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Anthropic Influences on the Quality of Underground Waters for Human Consumption in Russas, Ceará, Northeastern Brazil

Influências Antrópicas na Qualidade das Águas Subterrâneas para o Consumo Humano em Russas, Ceará, Nordeste do Brasil

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Abstract

In regions with semi-arid characteristics, groundwater is a precious source of water supply, mainly from alluvium, due to the decent quality of its waters. However, the sandy texture favors vulnerability, and the infiltration and percolation of fluids increase the risk of contamination of the aquifer in the presence of polluting sources. The population's knowledge about these problems is still ephemeral, which can lead to the consumption of contaminated water, putting health at risk. Thus, research was conducted in the municipality of Russas – Ceará, to study the quality of groundwater, the possible polluting sources in the urban area, and assess the possible risks to human health. First, technical visits for reconnaissance and survey of information were conducted, such as possible polluting sources and situations of existing wells. The selection of wells to collect water followed criteria of proximity to polluting sources, well conditions, and, mainly, those linked to the use of water for human consumption. The result showed that 43% of the samples are above the limits proved by Brazilian legislation for turbidity, total hardness, TDS, sodium, chloride, and nitrate, while the others are within the standard. Concerning chlorides and nitrates, the concentrations show there is possibly a relationship with anthropic contaminants (agricultural area; domestic effluents) for the aquifer recharge areas and condition common problems to human health. Therefore, it is of paramount importance to continue research in Medical Geology that will enable the monitoring and future management of water quality of groundwater for the population.

Keywords: Contamination; Medical geology; Health

Resumo

Em regiões com características do semiárido, as águas subterrâneas são fontes preciosas de abastecimento hídrico, principalmente, as provindas de aluviões devido à boa qualidade de suas águas. No entanto, a textura arenosa favorece a vulnerabilidade, e a infiltração e a percolação de fluidos aumentam o risco à contaminação do aquífero na presença de fontes poluentes. O conhecimento desses problemas por parte da população ainda é efêmero, e pode levar ao consumo de água contaminada colocando em risco a saúde. Dessa forma, foi realizada uma pesquisa no município de Russas – Ceará a fim de estudar a qualidade da água subterrânea, as possíveis fontes poluentes na zona urbana e avaliar os possíveis riscos para a saúde humana. Primeiramente, foram realizadas visitas técnicas de reconhecimento e levantamentos de informações, a exemplo das possíveis fontes poluentes e situações dos poços existentes. A seleção dos poços para coleta de água seguiu os critérios de proximidade às fontes poluidoras, condições dos poços e em especial, aqueles vinculados ao uso da água para consumo humano. O resultado mostrou que 43% das amostras estão com teores acima dos limites estabelecidos pela legislação brasileira para turbidez, dureza total, STD, sódio, cloreto e nitrato, enquanto as demais encontram-se dentro do padrão. No que diz respeito ao cloreto e nitrato, possivelmente há uma relação com os contaminantes antrópicos (área agrícola; efluentes domésticos) às áreas de recarga do aquífero e condicionam problemas comuns à saúde humana. Sendo assim, é de suma importância a continuidade de pesquisas voltadas a área de Geologia Médica que possibilite futuros monitoramentos e gestão da qualidade da água subterrânea para a população.

Palavras-chave: Contaminação; Geologia médica; Saúde

1 Introduction

The scarcity of rainfall is a problem that requires adaptation of the population to environmental conditions. With the growing demand for water use, especially in regions of climatic vulnerability, such as the Northeast region of Brazil, the implementation of a rational policy for the exploration and use of its water resources is fundamental (Borges 2021). Brazilian semiarid, defined per Ordinance Nº 89 of the Ministry of National Integration of March 16, 2005, covers the state of Ceará, which has 86.8% of its area inserted in the region (IBGE 2019). This scenario highlights the importance of underground water resources, especially when coming from alluvial deposits, where they are the main sources of water exploitation from a hydrogeological point of view, mainly in semi-arid regions with a predominance of crystalline rocks, which usually capture brackish waters (Gomes 2010).

Although underground resources are considered important sources of water supply due to their low susceptibility to pollution when affected by contaminants that alter their physical-chemical parameters, the inversion of the problem can become quite costly and generally unsatisfactory results. The concentrations of substances dissolved in groundwater increase not only due to the percolation in the rocks that make up the aquifer but also due to the interference of anthropic action, especially in urban areas associated with the release of pollutants and the precariousness of basic sanitation services. The main urban effluents come from black cesspools, leachate from cemeteries, poorly constructed dumps, and inadequate domestic sewage. Also included are contaminated surface watercourses, industrial waste, and manufactured products that release heavy metals into the soil and that can be loaded and leached to the saturated zone or discarded, equally, in water mirrors (Nobre 2018).

Proper treatment of groundwater sources is essential to avoid negative interference with human health. Waterborne diseases, whether due to direct contact, drinking water, or indirect contact, the consumption of vegetables and animals present in the same environment, are not always easy to diagnose. Diseases such as cancer, neurological, intestinal, kidney and liver problems are diseases with research related to pollutants in water (Centeno et al. 2013). The lack of maintenance and monitoring of water supply to the population directly affects health, and the precarious infrastructure contributes to people consuming water even without undergoing any type of treatment.

In Medical Geology, one of most significant procedures is assessing and identifying environmental hazards and health risks. This field involves the research on the effects of geological materials and processes on human and ecosystem health, and it includes both natural and anthropogenic sources of possible health issues (Bunnell 2004). Medical geology, as according Hasan (2019, 2021), is the field that studies the impact of anthropogenic and geological influences on human and ecological health. From early 1960s geochemical studies attempting to decipher alleged connections between both the natural geochemical environment and health of occurring in a specific area to the establishment of the International Association for Medical Geology (IMGA) in 2006, medical geology has advanced to the point where it is properly recognized as a discipline (Hasan 2021). However, in Brazil, this issue has only recently become more important in the previous 20 years (Oliveira 2006).

Given the above, the research aims to identify possible contaminating sources of groundwater, assess the quality of water for human consumption, and indicate areas with potential risk to public health in the municipality of Russas, Ceará.

2 Materials and Methods

2.1 Region of Study

The municipality of Russas is in the eastern region of the state of Ceará, 160 km from its capital, Fortaleza, with 1,611.091 km^2. It is in the region of Baixo Jaguaribe, and limited to the municipalities of Quixeré, Limoeiro do Norte, Quixeré, Morada Nova, Palhano, Jaguaruana and Beberibe (RIGeo 1998; IBGE 2020). Access to the municipality can be made, from Fortaleza, by BR-116 with southeast direction (Figure 1).

According to the *Fundação Cearense de Meteorologia e Recursos Hídricos* (FUNCEME) [Cearense foundation for meteorology and water resources] and the *Instituto de Pesquisa e Estratégia Econômica do Ceará* (IPECE) [Cearense institute for research and economic strategy], the regional climate is characterized by average temperatures ranging from 26 to 28ºC and average annual rainfall of 857.7 mm, in which the rainy period occurs from January to April (IPECE 2017).

The municipality includes distinct hydrogeological domains: crystalline rocks, undifferentiated Cenozoic formations, and alluviums. More than half of the municipality is formed by crystalline rocks that represent the fissured aquifer. These aquifers have low water potential due to the minimal permeability, and, in most cases, saline water, therefore, water storage is conditioned by the secondary porosity represented by fractures, which translate into

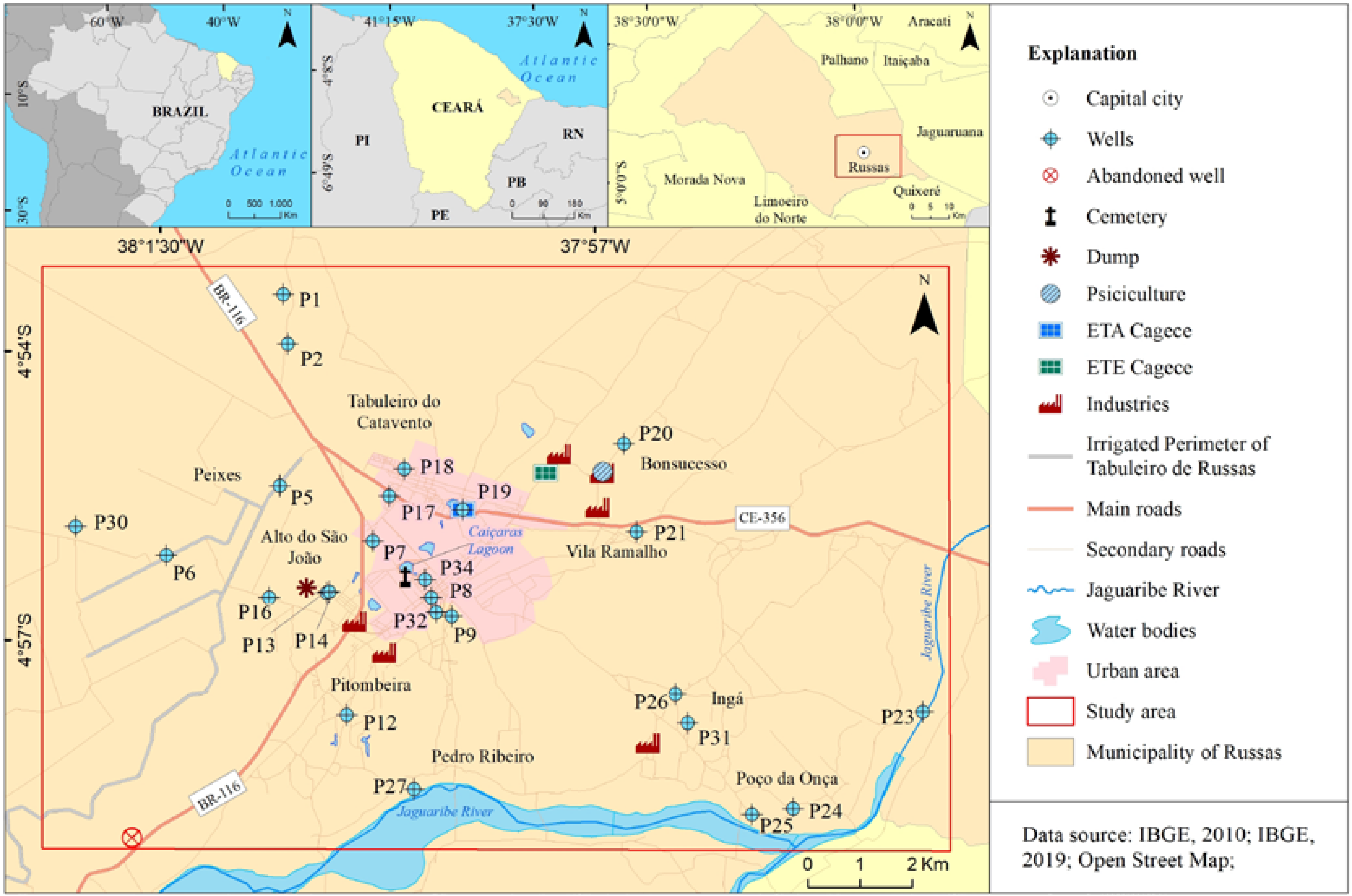

Figure 1 Location of the study area with visited points, Russas-CE.

random, discontinuous, and small reservoirs. extension. However, such conditions do not diminish their importance as an alternative of supply in cases of small communities or as a strategic reserve in prolonged periods of drought (RIGeo 2007; RIGeo 1998).

Cenozoic formations are sedimentary packages that include fractions of sand, silt, clay, gravel (lateritized or not), ferruginous laterites, undifferentiated colluvial, and eluvial sediments. They are characterized by having primary porosity, with high permeability in sandy soils, and are of low thickness and continuity. Although these aquifers have low hydrogeological favorability, depending on the thickness and the sand/clay ratio of these units, significant flows can be produced in the tubular wells (RIGeo 2007; RIGeo 1998).

The alluviums are represented by patches of sands, gravels, and clays with organic matter, which occur along the gutters of the main rivers and streams that drain the region. In general, a low hydrogeological favorability is expected. Along the first order rivers, there are places where they can acquire large possessions, with widths greater than 6 to 8 km and thicknesses greater than forty meters, and where medium to high hydrogeological favorability is expected. The waters are predominantly of good chemical quality. Therefore, aquifers in this domain are a viable alternative as a source, having great relative importance from the hydrogeological point of view, mainly in semi-arid regions with a predominance of crystalline rocks (RIGeo 2007; RIGeo 1998).

2.2 Field Planning

The office's activities consisted of bibliographic research on hydrogeology, economic activities, well profiles, and human health from different sources: Geological Service of Brazil, the *Sistema de Geociências do Serviço Geológico do Brasil* (GeoSGB) [Geosciences system of the geological service of Brazil], IPECE, *Sistema de Informações de Águas Subterrâneas* (SIAGAS) [Groundwater information system] and the United States federal public health agency system – Agency for Toxic Substances and Disease Registry (ATSDR). The information helped to determine the target area utilizing a pre-field map illustrating roads, water bodies, possible polluting sources, and tubular wells cataloged within the municipality of Russas. The field activity was conducted in September 2019. The walk was planned based on the accesses, situation, and usefulness of the recognized wells and mainly on the identification of possible polluting sources identified in the preliminary phase of the study and the field.

2.3 Chemical Water Collection and Analysis

The collecting water samples were determined based on the proximity of the wells to the polluting sources, the conditions of the wells, and the number of people who used the underground source. The samples were placed in properly decontaminated and labeled containers. Then, they were stored in polystyrene boxes with ice until they were taken for analysis.

The physical-chemical parameters (pH, electrical conductivity – EC, larger ions, turbidity, total dissolved solids (TDS), nitrogen, and chloride compounds) were determined at the environmental chemistry laboratory of the *Núcleo de Tecnologia e Qualidade Industrial do Ceará* (NUTEC) [Center for technology and industrial quality of Ceará]. Potability analyzes were performed according to the Standard Methods for Examination of Water and Sewage (APHA 2012).

2.4 Data Analysis and Interpretation

From the acquisition of material collected in the field, integration was performed in a georeferenced database for each collection point and the physical-chemical parameters obtained in the analysis. Then, the information was processed in a GIS environment to produce cartographic products.

3 Results and Discussion

3.1 Characteristics of Visited Wells

The city has a water supply from the *Companhia de Água e Esgoto do Ceará* (CAGECE) [Water and Sanitation Company of Ceará], however, residents report that, eventually, water does not reach the water supply system, especially in areas far from the center, where there are more needy communities. Thus, they choose to use water from dams, cisterns, cisterns, and, mainly, from wells for domestic supply.

Although the community itself does the maintenance of the water tank and desalters, there cannot maintain it because of the excessive costs, which leads residents to consume water without proper treatment and can compromise human health, as in the case of community wells P2 and P14.

The field stages allowed the visit to twenty-seven existing wells in the area, including two dug wells and twenty-five tubular wells. Of the studied wells, 70%

are active, 11% are paralyzed, 8% are disabled, 7% are abandoned and 4% are dry. The functional wells are destined for domestic supply (48%), multiple supplies (11%), and irrigation (11%). There are fourteen wells for human consumption, ten of which have their water used for direct and indirect ingestion (P8, P12, P14, P18, P20, P21, P24, P25, P31, and P32), the other four are for personal hygiene (P2, P17, P23, and P34). Seventy percent of the wells analyzed are deeper than thirty meters, eight are SIAGAS-registered, and only three have lithological profiles.

Two abandoned wells were visited, but other wells were found close to the irrigation channel in this situation. Visiting the Irrigation District of the Perimeter Tabuleiro de Russas (DISTAR), the official informed that, of the wells located around the irrigation channel of the municipality of Russas, only two are in operation, the rest are abandoned, deactivated, or interrupted. This situation occurred due to the low flows produced by the wells and high salinity present in the water. Another factor that may have contributed to the abandonment of the wells is the interruption of the second part of the Irrigation Program of Tabuleiro de Russas, due to the excessive costs of water rationing, which caused the suspension of agricultural activities on the site. Thus, the research was directed to the surroundings of the urban area of the municipality, where the largest number of active wells is concentrated.

3.2 Water Quality Analysis

The result of the well water analysis revealed that 57% of the samples (P8, P12, P18, P21, P23, P24, P25, and P31) meet the criteria established by the legislation. However, 43% of the samples (P2, P14, P17, P20, P32, and P34) had levels above the limits established by the legislation for chlorine, total hardness, nitrates, sodium, TDS, and turbidity, and, therefore, are not suitable. for human consumption.

The results of the analysis of the fourteen groundwater samples are illustrated in Figure 2. The parameters evaluated were based on the potability standards established by Consolidated Ordinance Nº 5, of September 28, 2017, from the Ministry of Health (Ministério da Saúde 2017).

3.2.1. Physicochemical Parameters

Turbidity ranged from 0.1 to 19.5 uT, with only one sample showing a value above the potability standard established by legislation, which is the Maximum Permitted Value (MPV) of 5.0 uT. The high concentration of turbidity in the water of well twenty must probably occur due to poor construction of wells or filters that are poorly sized and/or positioned, allowing the entry of impurities.

The total hardness of 71% of the analyzed samples is within the permitted limit (500 mg L^{-1}) by legislation. The highest value presented is in the water sample of P2 (1403.5 mg L^{-1}). Samples P14, P17, and P 34 showed values slightly above that allowed by the ordinance (591.5 mg L^{-1}, 551.4 mg L^{-1}, and 551.4 mg L^{-1} respectively). Almost all water hardness is caused by calcium and magnesium salts (bicarbonates, sulfates, chlorides, and nitrates) found in the solution. The objection to human use is due to the taste, which can eventually be considered an unpleasant characteristic of extremely hard waters, besides to being responsible for incrustations in pipes (Gomes 2018).

Among the results obtained, electrical conductivity (EC) ranged from 148 to 5,841 μS cm^{-1}, with 43% of the samples showing EC above 1000 μS cm^{-1}, indicating a strong presence of salts; the rest (57%) reveals values between 100 and 1000 μS cm^{-1}. Although the EC does not have a maximum value established in the ordinance, natural waters have conductivity values between 10 to 100 μS cm^{-1}, as they denote TDS concentrations below 60 mg L^{-1}, and in environments polluted by domestic or industrial sewage at values up to 1000 μS cm^{-1} (Gasparotto 2011). Nearly half of the samples collected had an EC greater than 1000 S cm^{-1}, which could indicate anthropogenic contamination.

For the physical parameters of the waters of the analyzed samples, the pH values show the predominance of neutral to slightly alkaline waters that vary from 6.47 to 8.20 to 25ºC and on average is 7.27 and, therefore, are within the standard for human consumption established by legislation.

3.2.2. Total Dissolved Solids (TDS)

The range of values is wide, 83.20 to 3285.30 mg L^{-1}, with a significant increase in the values of the samples observed in wells in the urban area. It is worth mentioning that the waters of wells P8 and P18 located in the urban area, go through desalinizes that reduce the TDS value in the waters. The highest concentrations of salts were identified at points P2, P17, P20, and P24 (3285.30 mg L^{-1}, 1708.90 mg L^{-1}, 1230.90 mg L^{-1}, and 2538.8 mg L^{-1}) that release water considered as imprints for human consumption according to CP Nº 05/2017 (1000 mg L^{-1}).

In 57% of the samples, the waters were classified as fresh water according to the TDS values and following the classification proposed by *Conselho Nacional Do Meio Ambiente* (CONAMA) [National environment council]

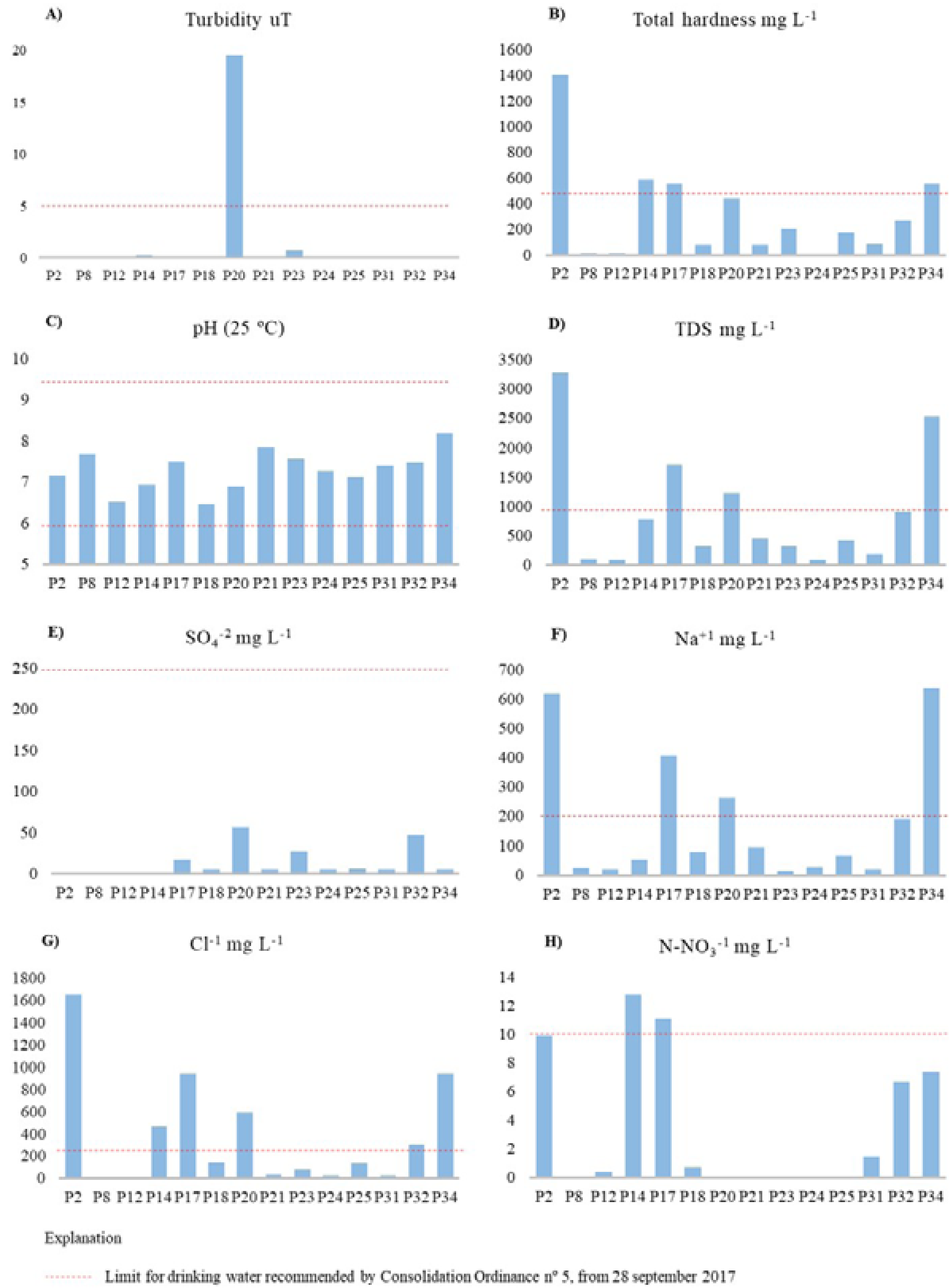

Figure 2 Concentration of analyzed parameters for Russas groundwater: A. turbidity – 5uT; B. Total hardness – 500 mg L^{-1}; C. pH – 6 a 9.5; D. TDS – 1000 mg L^{-1}; E. Sulfate – 250 mg L^{-1}; F. Sodium – 200 mg L^{-1}; G. Chloride – 250 mg L^{-1}; H. Nitrogen nitrate – 10 mg L^{-1}.

Resolution 357/2005 (Brasil 2005). Freshwater may be related to the fact that the wells are shallow, and, therefore, capture water from the alluvium (P12, P23, P25, P31) or have passed through a desalter (P8, P12, P18, P24). P21 is a deep well whose water does not pass through a desalter, where it was found that the TDS content is relatively high. Samples P14, P20, and P32 are brackish water, while P2, P17, and P34 are saltwater.

The entry of solids into the water can occur naturally (erosive processes, organisms, and organic debris) or anthropogenic (dumping of waste and sewage). In natural waters, dissolved solids are composed mainly of carbonates, bicarbonates, chloride, sulfates, phosphates, calcium, magnesium, and potassium nitrates (Gasparotto 2011).

3.2.3. Sulfates

The sulfate levels of the collected waters are within the potability standard (250 mg L^{-1}) established by PC nº 05/2017 and can be consumed. The values of the ten samples identified ranged from 5.00 to 56.40 mg L^{-1}. Mineral dissolution and air deposition are two sources of sulphate in groundwater. Gypsum is an important contributor to the high sulfate levels in many of the world's aquifers and they can have anthropic origins such as mining, fertilizers, among others (Sharma 2020). Rocks containing gypsum or other sulfated minerals are uncommon in the research area, owing to the low concentration of sulfur.

3.2.4. Sodium

The sodium content shows that 28.6% of the analyzed groundwater samples are outside the permitted limit (200 mg L^{-1}) by the legislation, it was observed that the water sample P34 had the highest result (637.30 mg L^{-1}), while the water sample P23 had the lowest result (14.60 mg L^{-1}). The high sodium content of the water suggests that it originated through the dissolution of silicate minerals such potassium feldspar, which are found in the crystalline rocks which constitute the Jaguaretama Complex in the municipality (RIGeo 2017; Mostafa et al. 2017).

Although it is a crucial element essential to human health when ingested at elevated levels and for prolonged periods it can develop health problems. Besides, concentrations greater than 200 mg L^{-1} affect the taste, making it unpleasant to consume. It is not possible to draw explicit conclusions about the possible association between sodium in drinking water and the occurrence of hypertension (WHO 2017).

3.2.5. Chloride

The chloride in the area appears in 43% of the samples with levels above the MPV (250 mg L^{-1}) in the ordinance for human consumption. The spatial distribution of the samples reveals that the chloride content gradually decreases from west to east (Figure 3).

The presence of chlorides from rocks, evaporation, intrusion of seawater, connate and juvenile water, or pollution by industrial waste or residential sewage all contribute to the concentration of chloride (Cl-) in groundwater (Saha, Reza, & Roy 2019). As its municipality is situated far from shore, none interaction between seawater and groundwater occurs. In Tabuleiro de Russas, in the westernmost portion of the research region, perhaps there is a link among chloride contamination and intensive agricultural activities in addition to the rocks. The P2 illustrates the situation as it is close to the cultivation areas, and the water sample showed the highest result (1652.50 mg L^{-1}). The anthropogenic source of chlorides in groundwater is fertilizers made with potassium or mining salts. Potassium chloride is the salt most used in potassium fertilizers, and potassium is one of three essential nutrients, along with nitrogen and phosphorus that are added to increase soil fertility in farms, home gardens, and lawns (Hunt 2012).

The urban perimeter of Russas presents potential sources of contamination, such as domestic effluents, gas stations, the Caiçaras lagoon that receives effluents from septic tanks, and the cemetery that may explain the presence of chlorine in the samples. P14, P17, P32, and P34 are in the urban area and their water samples showed values, respectively (467.70 mg L^{-1}, 946.40 mg L^{-1}, 305.50 mg L^{-1}, and 946.40 mg L^{-1}).

High concentrations of chlorides can restrict the use of water due to the taste they transmit and the laxative effect they can cause (Valente 2013).

3.2.6. Nitrate

Regarding nitrate, 14% of the samples are above the limit allowed by legislation (10 mg L^{-1} $N\text{-}NO_3$), the highest value is present in sample P14 (12.80 mg L^{-1}). Nitrate is commonly detected in various surfaces and groundwater, such as shallow and rural domestic wells. Considering the geology of the area present in the study area, the nitrate concentration values, its origin will be of an anthropogenic and non-geogenic character. Contamination of water systems is a consequence of the use of inorganic fertilizers, animal manure, septic systems and landfill leachate, wastewater

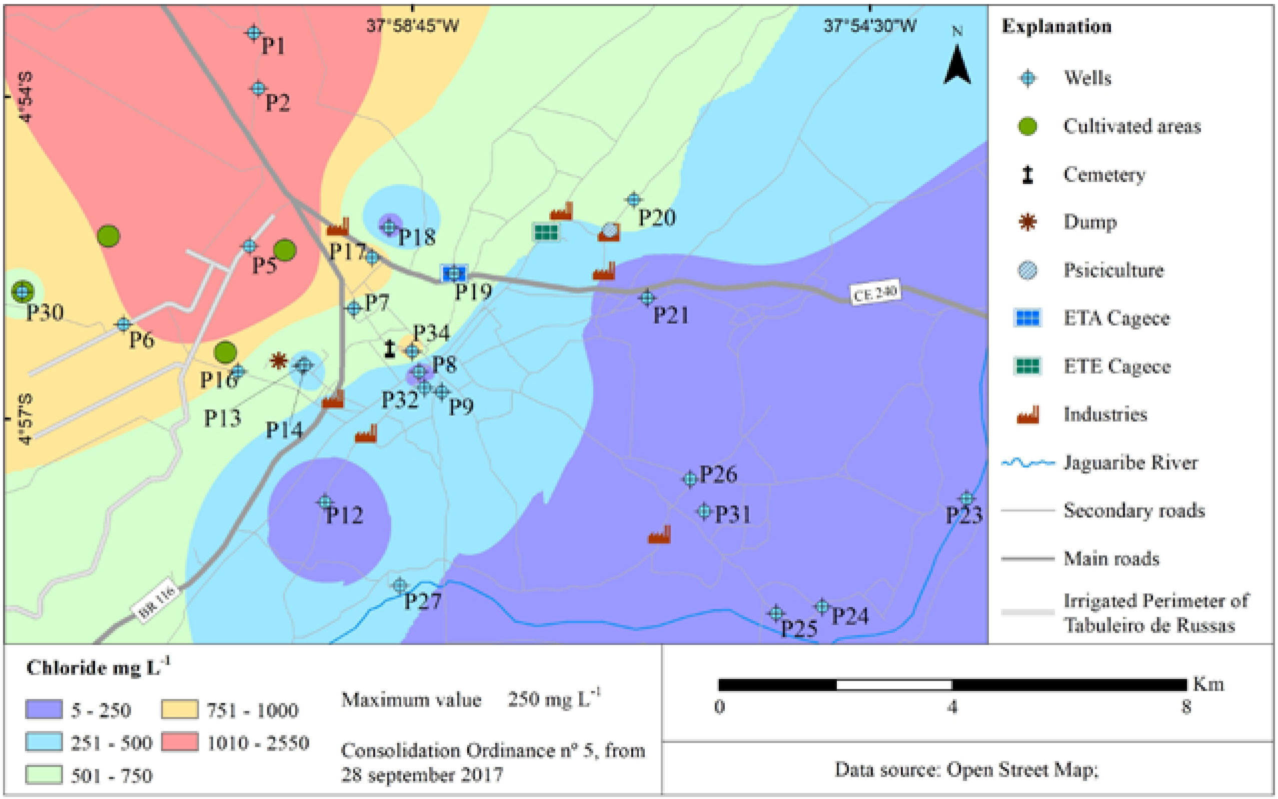

Figure 3 Map of the spatial distribution of chloride in the area.

treatment, overflow of storm sewage, and contributions of human waste should also be considered. Nitrate and inorganic nitrite in soil and water can be absorbed by plants used for human consumption (ATSDR 2017).

The nitrate in the samples shows a more punctual pattern on the map, which most likely indicates the impact of human activities (Figure 4). The basic sanitation service in the Alto do São João neighborhood (P14) is substandard, with domestic sewage being handled improperly of. In addition, the city dump is barely over 400 meters from the settlement and can contaminate local groundwater with pathogenic microorganisms and inorganic compounds like nitrate via infiltration of black pits, waste leachate, and animal excrement. The well at point seventeen serves as a source of water for the structure as well as a place to wash corpses.

Nitrate converts to nitrite in the human body, which can react with hemoglobin, preventing it from transporting oxygen to the body's cells. Oxygen deficiency leads to permanent neurological damage, difficulty in breathing (methemoglobinemia or "*blue baby syndrome*"), and, in more severe cases, death from asphyxiation. Besides, nitrite is a smooth muscle relaxant that can cause hypotension, rapid pulse, and rapid breathing at sufficiently high concentrations. Recent studies allow associations between nitrate in drinking water and/or in food sources and the development of thyroid and type 1 diabetes (ATSDR 2017).

3.2.7. Bicarbonate, Potassium, Calcium, and Magnesium

The bicarbonate, potassium, calcium, and magnesium ions do not have an MPV established by law. The bicarbonate values of the samples analyzed vary between 34.10 and 542.80 mg L^{-1}; potassium ranged from 0.50 to 24.10 mg L^{-1}; calcium ranged from 0.80 to 232.60 mg L^{-1} and magnesium from 4.7 to 75 mg L^{-1}, both in the northern portion of the area.

According to Stein (2012), bicarbonate in groundwater has a moderate concentration due to the balancing effect of the carbonate ion, which can reach high concentrations in the presence of excessive levels of carbon dioxide dissolved in the water when calcium and magnesium levels are low. This proportion is followed by

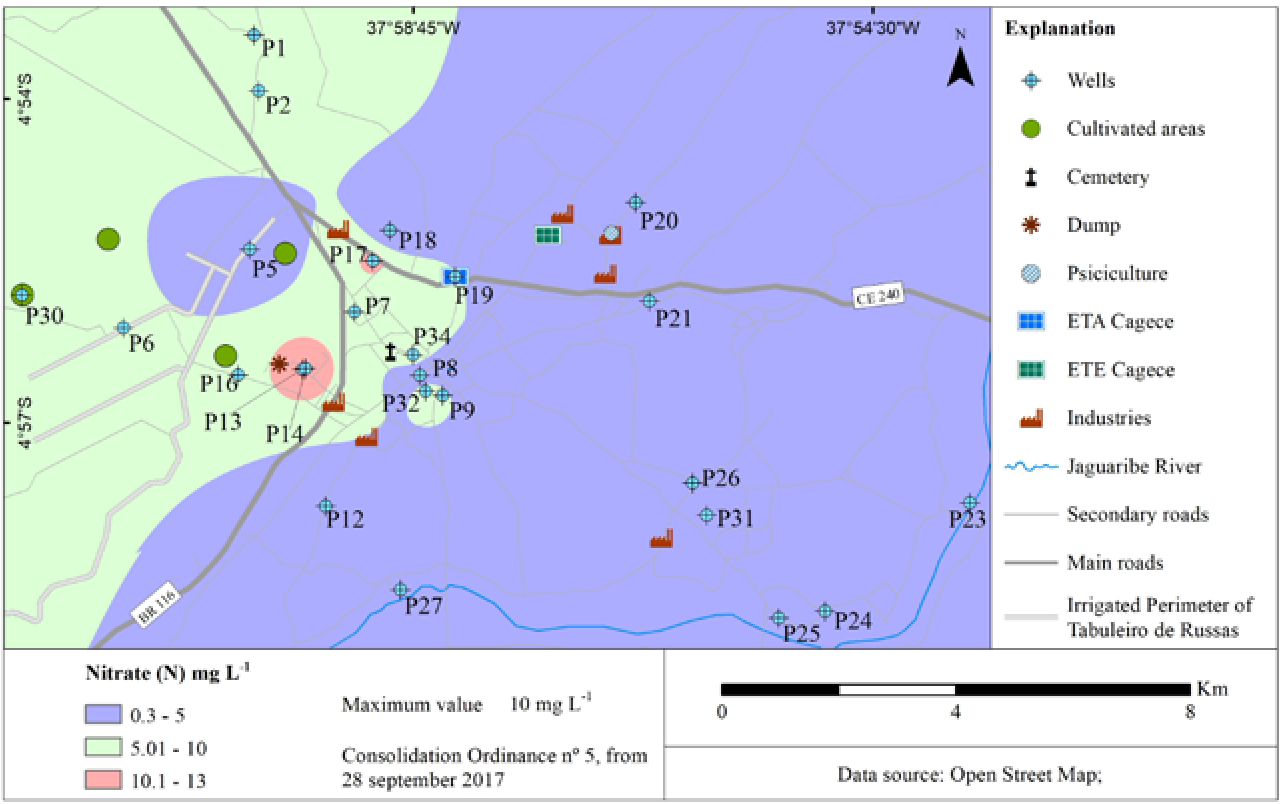

Figure 4 Map of the spatial distribution of nitrate in the area.

86 percent of the samples examined. Potassium is naturally present in clay minerals in greater proportions than in igneous rocks, as evidenced by water well fourteen, whose lithological profile shows capture in the crystalline aquifer and presented 2.0 mg L^{-1} of potassium, compared to point 32, which captures water from clayey material and presented 7.30 mg L^{-1} of potassium. Fertilizers and the decomposition of animal products or waste can be used to add potassium to groundwater (Saha, Reza, & Roy 2019).

The increased calcium concentration in groundwaters could be attributed to the dissolution of plagioclase feldspars. (Ganyaglo et al. 2010). Furthermore, it can be found in agricultural fertilizers like lime (Saha, Reza, & Roy 2019). Migmatites and granites with uncommon calcissilicates comprise the majority of crystalline rocks in the municipality (RIGeo 2006; RIGeo 2000). As a result, well water with high calcium content is most likely anthropogenic. Magnesium is formed when metamorphic rocks and minerals including dolomite, olivine, pyroxene, amphibole, and biotite decompose (Saha, Reza, & Roy 2019). The magnesium contents in the samples are rather low, showing that rock water and other minerals interact.

4 Conclusions

According to the survey, nearly half of the samples (43 percent) do not match the criteria set by the current ordinance for water intended for human consumption due to the chemical quality of the water, whether it was treated or not. Although physical-chemical analyses are required to characterize the waters, it is important to note that assessing the effects of contamination on human health necessitates ongoing research involving a greater number of water, soil, and sediment measurements, as well as information regarding the city's environmental and health conditions, in order to have a deeper understanding of the findings, which was not feasible in this study. The absence of lithological profiles of registered wells and depth, limited management, supply, and quality of water in that municipality, flow groundwater map, control of land use and coverage through restriction and inspection of human activities, and provision of health data by location were all identified as gaps in this study. As a result, the lack of a definitive conclusion on the relationship between water quality and human health impacts necessitates more research, mostly including collaboration between geologists and health specialists.

5 Acknowledgements

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