- States with specific legislation for groundwater

FEDERATION UNIT	LAW
Alagoas	Law No. 7,094, of September 2, 2009 Decree No. 49,419, of July 18, 2016
Ceará	Decree nº 31.077, of 12 December 2012
Distrito Federal	Decree No. 22.358, of September 03, 2001
Espírito Santo	Law No. 6.295, of July 27, 2000
Goiás	Law No. 13.583, of January 11, 2000 Law No. 16.501, of February 10, 2009
Maranhão	Decree No. 34,847 of May 14, 2019
Mato Grosso	Law No. 9.612, of September 12, 2011
Mato Grosso do Sul	Law No. 3.183, of February 21, 2006
Minas Gerais	Law No. 13.771, of December 11, 2000
Pará	Law No. 6105, of January 14, 1998 Decree No. 3.060, of August 26, 1998
Pernambuco	Ordinary Law No. 11.427, of January 18, 1997 Decree No. 20.423, March 26, 1998
Rio Grande do Sul	Decree No. 42,047, of December 26, 2002 Decree No. 52,035, of November 19, 2014

FEDERATION UNIT	LAW
Santa Catarina	CERH Resolution No. 02, of August 14, 2014 CERH Resolution No. 03, of August 14, 2014
São Paulo	Law No. 6.134, of June 2nd, 1988 Decree No. 32.955, of February 07, 1991

Source: Goiás (2009); Maranhão (2019); Souza-Fernandes; Oliveira (2018); Souza (2020)

In Pernambuco, Law No. 12,984 of December 30, 2005, which revoked Law No. 11,426 of January 17, 1997, implemented the State Water Resources Policy and the Integrated Water Resources Management System (SIGRH), following the principles, guidelines, and instruments propagated by the PNRH (GONÇALVES et al., 2017). Law 11.427, of January 17, 1997, deals with the conservation and protection of underground waters in the state, noting that, as indicated in its art. 2, in cases of risk of exhaustion of the aquifer's capacity, actions such as the establishment of protection areas, restriction of exploited flows and the stipulation of minimum distances between wells can be taken by the Executive Power (PERNAMBUCO, 1997).

Costa et al. (1998) published the Hidrogeological Study of the Metropolitan Region of Recife - HIDROREC Project, currently known as HIDROREC I. Among the project's objectives was to analyze the aquifers' reserves potential, and availability for exploitation of the msame, ascertaining the demand required by the Recife Metropolitan Region's population, and to propose laws for groundwater use and preservation.

In addition, HIDROREC I also proposed an exploitable zoning map of the aquifers of the Metropolitan Region of Recife (Figure 1a), including an area of total restriction to groundwater abstraction, located in the neighborhood of Boa Viagem, having been named as Zone A. The other zones were B, subdivided into B1, B2 and B3 - in which the restrictions are 50 to 100 m^3/day, 70 to 150 m^3/day and 120 to 200 m^3/day, respectively; and zones C and D, which did not require restrictions (COSTA et al., 1998).

At the time, the managing agency for water resources was the Secretary of Water Resources - SRH, which forwarded the suggestion for change to a partial restriction of 24m^3/day in Zone A to the State Council of Water Resources - CRH. The proposal was due to the critical situation faced by surface water sources, which caused severe rationing by the water supply concessionaire. The CRH decided on the theme and approved the maximum flow rate of 30 m^3/day for Zone A; 50m^3/day (residential) and 100m^3/day (commercial) for B1; 70m^3/day (residential) and 150m^3/day (commercial) for B2; 120m^3/day (residential) and 200m^3/day for commercial; and 400m^3; and without restrictions for D (SILVA; MONTEIRO; FRANÇA, 1999).

Still from the study conducted by Silva; Monteiro and France (1999), Zone A had deficit water balance, with difference between inputs and outputs equal to -10.5 x 106 m^3/year. This area already presented the serious consequences of overexploitation, among them, the lowering of the aquifer level by 100 meters, the risk of aquifer exhaustion and the possible flow of capture in the new wells between 600 and 1000l/h, or 14.4m^3/day at 24m^3/day.

In June 2002, the Hydrogeological Study of Recife, Olinda, Camaragibe and Jaboatão dos Guararapes (HIDROREC II), was disclosed as an update of the previous project, with the purpose of reassessing the groundwater balance and produce a new zoning of exploitation of

the region, based on recent data acquired. The update of the study took place through a bidding process carried out by SRH, whose winning company was COSTA Consultoria e Serviços Técnicos e Ambiental Ltda., which thanked the Monitoring and Inspection Committee of the studies in the Secretariat (PERNAMBUCO, 2002).

Unlike its antecedent, HIDROREC II added the location, the explored aquifer and its water level situation in each of the zones that make up the study area. The new zoning has been divided into 6 zones (Figure 1b). Zone A - no wells could be drilled and existing wells should have their flow reduced by half; zone B - maximum grant restriction of 30 m³/day and flow reduced by 30% in previously drilled wells; zone C - maximum grant restriction of 60 m³/day and reduced flow in 15% of existing wells; zone D - 70 m³/day should be the maximum flow to be granted, while the existing wells would not have a reduced flow, depending on the future behavior of the aquifer; zone E - maximum flow rate of 100 m³/day, with no restrictions for wells previously drilled; and zone F - no flow restrictions for wells to be drilled (PERNAMBUCO, 2003).

Pernambuco (2017) presented the Study on the Availability and Vulnerability of Groundwater Resources in the Metropolitan Region of Recife (HIDROREC III), aiming to analyze the availability and vulnerability of groundwater, seeking tools for integrated management.

The updated zoning of exploitable areas subdivided the 14 municipalities of the Metropolitan Region of Recife into 8 zones (Figure 1c), as follows: zone A – where no new wells should be drilled; zone B – Granted flow rates for new wells restricted to 30 m³/day; zone C - 60 m³/day limit for granted flow rates; zone D – 70 m³/day restriction for new well flow; zone D' (overlapping zone D) - no flow restrictions for new or old wells; zone E – the maximum flow rate for new wells is 100 m³/day; zone F - the flow rates for future drillings are conditioned to the well capacity; zone G – new and existing wells have no restrictions (PERNAMBUCO, 2017).

Over the years, since the publication of HIDROREC I to HIDROREC III, the CRH has published resolutions, aiming to establish and update the Exploitable Zoning of the Aquifers of the Metropolitan Region of Recife. Resolution CRH nº 04, of September 12, 2000 (CRH, 2000), approved the first exploitable zoning map, based on HIDROREC I and on the change suggested by SRH, as exposed above. In 2003, Resolution CRH nº 04/2003 (CRH, 2003) was published, which approved the exploitable zoning map proposed by HIDROREC II. Currently, through CRH Resolution No. 01, of March 14, 2019 (CRH, 2019), the Council homologated the Zoning for Exploitation of Aquifers of the Metropolitan Region of Recife, after analyzing the results obtained in HIDROREC III.

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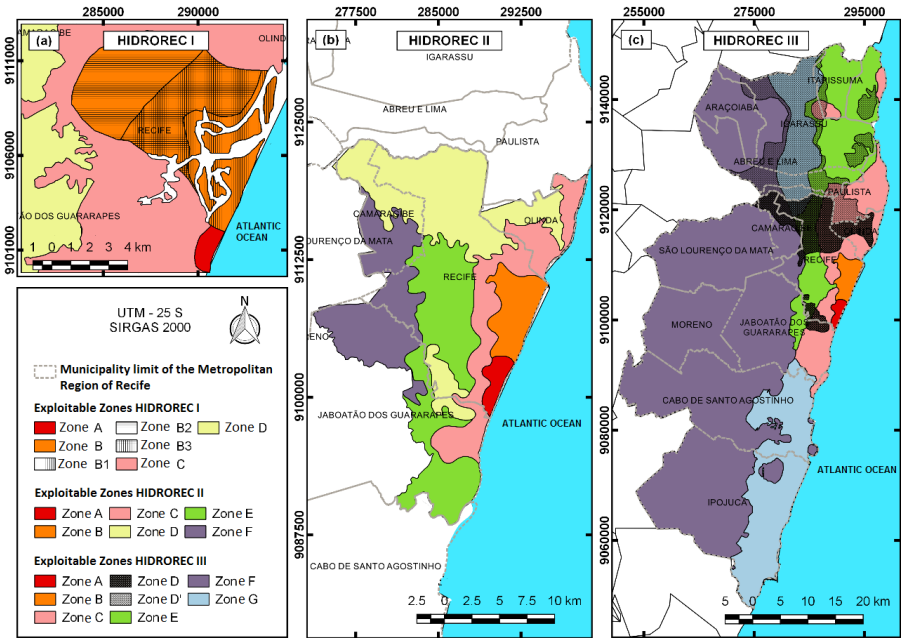
Figure 1 - Map of the exploitable zoning of HIDROREC I (a), HIDROREC II (b) and HIDROREC III (c)



Source: Elaborated by the authors

Also, as an aid to groundwater management in Pernambuco, a Technical Cooperation Agreement was signed between the Geological Service of Brazil (CPRM) and the then Secretariat of Water and Energy Resources (SRHE), contemplating the use of the information database of the Groundwater Information System (SIAGAS). SIAGAS is a groundwater information system developed by CPRM, which gathers a database on wells throughout Brazil (BORBA et al., 2013).

2 OBJECTIVES

The present study aims to analyze the effectiveness of exploitable zoning as a management tool in the neighborhood of Boa Viagem, located in the municipality of Recife, Pernambuco.

3 METODOLOGY

For the development of the present study, the information contained in HIDROREC I, II and III were used, as well as the groundwater grant database provided by the Pernambuco Water Agency (APAC). This database consists of an Excel spreadsheet containing the well records for which the grants were requested and their respective characteristics, such as location, purpose of use and latitude and longitude. The data processing is described below.

3.1 SELECTION OF THE STUDY AREA

The Metropolitan Region of Recife (RMR) is located in a Deltáica Plain, where the sediments have origins Fluvial, Marine, Coluvial, Mangroves, among others, which are able to

cover the Coastal Sedimentary Basins Pernambuco (north) and Cape (south)separated by the structural divisor Lineamento Pernambuco, generating aquifers with specific hydrodynamic characteristics (BORBA et al., 2019). Also according to these authors, the main coastal aquifers developed in the RMR (Boa Viagem, Barreiras, Itamaracá, Beberibe, Algodoais, Cabo and Fissural) contribute efficiently and progressively, mainly since the 1990s, to the water supply to various types of users.

Among the main coastal aquifers of the RMR, the Cabo Aquifer constitutes the main underground water source of the entire coastal region in terms of supplying several condominiums of residential buildings and the hotel network, particularly, between the municipalities of Recife and Jaboatão dos Guararapes, mainly in the neighborhoods of Boa Viagem, Pina, Piedade and Candeias (BORBA et al., 2019).

In order to achieve the objective of this study, an initial analysis of the groundwater grant database was carried out, in which it was found that there were 7,066 records of grant processes throughout the state in the period between 1998 and 2019. For those belonging to the municipality of Recife, the respective neighborhoods were assigned and then organized quantitatively. Thus, the Boa Viagem neighborhood, which is supplied by the Cabo Aquifer, was the one that presented the highest number of records, with a total of 788.

The Boa Viagem neighborhood is an important area for the RMR, since it has a bold infrastructure, including high standard residential buildings, reference hospitals and traditional schools. In addition to the commercial and tourist sectors, which are quite developed in the neighborhood, attracting a lot of customers and tourists. The occupation of Boa Viagem directly affects the water demand, and its contribution is significant. Another relevant aspect is the fact that Zone A is located within its geographical limits and because it is a zone of total restriction on the drilling of new wells, its study is of great importance.

3.2 COORDINATE VERIFICATION

First, the coordinates of the wells located in Boa Viagem were analyzed, resulting in the exclusion of 47 wells that did not present this data. The others, which contained the spatial location information, were georeferenced from the use of geoprocessing technology.

For data manipulation the free software QGis (Version 2.18.22) was used, in UTM coordinates, in the Geocentric Reference System for the Americas (SIRGAS). For the conversion of latitude/longitude coordinates to UTM, the Microsoft Excel software (Version 14.0) was used, adapted with the conversion form developed and made available by the Topographic Laboratory of Pernambuco (LABTOPOPE). Next, a geometry file of the points was generated, which was converted to CSV format for insertion into QGis.

After this procedure, it was observed that some wells presented coordinates that did not belong to the limits of the Boa Viagem neighborhood. Thus, these coordinates were adjusted to the standard of the region. However, even after correction, it was found that 32 wells still remained outside the study area. In addition, it was also found that 09 wells had duplicated coordinates. So that, at the end of the coordinate verification, the data to be used was reduced to 700 wells.

3.3 VERIFICATION OF THE CHARACTERISTICS "STATUS OF THE GRANTING PROCESS", "AQUIFER", "DEPTH" AND "PURPOSE OF USE"

The 700 wells were filtered according to the characteristics "status of the granting process", "aquifer", "depth" and "purpose of use", identifying those that did not present such information and excluding them. After this step, the data sample to be used in the analysis of this study was defined in 484 wells.

Finally, it is worth mentioning the methodology used for the structuring of the spatial database, which consisted in the conversion of the maps into images with JPEG extension and then in the submission of them to a spatial analysis, when inserted in qgis. Therefore, the images were georeferenced from the indication of their coordinates in UTM projection. After this step, the layers were delimited, in Shapefile format, for each exploitable zone, which were defined based on visual photointerpretation. The procedure described was carried out for the exploitable zoning maps of HIDROREC I and II, since HIDROREC III was already available with georeferencing.

4 RESULTS

From the initial analysis, as mentioned above, it was found that the current value of the registration of grant processes in the state of Pernambuco is 28% higher than the 5,500 wells registered in 2012, as described by Assis et al. (2012). However, compared to the 32,315 existing records in the Groundwater Information System (SIAGAS), the value presented in the APAC database corresponds to approximately 22%.

Restricting to Recife, there are currently 2,999 records in the database, which, when compared to the 1,800 existing wells in 1998 (COSTA et al., 1998), represent an increase of 67%. Comparing with the 4,580 wells registered in Recife in 2003, according to HIDROREC II, there is a difference of about 65%. Regarding SIAGAS, the current value is equivalent to 51% of the total presented by the system, which is 5,915 records.

For the Boa Viagem neighborhood, 788 records of grant processes were found in the APAC database, of which, after processing the data, only 484 of them were considered.

4.1 CHARACTERIZATION OF THE SELECTED WELLS

Of the records selected for Boa Viagem, 431 of them are listed as catchment in the Cabo aquifer, corresponding to 89% of the total. This aquifer is overexploited, which may be related to the high number of existing wells, which together are responsible for large water extractions. As stated in HIDROREC III, in the Boa Viagem area, this aquifer presents a minimum piezometric value of -103m (PERNAMBUCO, 2017). In addition, a higher number of wells may imply less control over their construction quality, which, according to Borba et al. (2012)can be considered an influencing factor in the hydrochemical variations that concern the water quality of the Cape aquifer.

In second place, the Boa Viagem aquifer is the most recurrent, appearing in 42 records, or approximately 9%. This aquifer presents a surplus in the balance of inflows and outflows, not being in an overexploitation regime (PERNAMBUCO, 2017). The remaining 2% correspond to records in the Beberibe, Barreiras, “Aluvionar” and “Freático” aquifers.

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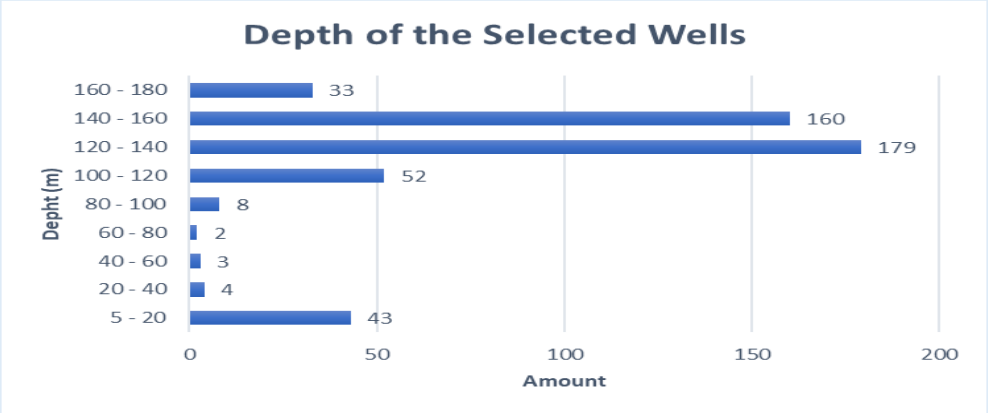
From figure 2, it can be seen that most of the wells are deeper than 100 meters, corroborating the information presented earlier about the large concentration of wells in the Cape aquifer. Also noteworthy are the 43 wells with a maximum depth of 20m, most of which are found in the Boa Viagem aquifer and ratify the information previously presented.

Considering that the Cape aquifer is the one with the highest number of wells, it was obtained that the calculated average depth is about 136m, which resembles the average of 134m presented for the aquifer throughout the Metropolitan Region of Recife (BORBA et al., 2012) and 134.20m for the city of Recife (PERNAMBUCO, 2003).

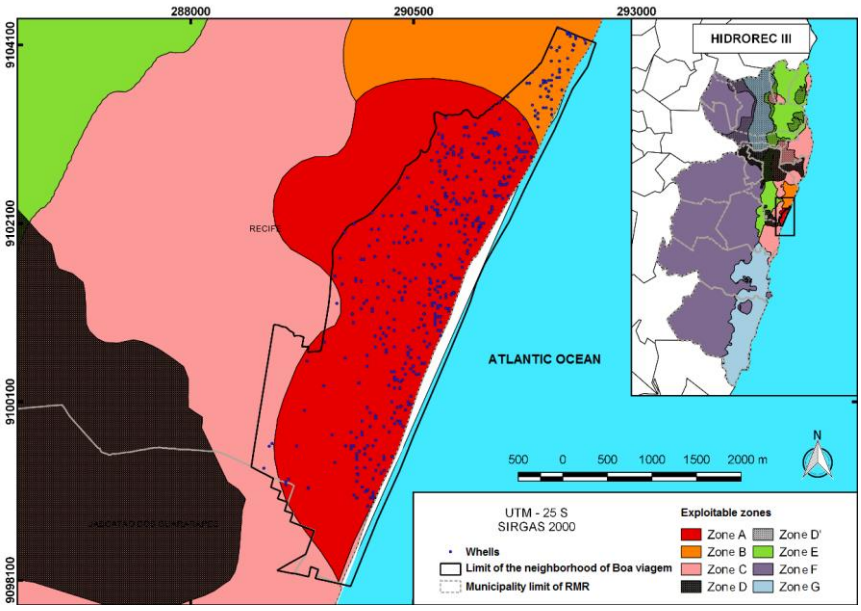
Figure 2 - Depth characterization of selected wells in Boa Viagem



Source: Elaborated by the authors

As for zoning, 425 wells are located in Zone A, which is the most preponderant, corresponding to approximately 88% of the total. Secondly, there is Zone B with 55 wells and finally Zone C with 04 wells. Figure 3 shows the spatial distribution of the selected wells in Boa Viagem.

Figure 3 - Spatial location of selected wells in the neighborhood of Boa Viagem



Source: Elaborated by the authors

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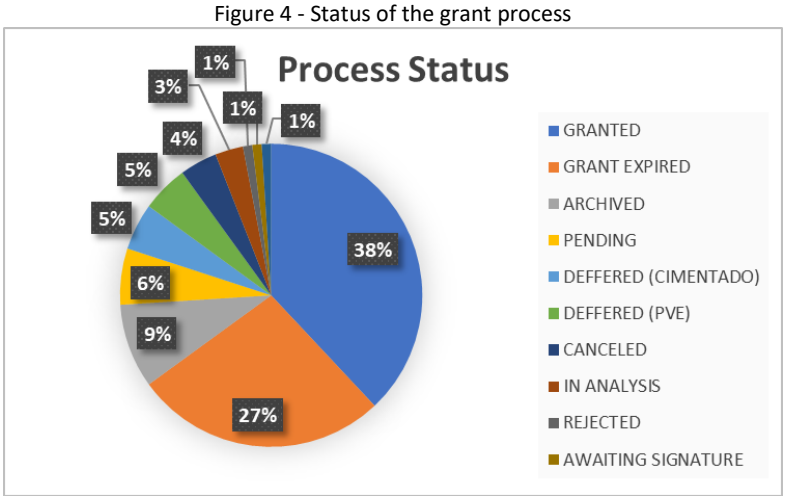
The majority purpose of use for the selected wells in the study area is private residential supply (80%). This is followed by use in commercial establishments (8%) and hotels (6%). The remaining 6% correspond to schools, gas stations, industries, hospitals, restaurants and "others". The residential supply figure as the main purpose of use, from the number of grants, as well as in the study conducted by Silva, Monteiro and France (1999).

Still analyzing this characteristic, from the granted flow data, the total value corresponds to 9,295.69m³/day, of which private residential supply is the largest use (80%), followed by hotel use (8%) and commercial establishments (7%). The remaining 6% comprises schools, hospitals, industries, gas stations and "other". In the study by Silva, Monteiro and França (1999), the main purpose of use from the granted flow was public supply, differing from the result obtained in this work.

4.2 GRANTING OF WELLS IN THE STUDY AREA

According to the APAC database, of the 484 wells selected in Boa Viagem, 38% are listed as granted, that is, they have the current grant. Then, with a value of 27%, there are those who meet the overdue grant (Figure 4). For the latter, it is of fundamental importance to regularize them, not only to comply with legal requirements, but also to contribute to groundwater management.

Figure 4 - Status of the grant process



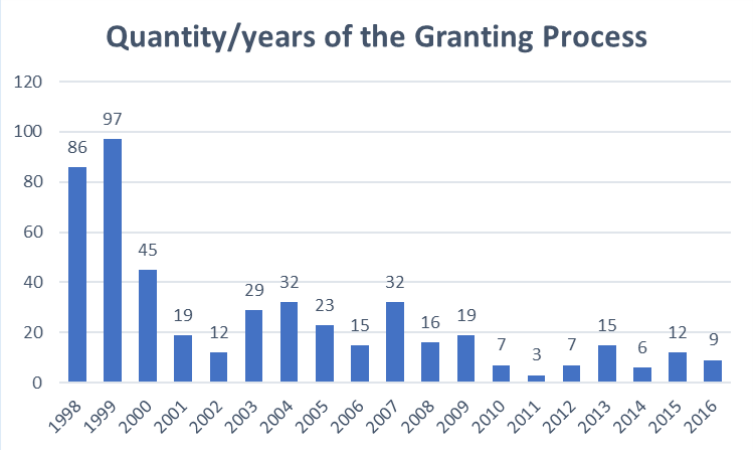
Source: Elaborated by the authors

It can also be observed, from Figure 4, that the processes with archived status are equivalent to 9%, that is, 46 wells. A hypothesis for the new drilling cases is the lack of any documentation required for the request of the Exploration Feasibility Opinion (PVE), which may imply the archiving of the process without notice, as shown in the form "PVE Application - Exploration Feasibility Opinion (Well Drilling)", available on the APAC website.

Figure 5 shows the annual quantities of the grant process records, which can be interpreted as the increase/decrease in demand for regularizing the exploitation of groundwater. In fact, it can be seen that the years 1998 to 2000, as well as the period from

2003 to 2005, present relevant numbers and coincide with the periods of preparation of HIDROREC I and II and publication of Resolutions CRH nº 04/2000 and nº 04 /2003.

Figure 5 - Characterization of grant process records in the period from 1998 to 2016



Source: Elaborated by the authors

4.3 GRANT X EXPLOITABLE ZONING

4.3.1 ZONE A

Zone A represents the area with the greatest restriction on water withdrawal, since the first HIDROREC project, and covers neighborhoods in Recife, such as Boa Viagem, and Jaboatão dos Guararapes, being supplied by water from the Cabo Aquifer. Figure 6 shows a comparison between the areas of the aforementioned zone, so that it is possible to observe the expansion that occurred between the elaboration of HIDROREC I and HIDROREC II.

This advance can be attributed to the droughts that occurred in the 90s, especially in 1998/99, since it was in this period that groundwater became the main source of supply in Recife, especially in Boa Viagem (MONTEIRO; COSTA; FRANÇA, 2001). At the time, the same authors recommended that it was necessary to carry out a new study, which culminated in HIDROREC II, in order to assess the consequences of the drought on groundwater.

As for the comparison between HIDROREC II and HIDROREC III, it was observed that the area corresponding to Zone A was not changed (Figure 6).

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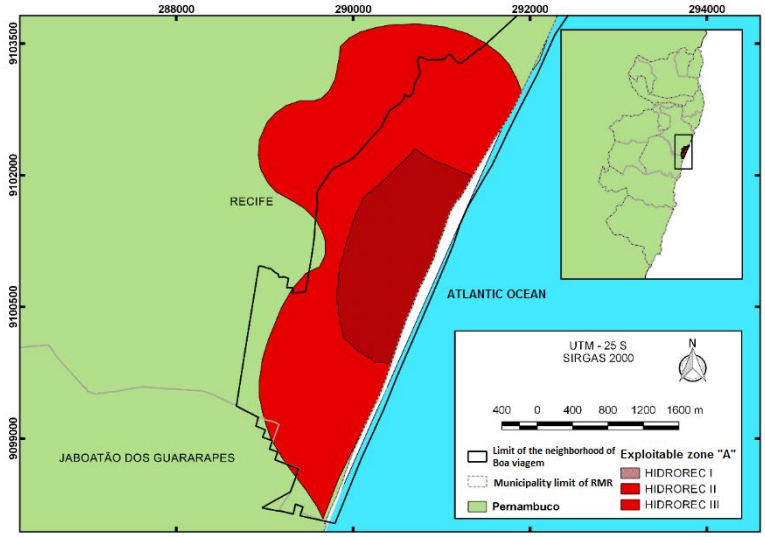
Figura 6 – Comparativo entre as áreas da Zona A, conforme HIDROREC I, II e III.

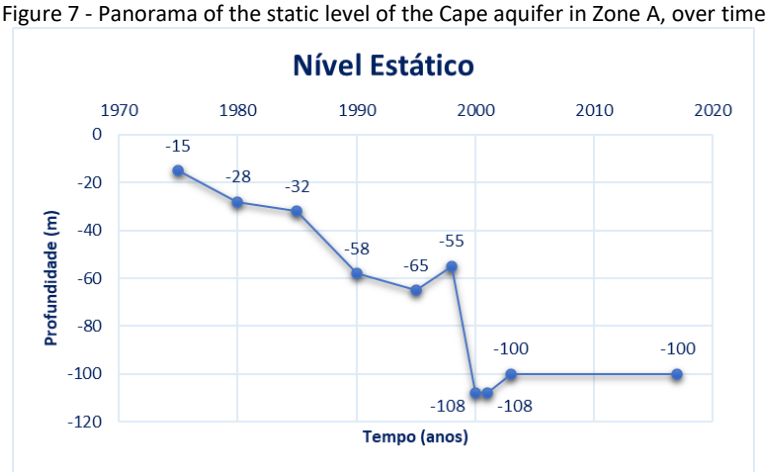


Source: Elaborated by the authors

Figure 7 presents the overview of the static level of the Cape aquifer in Zone A over time, based on information obtained from the literature. In general, it can be observed that, in the period from 1975 to 2000, there was a lowering of the same, reaching the maximum value of -108m. Such decreasing behavior was also observed in HIDROREC II, from data of deep well maintenance performed in the 1990s (PERNAMBUCO, 2003).

The droughts occurred in the 90s, figure as one of the causes of the decrease, due to the increase in the number of drilled wells and large water extractions. According to Monteiro, Costa and France (2001), in the 10-year interval (1990-2000), the wells located in Zone A increased by 329.20%.

Figure 7 - Panorama of the static level of the Cape aquifer in Zone A, over time



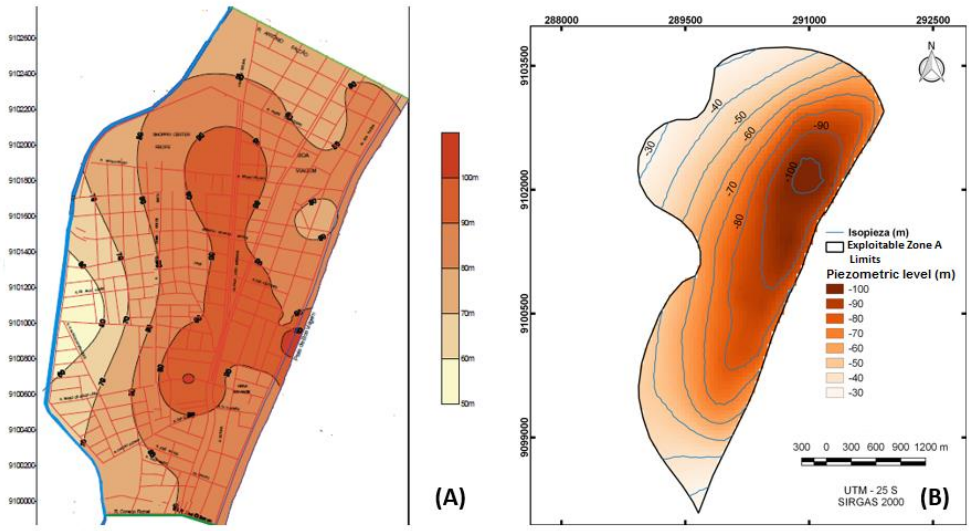
Source: Elaborated by the authors based on Costa et al. (1998); Monteiro; Costa; França (2001); Costa; Costa Filho (2004); Pernambuco (2003); Pernambuco (2017)

From 2003, a trend towards stabilization in the depth of the static level is noted, which maintains -100m in 2017 (Figure 7). It is important to emphasize that, in the same year, there was the approval of the RMR's exploitable zoning map and the establishment of flow and

drilling criteria for new wells, through CRH Resolution 04/2003. Thus, a probable hypothesis for the stabilization verified, is the effective application of the referred normative.

The comparison between the piezometric maps of the Cape aquifer in Zone A at time intervals before and after the referred Resolution has entered into force, endorses the hypothesis raised, since such analysis results in the observation of an increase in the piezometric level. In the situation presented for 2001, the levels vary from -100m to -50m, with most of the area varying between -80m and -90m levels. While in the period from 2013 to 2015, the variation in levels covers a wider range, going from -100m to -30m. In addition, the areas are more distributed with respect to levels, with the greatest depths concentrated near the coast (Figure 8).

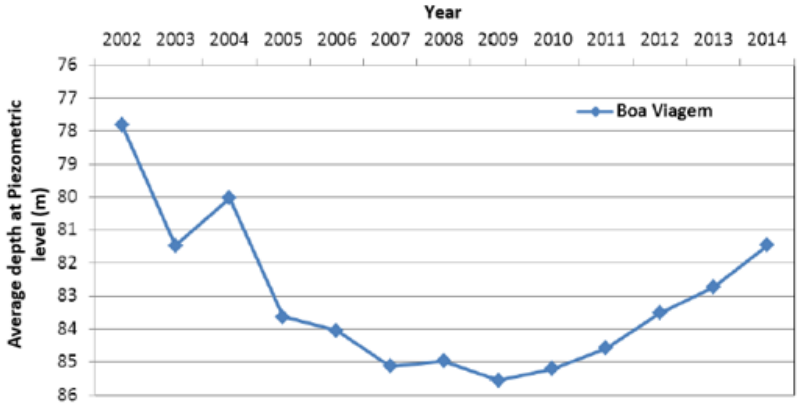
Figure 8 - Piezometric maps of the Cape aquifer in Zone A in the periods 2001 (A) and 2013-2015 (B)



Source: Elaborated by the authors based on Monteiro et al. (2001); Pernambuco (2017)

HIDROREC III also presents the recovery of the piezometric level of Zone A, from 2009, as shown in Figure 9. The graph was based on the depth data of 51 wells located in Boa Viagem, in that zone (PERNAMBUCO, 2017).

Figure 9 - Mean depth at static piezometric well level located in Zone A between 2002 and 2014



Source: Pernambuco (2017)

Pernambuco (2017) cites that this behavior was possibly motivated by three causes: the ban on drilling new wells in Zone A from 2003; the gradual decrease of the values granted to the wells in that area, when the renovations of the grants; and the entry into the public network of water from the Pirapama Reservoir (PERNAMBUCO, 2017). The first two causes are guidelines established in Resolution CRH nº 04/2003, denoting its importance for the observed improvement.

4.3.2 ZONES B E C

According to item 3.1, from the selected data, 55 wells were found in Zone B of Boa Viagem, of which only 18 are granted in the status of the situation of the granting process. Analyzing the same regarding the compliance with the CRH Resolutions, it was found that none of the granted flows was higher than 30m³/s. Although there is no distinction between new and existing wells, the maximum flow limit is being respected, therefore, it can be inferred that the determinations of this regulation are being met.

For Zone C it was not possible to perform the analysis, due to the absence of some information from the database.

5 CONCLUSION

The exploitable zoning map represents an important tool for the application of the groundwater grant instrument and has been improved over the years, from the update of hydrogeological studies developed for the RMR, namely, HIDROREC I, II and III.

From the analysis of the temporal panorama of the static levels of the wells in Zone A, in Boa Viagem, and the comparison of the piezometric maps of the Cape aquifer, in the same area, in periods before and after the beginning of the CRH Resolution 04/2003, improvements were observed in both levels. Such improvements represent an indication of the effectiveness of the regulation, which, by having its criteria for new drilling and flow, can provide favorable results. In zone B, it can be concluded that this resolution is also being respected.

Despite the positive scenario, groundwater management still needs actions that provide greater quantitative and qualitative control over the resource. Filling out all the information requested in the grant registration process database, for example, is characterized as one of these actions. The monitoring of wells is also a strategic action, since it allows monitoring and reevaluating the restriction measures imposed on groundwater abstraction. The inspection of groundwater users is a complementary and fundamental action, since it is not enough to impose restrictions on abstraction through grants, but to ensure compliance with them.

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