ISSN: 2447-3359

REVISTA DE GEOCIÊNCIAS DO NORDESTE

Northeast Geosciences Journal

v. 8, nº 1 (2022)

https://doi.org/10.21680/2447-3359.2022v8n1ID25369

Contribution to the knowledge of the hydraulic behavior of the fissural aquifer in the semiarid region of Brazil

Contribuição ao conhecimento do comportamento hidráulico de um aquífero fissural na região semiárida do brasil

Gisely Maria da Silva[1]; José Geilson Alves Demétrio[2];

[1] Universidade Federal de Pernambuco, Recife/PE, Brasil. Email: giselymaria.silva@gmail.com
ORCID: https://orcid.org/0000-0002-7861-8199
[2] Universidade Federal de Pernambuco, Recife/PE, Brasil. Email: jose.demetrio@ufpe.br
ORCID: https://orcid.org/0000-0002-4908-4888

Abstract: Most fractured aquifers occur in crystalline rocks and are marked by low porosity and low production capacity. The studied area is located in the southeastern portion of the municipality of Passira (PE). This region stood out for presenting wells with flow rates above the expected average for the context of the semiarid region. To raise hypotheses that justify these anomalous flows, field activities were carried out, 62 wells registered and 7 pumping tests performed lasting up to 60 minutes. Information on static water level, flow rate and elétric conductivity was registred. It was observed that the main lithotype of the area is the Metanortositic Complex of Passira (CMAP), which is composed of anortositic rocks with intense fracturing. This fracturing, together with the characteristics of the rock itself, are favorable to the storage and percolation of water. However, most of the wells are currently deactivated or with flow rates below the initial ones. It is suggested that this scenario has changed due to the large exploitation of water, coupled with the large number of new wells drilled and the low recharge rates. Thus, although the rock has good storage characteristics, the heterogeneity of the aquifer lomites its production capacity. Hence monitoring is essential for a better management of the aquifer.

Keywords: Fractured aquifers; Metanorthosite; Anomalous flows.

Resumo: Os aquíferos fraturados, em sua maioria, ocorrem em rochas cristalinas sendo marcados por uma baixa porosidade e baixa capacidade de produção. A área estudada localiza-se na porção sudeste do município de Passira (PE). Esta região destacou-se por apresentar poços com vazões acima da média esperada para o contexto do semiárido. Para levantar hipóteses que justifiquem essas vazões anômalas, foram realizadas atividades de campo, cadastro de 62 poços e 7 ensaios de bombeamento com duração de até 60 minutos. Foram coletadas informações de nível estático, vazão e condutividade elétrica da água. Observou-se que a área está inserida geologicamente no Complexo Metanortosítico de Passira, que é composto por rochas anortosíticas com intenso fraturamento. Esse fraturamento, juntamente com as características da rocha em si são favoráveis ao armazenamento e percolação da água. No entanto, a maior parte dos poços atualmente encontram-se desativados ou com vazões abaixo das iniciais. Sugere-se que esse cenário tenha mudado devido a grande explotação de água, aliada à grande quantidade de novos poços perfurados e à baixa recarga. Assim, embora a rocha apresente boas condições de armazenamento, a heterogeneidade do aquífero leva a limitações na sua capacidade de produção, sendo essencial um monitoramento para a melhor gestão do aquífero.

Palavras-chave: Aquíferos fraturados; Metanortosito; Vazões anômalas.

Received: 27/05/2021; Accepted: 12/07/2021; Published: 31/03/2022.

1. Introduction

The northeastern semi-arid region is characterized by low relative rainfall and, for the most part, the local geology is composed of crystalline rocks. These rocks have low water production capacity and low primary porosity, when compared to porous media, thus, the water in this system is found in its fractures and discontinuities. These discontinuities make this medium heterogeneous and anisotropic. In addition, the scarcity of rain tends to form thin weathering mantle, which together with the predominance of physical weathering, reduces the accumulation of water that recharges the fractures. In the general context, water availability is limited and the hydrogeological system is complex. The average flow rate for the wells in the crystalline region of northeastern Brazil is 3.02 m^3/h, according to a survey carried out by the Geological Survey of Brazil (CPRM) between the late 1990s and 2003 (DEMETRIO *et al.*, 2007). . The area of interest in this study was highlighted in the late 1990s by researchers who observed flows higher than the general average, reaching 20 or 30 m^3/h in several wells. These data were verified in the field by one of the authors of the present work and were not published. Thus, until then, there were no studies to clarify the hydrogeological system of the region. The objective of this work is to understand the context of the aquifer, raising hypotheses that justify these observed flow anomalies.

1.1 Location of the study área

The study area is located in the district of Bengala, municipality of Passira, rural state of Pernambuco. Access from Recife is via the paved highways BR-232, PE-50 and PE-95, with a total distance of approximately 100 km (Figure 1).

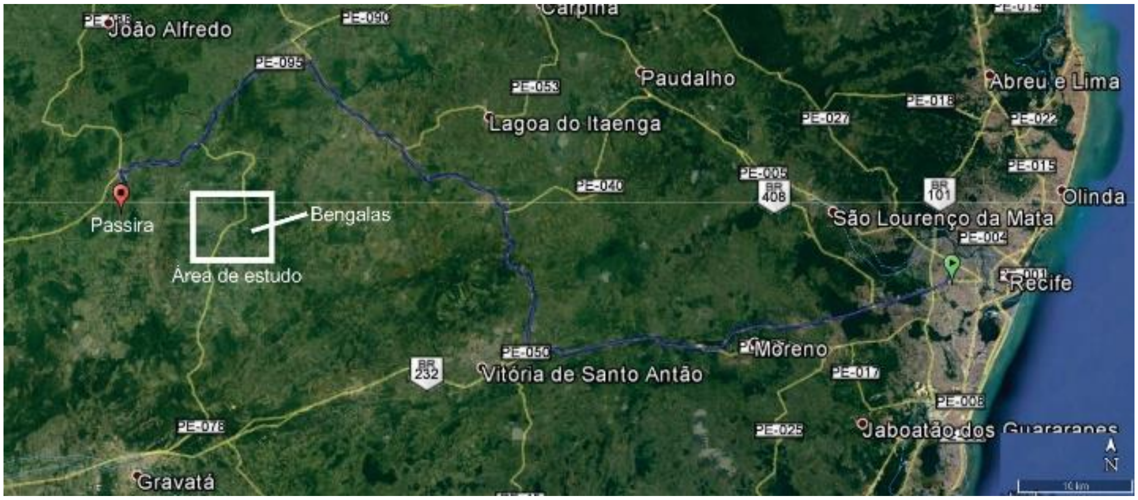

Figure 1 – Access roads to the municipality of Passira (PE), from Recife. The study area is highlighted. Source: Landsat image available in Google Earth software.

1.2 Geological and Hydrogeological Context

The area studied is geologically located in the Central sub-province or Transversal Zone of the Borborema Province (PB) (Figure 2), initially proposed by Almeida *et al.* (1977; 1981). The aquifer is formed by the rocks of the Metanorthositic Complex of Passira (CMAP). Geological studies of this complex began in the 1970s with Sial & Menor (1973), Guimarães (1979) and da Silva Filho (1979), with these works focused on geological description, petrography and occurrences of Fe-Ti-V. In the 1990s, CPRM mapped the area at a scale of 1:100,000 (BARBOSA, 1990; ROCHA, 1990) which are part of the Vitória de Santo Antão and Limoeiro geological maps. Accioly (2000) stands out for describing the CMAP with a geochemical and tectonic approach. The CMAP is mainly composed of massive medium to coarse-grained metanorthosites, with metagabbros, foliated metanorthosites and subordinate metanorthosites also being found. The complex is limited by the Paudalho and Limoeiro shear zones. There are occurrences of granitic orthogneisses interspersed with CMAP. This lithology stands out topographically, presenting itself in the form of ridges with a NE-SW direction varying to N-S. Accioly *op. cit* highlights the plutons of Passira, Bengala, Sipuá and Candeais. There is also a series of dioritic dykes, deformed, oriented, as intercalations in the metanorthosites or embedded in the tonalitic orthogneisses of the basement.

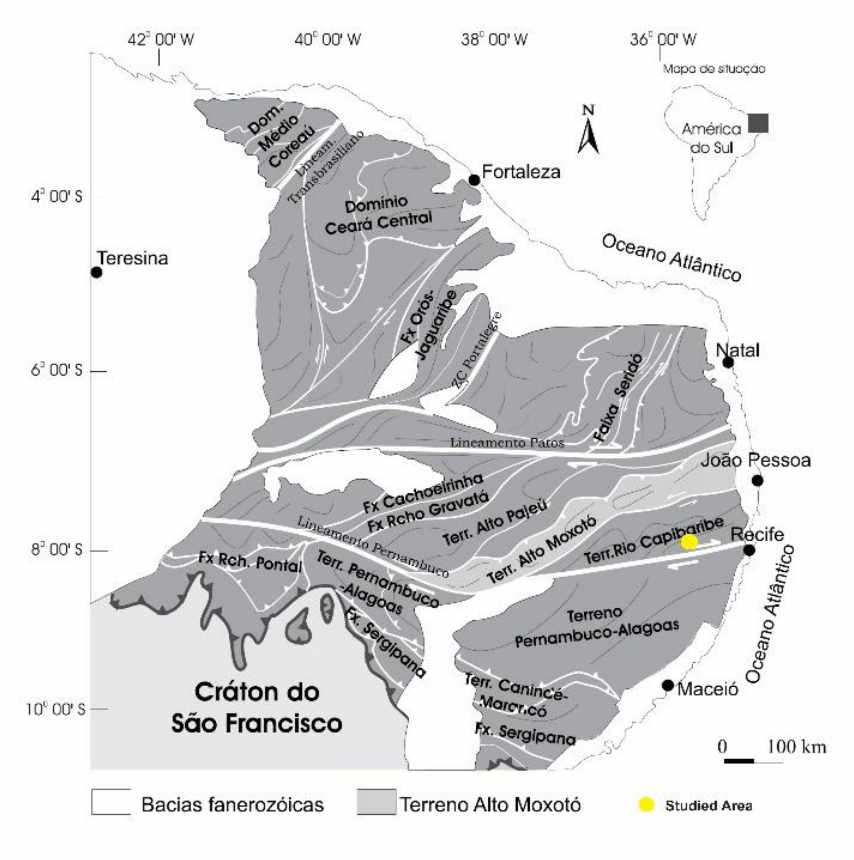

Figure 2 – Tectonic subdivision of Borborema Province and highlighted area studied.
Source: Modified from Santos et. al., 2004.

Within the hydrogeological context, the dominant aquifer system is composed of the CMAP, fractured, free and shallow, ranging from 50 to 60 m. Most of the aquifer is under residual cover of alteration of the rock itself. The underground flow is complex, as it occurs through the fractures network regionally obeying the preferred directions of the rock fissures. In 2005, the Project Registration of Sources of Supply for Underground Water carried out by CPRM registered 123 water points throughout the municipality of Passira, 122 of which were tubular wells and 1 Amazon type well. Of this total, 71 wells were in operation and another 9 wells were discarded (abandoned) because they were dry or clogged. The remaining 42 wells would be paralyzed or not installed for various reasons. In the region there are about 100 wells registered in the Groundwater Information System (SIAGAS/CPRM) until 2019, however, many of these wells no longer exist or are abandoned. On the other hand, there was also an increasing number of new wells that are currently not registered. The most frequent use of water in the region is irrigation, such as corn, beans, peppers, lettuce, coriander, okra and others. In addition, the water is also intended for animal and domestic use (Figure 3). Although the fractured aquifer system does not have a good production capacity, the wells in the region stand out with high flows and thus there is a great demand for drilling more wells, always in a disorderly way.

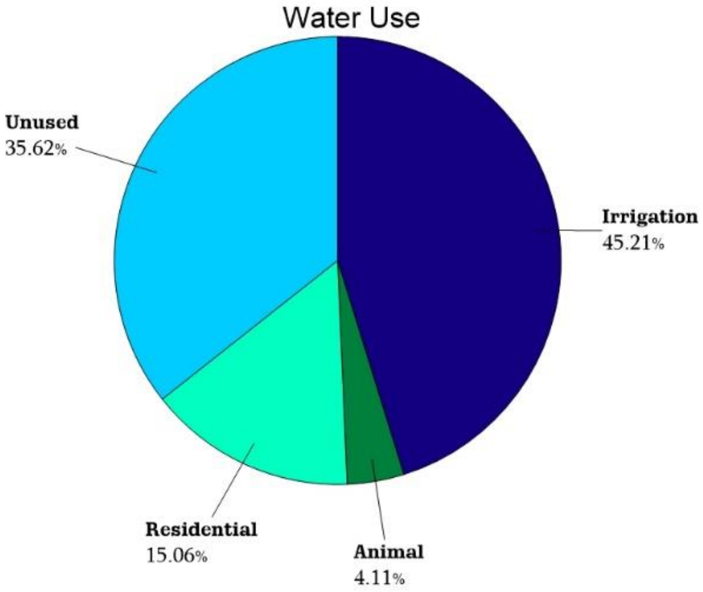

Figure 3 – Distribution of water use in the region according to the registration of wells carried out. Source: From the author, 2021.

2. Methodology

The methodology used in the present work comprised, in addition to the bibliographic research about the studied area, four stages: (i) outcrop studies; (ii) registration of wells; (iii) pumping tests and (iv) data processing and interpretation. A registration of wells was carried out to complement the information about the current condition of the wells. 62 wells were registered in the entire area and, when possible, the Static Water Levels (SWL) or Dynamic Water Levels (DWL) were measured, water samples were collected for field measurements of Electrical Conductivity of water (EC), while for the measurement of flow of the wells (Q) an ultrasonic meter (PORTAFLOW 330) was used, allowing data collection without altering the existing piping. The geological and hydrogeological parameters were gathered in the Arc Gis 10.2 software and for the other interpretations and graph construction, Excel integrated with the grapher 9 graphics software was used.

3. Results and discussion

In the entire studied area, no major lithological variations were observed (Figure 4), with the predominance of CMAP metanorthosites with their compositional changes, sometimes more felsic feldspars, sometimes more mafic minerals. The entire complex is intensely fractured and weathered, with few outcrops and in many cases masked by soils resulting from the weathering of the rock itself. In addition to the CMAP, the presence of migmatized gneisses was observed in the western portion of the area, in a lesser state of weathering. There is also the presence of intercalations of granitic orthogneisses forming higher hills. Morphologically, the CMAP occupies the most devastated areas, while the granitic orthogneisses stand out in the relief.

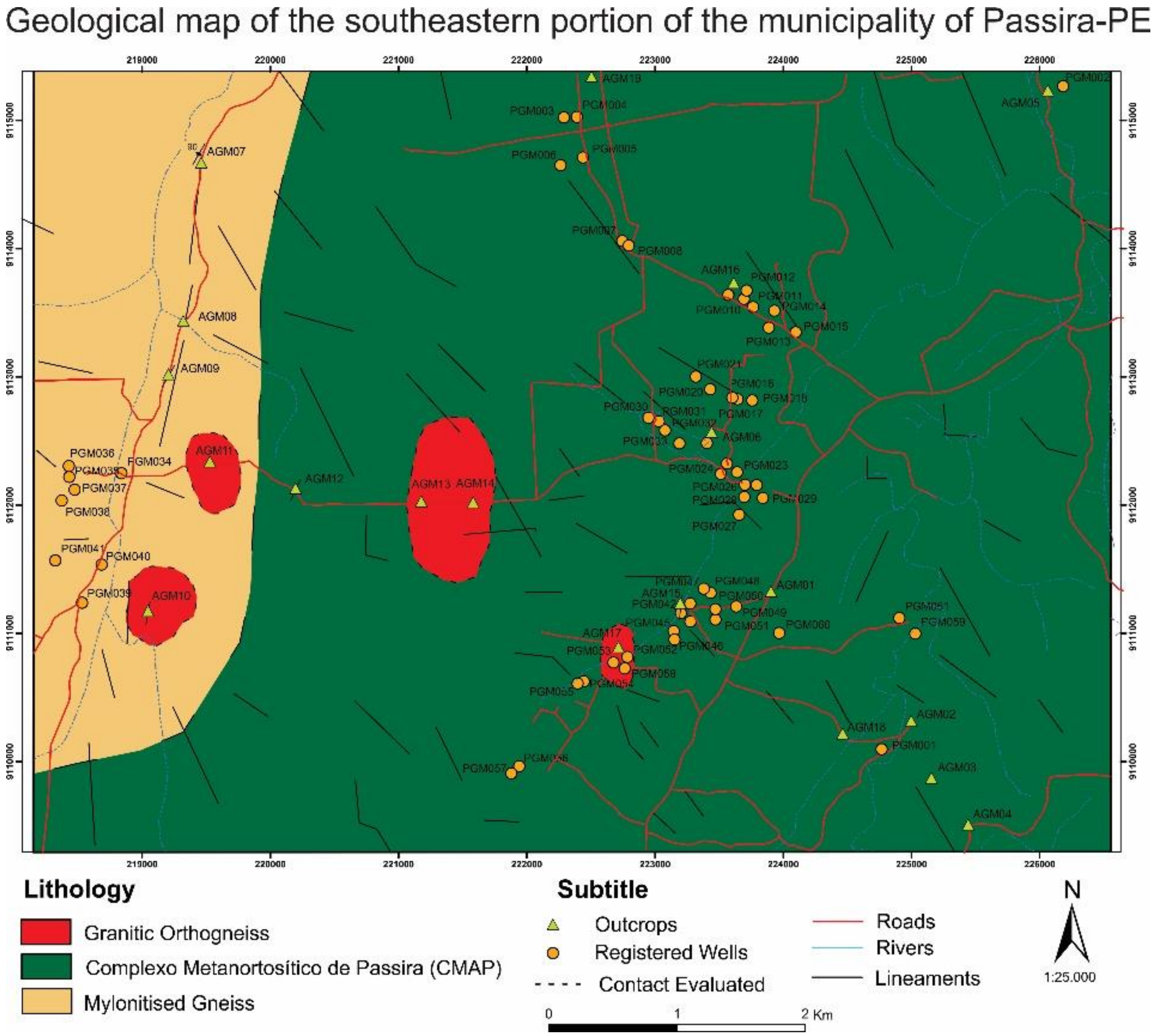

Figure 4 – Geological map of the studied área.
Source: From the author, 2021.

3.1 The Passira Metanorthosite Complex (CMAP)

The CMAP rocks have a massive texture, medium to coarse grain, and their mineralogy is mainly composed of plagioclase, hornblende, biotite and epidote (Figure 5A). Within the CMAP there are compositional variations, some more gabbroic, and the presence of dykes with minerals of more potassium composition (Figure 5B) and NE-SW direction. Amphibole lenses possibly linked to the Fe and Ti mineralization sources described by Guimaraes & Silva Filho (1979) are observed (Figure 5C). These amphibolites are mainly composed of hornblende and biotite. The metanorthosites have sub-horizontal foliation with N-S direction and this banding is composed of plagioclases alternating with mafic minerals forming the main foliation "Sp". Figure 5D shows the two main rock fracture systems (NE-SW and NW-SE), the entire complex is highly fractured.

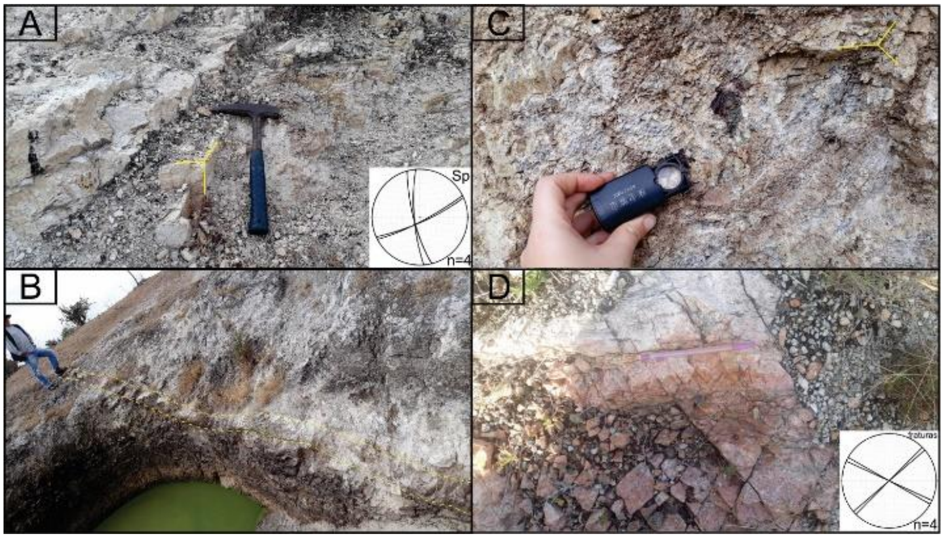

Figure 5 – A) CMAP overview, highlighting the 3 rock breakage planes. B) Dike on CMAP. C) Amphibolic enclave. D) Highlight for the large number of fracture planes in the CMAP.
Source: From the author, 2021.

The existence and amount of water in the underground environment, in crystalline rocks, will depend on the density, opening and connectivity of the fractures. Regionally, the orientation of the main fracture families can be evaluated, however, all other properties such as length, density, connection and opening are punctual and scale dependent. Therefore, the same rock can vary from region to region in several aspects, affecting well flow and water quality. A single fracture may have higher hydraulic conductivity, but the long-term storage and behavior of the aquifer depends on the density of this fracturing, as well as its connectivity. Among the factors that control the groundwater flow in the fissure environment, we have in the CMAP a large number of lineaments with at least two fracture families (Figure 5). All rock is very fractured, which favors the storage and percolation of water. In addition, the weathering mantle present in the area helps in the recharge of the aquifer, although it does not present continuity. When present, this material absorbs precipitation and recharges fractures. Assessing the flow through this unconsolidated mantle is not simple, as this material is not homogeneous both laterally and vertically. The control exerted by lithology, despite being subordinated to tectonics, stands out for being composed of rocks with discontinuity planes, such as the feldspar cleavage planes, which during deformation resists less to rupture, as it is linked to the modulus of elasticity (E) from the rock. Added to this, the foliation of the rock also favors the opening of fractures and, consequently, greater water storage. These physical and textural characteristics influence its shear strength, as all CMAP has a medium to coarse texture, which makes it more brittle compared to fine-textured rocks.

3.2 Local Hydrogeology

Were registered 62 wells in the study area (Figure 6). At each point, information such as geographic coordinates, well owner, year of construction, well depth, operating regime and water use were collected. Whenever possible, SWL, EC and Q were measured. Pumping tests carried out in crystalline terrains serve as a comparison, or rather, an equivalent value and must be interpreted with caution, because in porous aquifers the pumping can last 24 hours or more and use pre-established equations that evaluate the Transmissivity (T), Hydraulic Conductivity (K) and Storage Coefficient (S) of the aquifer, however, these calculations take into account specific boundary conditions of this medium (FEITOSA, 2008). In this equivalent porous medium model, the equation of Theis (1935) was used. Regarding the duration of pumping tests, due to the spatial discontinuity of the aquifer and numerous factors such as the feasibility of pumping for a longer time, tests of up to 60 min were carried out, with the objective of evaluating the behavior of the aquifer during pumping. Seven pumping tests were performed in the following wells: PGM01, PGM09, PGM042, PGM054, PGM057, PGM061 and PGM062.

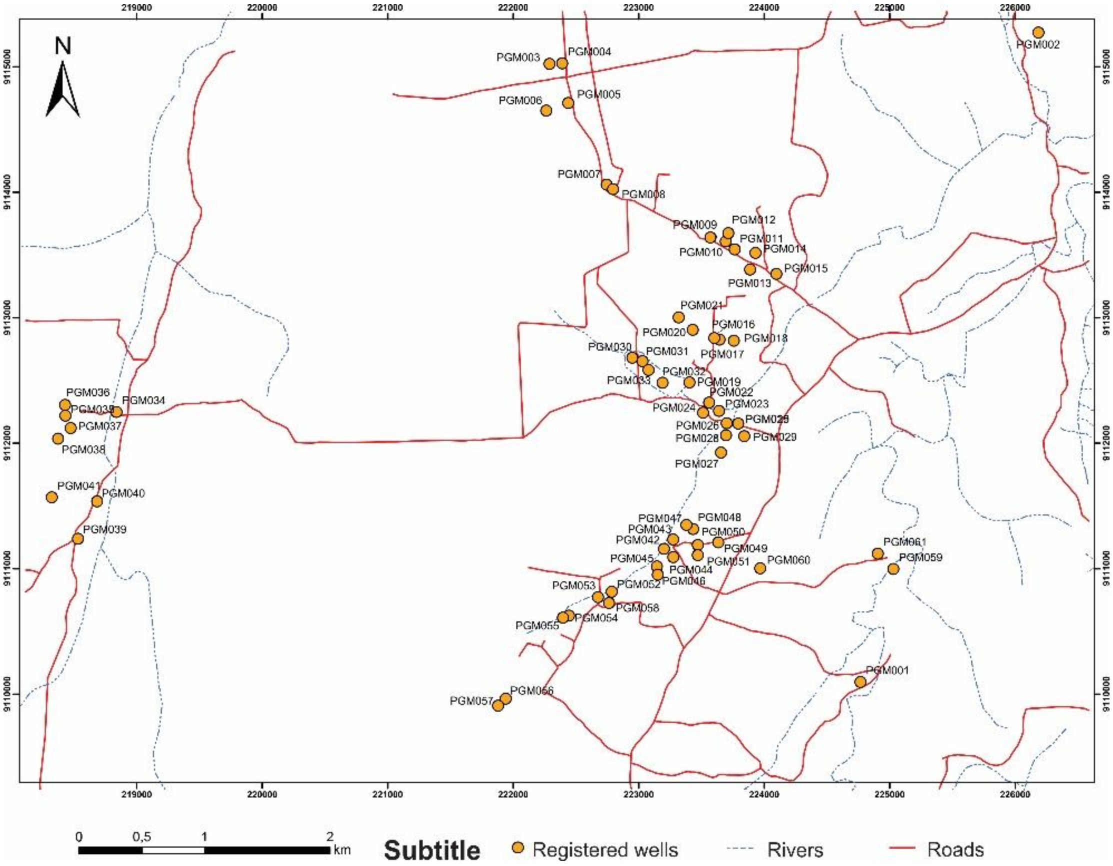

Figure 6 – Map of the study area with all registered wells.
Source: From the author, 2021.

Some wells, as there was no regulation device, showed a drop in flow throughout the test, which is common in fissure aquifers. In cases where the flow is not constant, it can be approached in two ways: one is to observe the recovery in the pumped well, the other is to use the Specific Drawdown (sw/Q), or its inverse, which is the Specific Flow (Q /sw). The results are shown in Table 1.

Table 1 – Calculated Transmissivity Values

Well	**T (s_w/Q) [m²/s]**	**T (recovery) [m²/s]**	**Cooper-Jacob [m²/s]**
PGM01	7,48.10^{-06}	5,21.10^{-06}	-
PGM09	4,75.10^{-05}	-	-
PGM042	6,11.10^{-05}	-	8,08.10^{-05}
PGM054	1,80.10^{-05}	-	1,94.10^{-05}
PGM057	8,11. 10^{-03}	-	9,90. 10^{-03}
PGM061	5,27.10^{-05}	-	-
PGM062	2,02.10^{-03}	-	1,95.10^{-03}

Source: *From the author, 2021.*

The values presented in Table 2 strengthen the understanding of the condition of aquifer heterogeneity. One of the initial hypotheses for the high flows would be that the aquifer would have such a high degree of fracturing that its behavior would approach a porous medium. However, with pumping tests and geology, it was realized how heterogeneous the medium is and this hypothesis was discarded. The T values ranged from 10^{-3} to 10^{-6} (m²/s), these values show how heterogeneous the aquifer is and, although it is possible to delineate the regions with higher transmissivity, this demarcation is not guaranteed, because locally and vertically the distribution of fracture families can change and with that change the productivity of the well at that point. In the case of the PGM042 well, where two pumping tests were carried out, in the first field stage the water level dropped rapidly, the flow dropped by half in less than five minutes, and in six minutes of testing the pumping was stopped, because the DWL has reached the pump limit. About six months later, in the second field stage, the static levels in the region rose and a difference was noticed. This time, the flow remained almost constant and it was possible to perform the test normally. Certainly, the rainy season contributed to the level rise and covered a more fractured stretch that stored a good part of the water (Figure 7).

Table 2 – Average Transmissivity Values of the wells carried out in the pumping tests.

Well	**T (m²/s)**
PGM001	$6{,}34.10^{-06}$
PGM009	$4{,}75.10^{-05}$
PGM042	$7{,}10.10^{-05}$
PGM054	$1{,}87.10^{-05}$
PGM057	$9{,}00.10^{-03}$
PGM061	$5{,}27.10^{-05}$
PGM062	$1{,}98.10^{-03}$

Source: From the author, 2021.

The Figure 7 shows a comparison between the historical average, calculated with data from 1998 to 2018, and the year 2019 for these months. With the exception of the month of May, all the months of 2019 had precipitation greater than the historical average. In drier periods, the level drop causes the most producing fractures to be discovered and the flow drops considerably.

3.3 Flow of the wells

The flow values for the wells in the crystalline are normally low, on average 3 m³/h. The initial motivation for this research was to understand why so many wells in the region had high flows, often more than 20 m³/h. However, when starting the data collection, a different scenario was observed. Many of the wells had dried out or had 50 to 90% reductions in their flows (Table 3). The well registration stage was important to seek information from the owners about the water condition of the place. Many residents reported a similar picture, in which 10 to 20 years ago, wells in the region had higher flows, on the order of 10, 15 or even more than 30 m³/h (Figure 8A). Over time, this picture has changed and there are few wells with high flows today. Flow rates were measured in 18 wells and the result is shown in Figure 8B. It can be seen that there were many wells with flows above 5 m³/h, about 50% of the reported data. Today, with the measured data, we have about 20% of the wells with flow rates above this value.

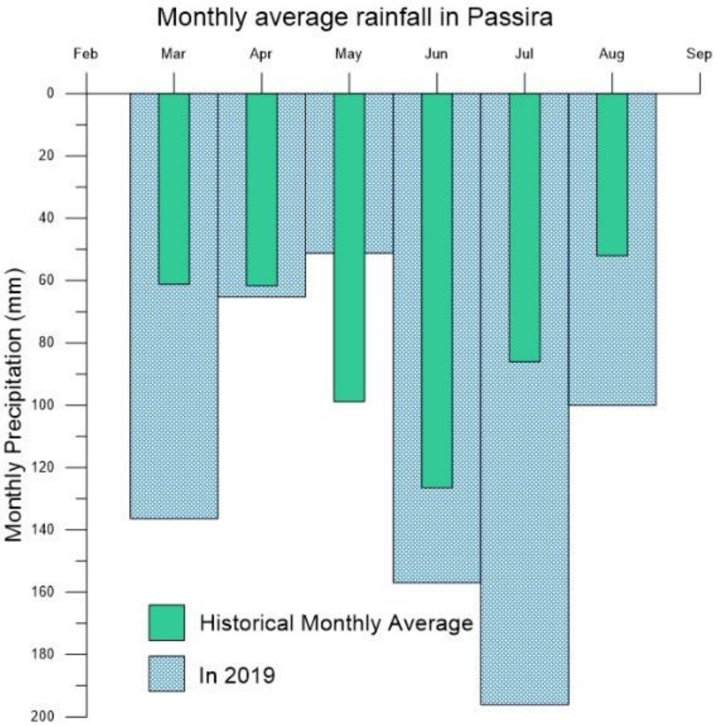

Figure 7 – Comparison between the rainfall from March to August 2019 and the historical monthly average. Source: From the author, 2021.

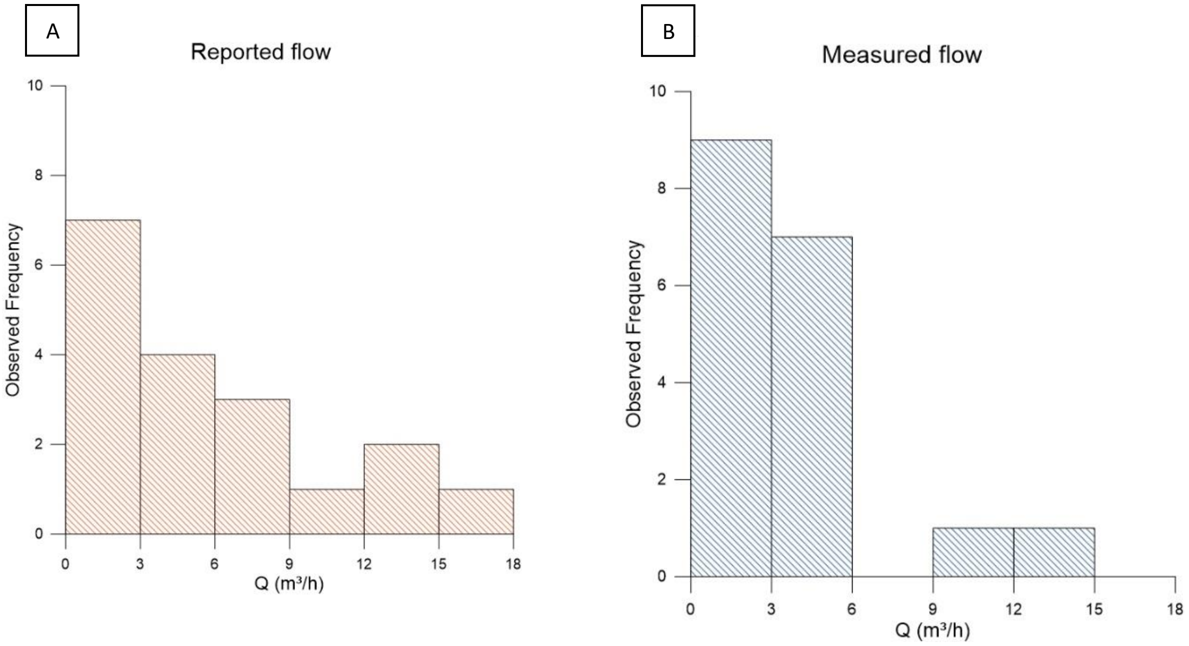

Figure 8 – A) Flow distribution reported by owners for about 10 to 20 years. B) Flows measured in the field currently. Source: From the author, 2021.

The oldest wells, for the most part, had reduced flow. Many clustered wells were built during the data collection, these being for irrigation. These wells had been drilled approximately one month before the registration of wells and good flow rates were obtained (Table 3). Although it was not possible at first to measure the value of these flows, the irrigated area was compatible with high values of declared flows. In the second field stage (March 2019) it was noticed that many of these wells had been deactivated due to low productivity, as some had their flow reduced by 70 to 90%.

Table 3 - Comparison of flow values between August 2018 and March 2019.

Well	**Q_{inf} (m^3/h) Aug/18**	**$Q_{measure}$ (m^3/h) Mar/19**
PGM020	18,000	4,880
PGM021	9,000	0,920
PGM022	6,000	0,786

Source: From the author, 2021.

Thus, it is noted that initially there is a good productivity, probably related to the storage of water in producing fractures not yet exploited, but that with time of use this flow drops because it is a limited reservoir, where there is no spatial continuity. Another factor that contributes to this drop in flow is overexploitation of the aquifer.

The lack of knowledge about the aquifer's production capacity leads well owners to use more water than is feasible for a long-term demand. There are many reports of landowners who use water for agriculture, some even planted crops that require a lot of water, such as bananas, which is not suitable for the place. When wells are drilled and have a good flow, the owners mistakenly decide on a production flow greater than the aquifer's capacity, in this way, many wells dry up. The time it took to reduce the flow over these years depended on the local hydrogeological conditions along with the demand for exploitation of each well.

3.4 Rainfall Monitoring

When starting the research with the registration of the wells, many owners narrate that a long dry period would have been responsible for the drop in the productivity of the wells. When analyzing the data provided by the Agencia Pernambucana de Águas e Climas (APAC), in the period from 1994 to 2019, at the rainfall station of Passira, it is clear that throughout this period there are years when it rains more and drier years, however, in most cases, the volume of rain does not deviate from the general average. The rains in this region are few and poorly distributed, thus, the recharge cannot naturally follow the great exploitation of the wells over the years. Making a simplified estimate of recharge, for the work area, which is 48,000,000 m^2, the precipitated volume would be 31.2 million m^3/year. Considering that the effective recharge is 10% of this value, there is 3.12 million m^3 of recharge for the aquifer per year. In the area, 62 wells were registered, which means that for each well there are 50,322 m^3/year of recharge, or 5.74 m^3/h. This value shows, therefore, that exploitation flows of 10 or 20 m^3/h are not sustainable. It is worth noting that this estimate does not constitute a water balance and not all registered wells are activated, however it is sufficient to demonstrate that aquifer recharge is incompatible with discharges extracted for consecutive years, leading to aquifer exhaustion, or rather, to the captured fracture system. This finding is one of the plausible explanations, for wells that produced flows of 20 m^3/h, or more, today are deactivated due to the drastic decrease in their production flow.

3.5 Monitoring of static levels

Throughout the three field stages, whenever possible, the SWL were measured and the result is shown in Table 4. From the first to the second field stage (August to March) the dry season ended, thus the levels in the wells have mostly dropped. As expected, in September/19 at the end of the rainy season, in most of the wells, in response to the rains, the static water levels rose.

Some showed a higher SWL rise than others. The reasons for this are specific, and may depend both on the characteristics of the environment in each region, that is, on the disposition and number of fractures, and on the dynamics of exploitation of each owner. With more frequent use and greater discharge of some wells, some levels drop faster than others.

Table 4 – SWL measurements of the wells in the three field stages.

Well	SWL (m) Aug/18	SWL (m) Mar/19	SWL (m) Sep/19	Dif** (m)
PGM001	20,663*	20,644	12,535	8,109
PGM013	37,432*	29,975	26,404	3,571
PGM024	36,523*	-	35,227*	-
PGM029	36,09	-	34,412	-
PGM034	5,913	-	4,393	-
PGM040	-	7,265	6,230	1,035
PGM042	-	21,390	16,245	5,145
PGM049	30,715	-	30,268	-
PGM051	24,843	-	24,360	-
PGM054	-	29,552	22,657	6,895
PGM056	17,310	19,1555	17,435*	1,7205
PGM057	16,961	18,662*	16,800*	1,862
PGM058	19,392	-	18,012	-
PGM059	-	22,261	21,315	0,946
PGM061	18,574	-	21,036	-
PGM062	-	17,237	16,403	0,834

** Dynamic Level Values*

*** Difference in levels between March and September/19.*

Source: From the author, 2021.

3.6 Resource Planning or Water Management

One of the biggest difficulties in fissure aquifers is making predictions of drawdowns and a safe long-term exploitation flow. As it is a heterogeneous medium, it is essential to monitor levels, discharges and precipitation over time. With the tests carried out, safe flows were calculated for better planning of discharges. As an example, the specific flow rate (Q/sw) for one year was used from the Q/sw versus time graph for well PGM0009 (Figure 9), extending the data trend to t = 1 year. This value is multiplied by the drawdown available for each well, thus obtaining a safe flow for a given drawdown (Table 5). The drawdown value is not available for all wells, however, in the crystalline, the depth of the main water inlet is considered as the available drawdown, thus, we chose 20 meters, below the SWL, as it is a depth common water inlet. Recommended flow rates, based on pumping tests, are shown in Table 5, except for wells PGM057 and PGM062. These two wells, during pumping, had small drawdowns, which reflects a good fracture system. Thus, the specific flow rates are high, however, as it is a heterogeneous medium, these extremely high flows are not recommended. In addition, to suggest a production flow greater than the test flow, which were 4.7 m^3/h for the PGM057 and 2.5 m^3/h for the PGM062, it is necessary to carry out other tests with higher flow rates and higher pumps capacity. Thus, there would be a closer answer to how the behavior of fractures at those points would be when the flow rates were high. It is important to highlight that although the well has a few meters of drawdown available, the production flow will not be constant along its length, as it is possible that at a certain depth some important producing fractures will be discovered and this will cause oscillations in the well exploration flows. Thus, the importance of monitoring the wells is highlighted, in addition to more detailed studies with vertical mapping of the main producing fractures.

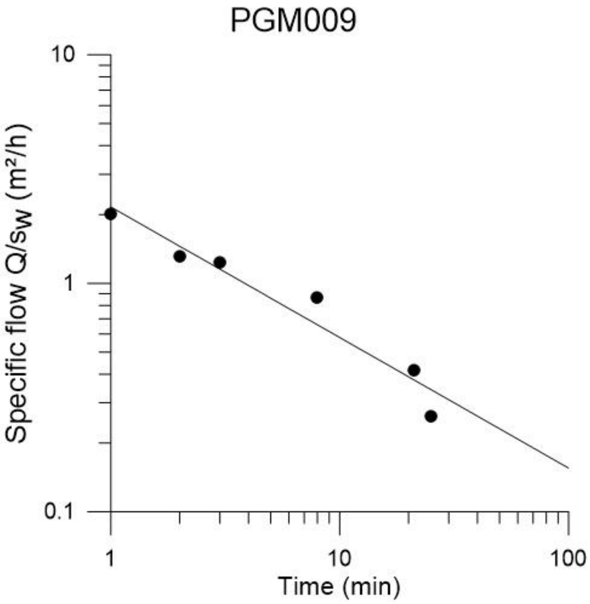

Figure 9 – Example of well PGM009 shows the graph of Specific Flow (Q/sw) with time.
Source: From the author, 2021.

Table 5 – Examples of specific flow for 1 year of pumping and production flow for 20 meters of available drawdown.

Well	Q/s_w for 1 year (m^2/h)	Q for 20 m of available drawdown (m^3/h)
PGM001	0,028	0,563
PGM009	0,001	0,023
PGM042	0,058	1,157
PGM054	0,001	0,018
PGM057	12,863	257,260*
PGM061	0,010	0,197
PGM062	3,339	66,772*

Source: From the author, 2021.

3.7 Electrical conductivity of water

The sum of all chemical constituents dissolved in the water is called Total Dissolved Solids (TDS) and can be estimated from the conversion of the electrical conductivity measurement, the EC value being multiplied by a conversion factor that can vary from 0,54 to 0,96. The conversion factor suggested by Custodio & Llamas (1996) is 0,64, and this was used here. Water samples were collected in 38 wells for EC analysis, the values are shown in Table 6. When possible, measurements were made in the second field stage of these same wells. Figure 10 shows the difference, in percentage, between these measures. Most of the samples had an increase in EC value by up to 20%.

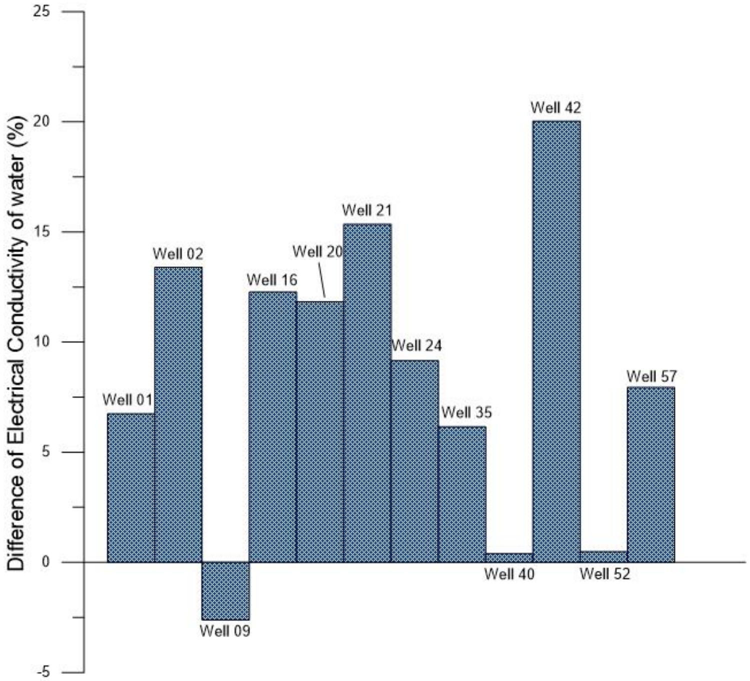

Figure 10 – Difference, in percentage, of the Electrical Conductivity measurements of water between two field stages. Source: From the author, 2021.

Table 6 – EC and TDS measurements of water in the first and second field stages.

Well	**EC (uS/cm) 1ª stage**	**TDS (mg/L)**	**EC (uS/cm) 2ª stage**	**TDS (mg/L)**
PGM01	3232	2068,48	3450	2208,00
PGM02	1821	1165,44	2065	1321,60
PGM05	9988	6392,32		
PGM06	3493	2235,52		
PGM08	1346	861,44		
PGM09	1070	684,80	1042	666,88
PGM013	1329	850,56		
PGM016	970	620,80	1089	696,96
PGM017			1243	795,52
PGM020	980	627,20	1096	701,44
PGM021	964	616,96	1112	711,68
PGM022			3116	1994,24
PGM024	2653	1697,92	2896	1853,44
PGM025	3089	1976,96		
PGM026	3244	2076,16		
PGM030	931	595,84		
PGM031	984	629,76		
PGM034			10560	6758,40
PGM035	5087	3255,68	5400	3456,00
PGM036			4609	2949,76
PGM037	4485	2870,40		
PGM038	4485	2870,40		

PGM039	9410	6022,40		
PGM040	12600	8064,00	12650	8096,00
PGM041	3470	2220,80		
PGM042	5755	3683,20	6908	4421,12
PGM045	5535	3542,40		
PGM047	5200	3328,00		
PGM048	6268	4011,52		
PGM052	5444	3484,16	5470	3500,80
PGM053	5120	3276,80		
PGM054			5170	3308,80
PGM056			6500	4160,00
PGM057	4280	2739,20	4620	2956,80
PGM058	6273	4014,72		
PGM059	4305	2755,20		
PGM061			6304	4034,56
PGM062			2730	1747,20

Source: From the author, 2021.

Many well owners report water salinity values at the beginning of the first wells being drilled as being of good quality. However, the EC measurements collected show that the values currently increased, with 76% of the samples with values above the allowed for human potability (Figure 10). The upper limit of TDS for potability of water for human consumption, according to the Portaria de Consolidação. 2914/11 of the Health Ministry of Brazil, is 1000 mg/L. However, TDS values found above the maximum allowed by the Health Ministry ordinance are tolerated for animal consumption according to Table 7 proposed by McKee & Wolf (1963).

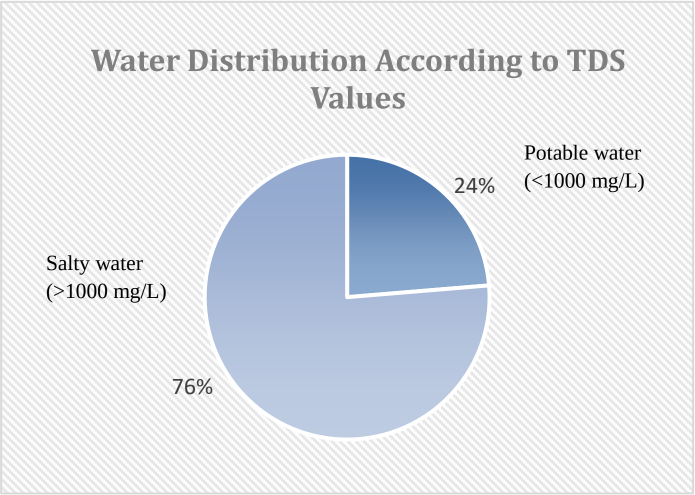

Figure 10 – STD values of registered wells classified according to potability.

Source: From the author, 2021.

Table 7 – Upper limits of TDS for animal consumption, according to McKee & Wolf (1963).

Animal	**TDS (mg/L)**
Poultry	2860
Pigs	4220
Horses	6435
Cattle (dairy)	7180
Cattle (cut)	10000
Sheep and Goats	12900

Source: From the author, 2021.

4. Final Considerations

The study of fissure aquifers constitute a unique work that can hardly be extrapolated to larger regions. The use of small scales implies high uncertainties and should be avoided. Fracture distributions may vary from region to region, however some correlation analyzes between the production data of the wells and the factors that supposedly influence the flow were carried out with the objective of understanding the hydrodynamic behavior of the region, as well as assisting in the exploitations. It was found that the CMAP has characteristics favorable to the storage and percolation of water, such as its texture and fracturing density. Although the rock has elements that are favorable to the accumulation of water, factors such as disordered exploitation and a great densification of wells have led, over the years, to a generalized drop in the productivity of these wells. It was noted that many of them that at the beginning of the explorations had flows above 20 or 30 m³/h do not remain with these flows. Because it is a limited aquifer, although new wells initially drilled have good flows, with excessive discharge they tend to decrease their levels. With the rainfall data in the area, it was inferred that the recharge does not follow the intense exploitation of the wells by the owners, who often see high flows at the beginning of drilling, imagine that this flow will be maintained. Although the amount of rainfall in the region is low, this is not the main reason that led to the drop in levels in the wells. In addition to the few rains, there is a limited reservoir with a large amount of water withdrawal. Pumping tests helped to understand the heterogeneity of the aquifer with equivalent T values (m²/s) in the order of $1.0x10^{-3}$ to $1.0x10^{-6}$ m^2/s. Although these values are not consistent to perform drawdown predictions, specific flow values (Q/sw) were used for a given pumping time, where it was possible to obtain "safe" flow values, in which explorations can start and with proper monitoring to track levels and recharge over the years. Regarding the salinity of the water, the TDS values ranged from 595 mg/L to 8096 mg/L. About 76% of the analyzed samples showed values greater than 1000 mg/L, the recommended limit for human potability (consumption). However, the range tolerated by animals is greater, making it possible to use this water for animal consumption and also for some types of crops, those more resistant to water with higher levels of salts.

References

ACCIOLY, A. C. A., 2000. *Geologia, Geoquímica e Significado Tectônico do Complexo Metanortosítico de Passira-Província Borborema-Nordeste Brasileiro*. PhD. Thesis, Instituto de Geociências, Universidade de São Paulo.

ALMEIDA, F.F.M, et al. Províncias estruturais brasileiras Simpósio de Geologia do Nordeste, 8, Campina Grande, 1977. Atas. Campina Grande (1977), pp. 363-391.

ALMEIDA, F.F.M., Hasui Y., Brito Neves B.B., Fuck R.A. Brazilian structural provinces: an introduction Earth Sci. Rev., 17 (1981), pp. 1-29.

APAC site <http://www.apac.pe.gov.br/meteorologia/monitoramento-pluvio.php>, Accessed in 28 de December 2019.

BARBOSA, A. G - 1990 - Folha Limoeiro - Programa de Levantamentos Geológicos Básicos do Brasil - 1:100.000 - Recife. CPRM/DNPM 124p il.

BRASIL. Ministério da Saúde. Gabinete do Ministro. Portaria nº 2.914, de 12 de dezembro de 2011. Brasília, 2011.

CUSTODIO, E.; LLAMAS, M. Hidrología Subterránea. 2. ed. Barcelona: Omega, 1996.2v.

DEMETRIO, J.G.A., Feitosa, E.C., Saraiva, A. L., Água Aquíferos Fissurais, cap 4, in O Uso Sustentável dos Recursos Hídricos em Regiões Semi-Áridas, org Cirelo, J.A., Cabral, J.J.S.P., Ferreira, J.P.C.L., Oliveira, M.J.P.M., Leitão, T.E., Montenegro, S.M.G.L., Góes, V.C., Editora Universitária da UFPE, 2007.

FEITOSA, E. C; Demetrio, J. G. A. (Coord). Hidrogeologia: conceitos e aplicações. CPRM, LABHID,UFPE. 3ª Edição Revisada e Ampliada. Rio de Janeiro, p:121-151; 2008.

GUIMARÃES, I.P e SILVA FILHO, A.F, Petrologia e Cadastramento das Ocorrências de FE-TI no município de Passira-PE. Atas do IX Simpósio de Geologia do Nordeste, Natal-RN, 1979.

MCKEE, J.C and WOLF, H.W, "Water Quality Criteria", 1963, Second Edition, The Resources Agency of California, State Water Quality Control Board Publication, 3-A, 548p.

ROCHA, D.E.G.A. - 1990 - Projeto Folha Vitória de Santo Antão - PLGB, 1:100.000. Recife - DNPM/CPRM.il.

SANTOS, E., Nutman, A., & Neves, B. (2004). Idades SHRIMP U-Pb do Complexo Sertânia: implicações sobre a evolução tectônica da Zona Transversal, Província Borborema. Geologia USP. Série Científica, 4(1), 1-12.

SIAGAS site < http://siagasweb.cprm.gov.br/layout/>, accessed in December 2019.

SIAL, A.N. & MENOR, E. de A. - 1973 - Eulysite and associated mineralization of iron-titanium, Passira district Pernambuco, Brazil. In: Morim Philipe – Les Roches plutoniques dans leurs rapports avec les gites mineraux. Paris, Massom et Cie, 403p il. (Colloque Scientifique Internacional E. Raguin) p.239.

SILVA FILHO, A.F. da, & Pinho Guimaraes, I. de. (1979). Petrology and mapping of Fe and Ti occurences in Passira country, PE, Brazil. 9 Symposium of Geology in Northeast, Brazil.

THEIS, C. V. 1935. The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage. Trans. Am. Geoph. Union. 16. p. 519-524.