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Groundwater Quality Assessment in Rural Areas of Caapiranga City in Brazilian Amazon

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Abstract: About 75% of the entire surface of the planet Earth is covered by water, with only about 3% of freshwater. The Amazon region has the largest freshwater basin in the world and the uncontrolled growth of the population in this region has become a problem concerning water contamination since a large part of the region's population obtains water from artesian wells. This study aimed to investigate some physical-chemical parameters of groundwater in the municipality of Caapiranga, Amazonas (AM), Brazil. Water samples obtained from 14 tubular wells were evaluated, as well as a sample of surface water from Lake Caapiranga that passes in front of the municipality. The vast majority of water samples showed low pH, and were of the parameters established for drinking water, aquaculture and animal watering. High levels of nitrate are also found in most samples, which indicates contamination of these waters by domestic effluents. In wells 1, 6, 9 11, and 13 the levels of nitrate were very high and can cause serious diseases in people who use this water for consumption. According to the parameters evaluated, the quality of groundwater in 5 of the 14 wells is unfit for human consumption.

Key words: Water quality, human consumption, aquaculture, animal consumption, hydrogeochemistry, pollution.

1. Introduction

About 75% of the entire surface of planet Earth is covered by water, with only about 3% of fresh water, 90% of which is found in the glaciers [1]. It is worth noting that human beings have about 70% of water by mass and that the water used for human consumption is fresh water. In this way, the human being obtains fresh water in two main ways: surface and underground water. Groundwater is stored in the pores and fissures of rocks that precede the earth's crust, developing an almost inexhaustible natural reservoir of drinking water, naturally free from any impurity or bacteriological contamination [2].

Water according to National Environment Council (CONAMA) Resolution No. 357 is special in: (I) fresh water (salinity ≤ 0.05%); (II) brackish water (0.05% < salinity < 3%); (III) saline water (salinity ≥ 3%); (IV) lentic environment (still water, with slow or stagnant movement) and; (V) lotic environment (moving continental waters) [3].

The Amazon region has the largest freshwater basin in the world, accounting for about 20% of freshwater discharged into the oceans [4, 5]. The unrestrained growth of the population in the Amazon region has become a problem in relation to water contamination, since a large part of the population in the region obtains water from artesian wells, often granted irregularly and without any care [6, 7].

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The natural quality of groundwater depends on the geological conditions of the land in the hydrographic basin, in addition to the depth of the wells and pumping conditions [8]. Groundwater, when available in sufficient quantity, is preferable given the uniformity of its physical-chemical characteristics. Sometimes, they have the inconvenience of excessive mineralization, which is dependent on the geological nature of the land. The characterization of this type of water requires knowledge of its flow direction and the nature of the geological formations from which it originates, in order to ensure that the sources of sources, which may exist upstream, do not affect the origin.

Underground waters that present protection are considered to be of low risk; on the contrary, if there are deficient conditions of protection, such as origins, they become more vulnerable to contamination, which will require greater care in their control and treatment [9]. Water quality standards are used so that you can regulate and control the quality levels to be beautiful in a water body, depending on its intended use. The use of quality standards serves two purposes: (1) to maintain the quality of the watercourse or define a target to be achieved and (2) to be the basis for defining the treatment levels to be adopted in the basin, so that the effluents released do not change the characteristics of the standard watercourse by the standard [10].

The water quality standards to be taken can be divided into four broad classes: standards for etiological agents (e.g. pesticides), data standards by indicators (e.g. coliforms for investigation of pathogenic organisms), standards for precursor agents (for example, biochemical oxygen demand (BOD)), other factors that will produce important environmental changes [11].

CONAMA Resolution No. 20 of 8/18/86, a Brazilian instrument responsible for defining, quantifying and applying quality standards, a requirement on 11 quality parameters and 66 potentially harmful substances. Water suitable for consumption, or potable water, must comply with certain requirements in the following order: not have an objectionable odor and taste, be pleasant in appearance, have no color and turbidity above the potability standard, and not contain harmful or toxic substances above the tolerance limits for man [12].

The Ministry of Health Ordinance No. 518, of March 25, 2004, requires the procedures and those relating to the control and surveillance of the quality of water for human consumption and its mandatory drinking water standard throughout the national territory. Among others, the maximum allowed value (VMP) for water to be considered water is 10 mg/L of nitrogen in the form of nitrate (Table 1), 1 mg/L of nitrogen in the form of nitrite and 1.5 mg/L of ammonia [13]. CONAMA Resolution No. 357, of March 17, 2005, provides for environmental classification and guidelines for the classification of surface water bodies, as well as supply as conditions and water quality standards and effluent discharge standards [3, 14].

In the city of Caapiranga, there are dozens of tubular wells, offering untreated supply and exposing the aquifer and the population to contamination. The random and indiscriminate use of groundwater, without prior analysis of variables that can identify and quantify substances harmful to human health, could cause a series of complications to the population in the study area [15, 16]. The local population builds and uses the wells without any type of treatment or control over the quality of the water, which can cause diseases in humans and animals which consume this water. There is no supervision and regularization by the government. The lack of information about the importance of water quality from wells can become a basic sanitation problem, as the population is not aware of the need for improvements in the conditions of the water supply and sanitary sewage system [15]. The present work evaluated some physicochemical characteristics and underground water resources in the municipality of Caapiranga, Amazonas (AM), Brazil.

Table 1 Acceptable usual inorganic parameters of potability of water for human consumption, aquaculture and animal consumption.

Parameter	Unit	Maximum
Nitrate (as NO_3^-)	mg/L	10.0
Nitrite (as NO_2^-)	mg/L	1.0
Chloride Cl^-	mg/L	250
Sulfate SO_4^{2-}	mg/L	250

Source: Brazil (2005).

2. Material and Methods

2.1 Location

This study was carried out in the Caapiranga city (3°10′15″ south and 61°38′59″ west) (Fig. 1), where samples were collected from the tubular wells selected for supply with greater importance to the population. The different characteristics of each well were considered, such as: soil type, depth of the wells and operating time. The characteristic climate is tropical rainy and humid, with a maximum temperature of 38 °C, a minimum of 22 °C and an average of 29 °C. The geography of Lake Caapiranga is highly viscous. The forest is dense and tropical.

The collections were carried out in September and October 2018. Samples were collected from 14 wells in rural area with a depth ranging from 17 to 60 m and also from surface water at the entrance and exit of the river that is located in front of the city, called Caapiranga lake (Table 2). The properties where the water wells are located use it for human use, aquaculture, animal watering and horticulture.

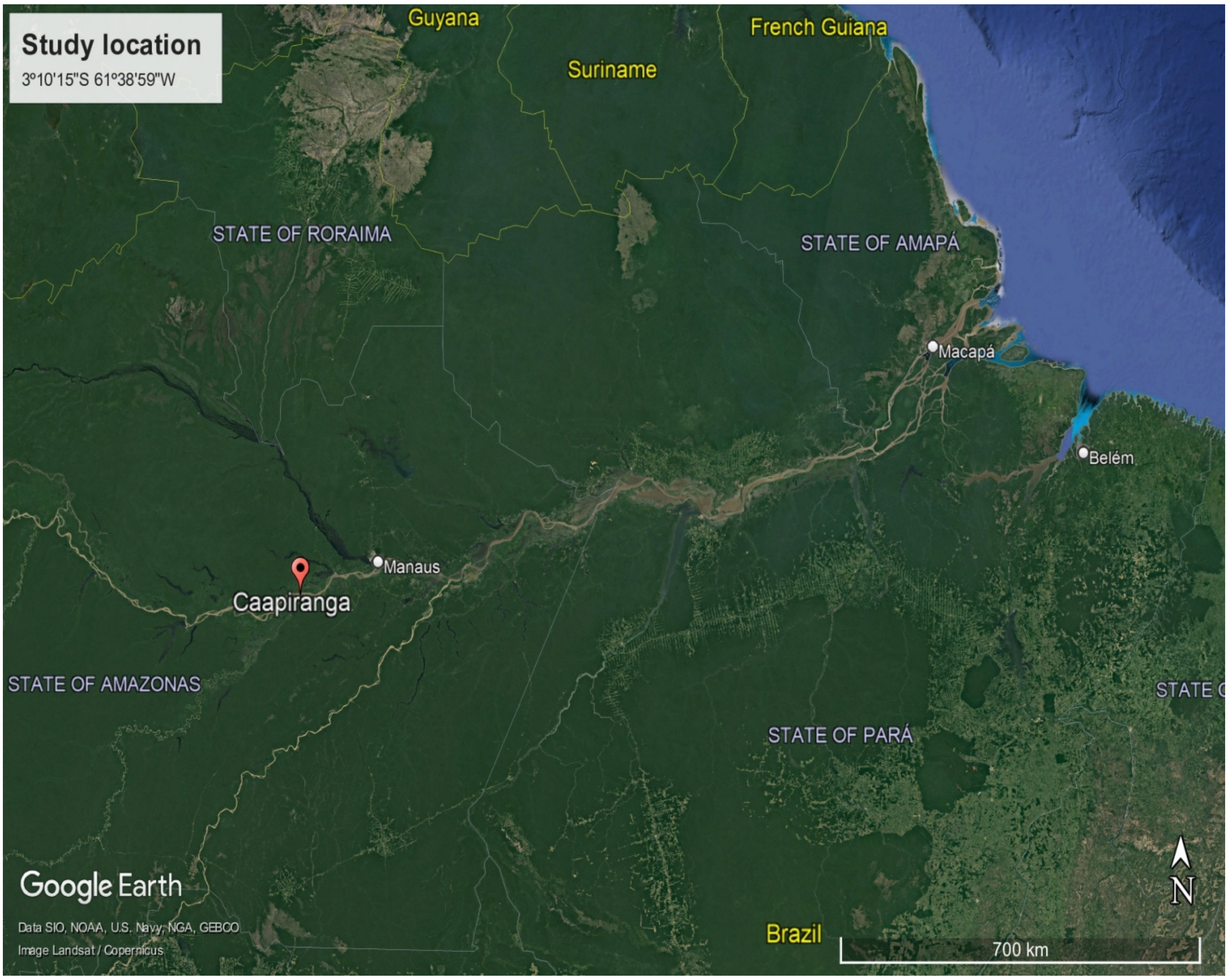

Fig. 1 Location of the city of Caapiranga draw on Google Earth.

Table 2 Information on collection locations.

Sample	Depth (m)	Foundation date	Coordinates
Well 1	24	March 2007	3°19′685″ S, 61°12′580″ W
Well 2	30	January 1982	3°19′705″ S, 61°12′607″ W
Well 3	60	May 1999	3°19′830″ S, 61°12′678″ W
Well 4	24	January 2007	3°19′704″ S, 61°12′692″ W
Well 5	22	January 2008	3°19′704″ S, 61°12′630″ W
Well 6	18	September 2006	3°19′646″ S, 61°12′692″ W
Well 7	35	May 2007	3°19′648″ S, 61°12′561″ W
Well 8	36	September 1999	3°19′627″ S, 61°12′546″ W
Well 9	42	September 1997	3°19′628″ S, 61°12′547″ W
Well 10	40	May 2008	3°19′642″ S, 61°12′696″ W
Well 11	30	September 2002	3°19′631″ S, 61°12′686″ W
Well 12	24	April 2008	3°19′673″S, 61°12′609″ W
Well 13	60	September 1998	3°20′002″ S, 61°12′744″ W
Well 14	17	February 2008	3°19′228″ S, 61°12′469″ W

2.2 Physicochemical Analysis of Water

Sampling was carried out by collecting water from the wells by pumping, being stored in 1 L glass bottles and packed in styrofoam boxes properly identified and taken to the Laboratory of Environmental Chemistry of the National Institute for Research in the Amazon (INPA), where they were analyzed.

The pH was determined using a portable pH meter microprocessor Quimis model Q400HM (Diadema, SP, Brazil), previously calibrated with buffer solutions pH 7.0, pH 4.0 and pH 10, with the results expressed in a logarithmic pH scale. Electrical conductivity (CE) was determined using a portable conductivity meter from Lutron (Jacareí, SP, Brazil), model CD-4303, with results expressed in the scale of µS/cm.

Sodium, potassium, calcium and magnesium contents were determined by flame atomic absorption spectrophotometry (EAA) using a Perkin-Elmer model 1100B atomic absorption spectrophotometer (Waltham, Massachusetts, USA) [17]. Nitrate, ammonia, nitrite, chloride, sulfate and phosphate levels were determined by spectrophotometry using Shimadzu model UV-1800 spectrophotometer with flow injection system (FIA) [17].

3. Results and Discussion

The pH of the collected waters presented values from 4.24 to 6.27, characterizing them as acidic waters (Table 3), the pH values found in the river were 6.42 and 6.43 respectively. Approximate values were observed by M. L. Silva and M. S. R. Silva [18], in the waters of tube wells in the city of Iranduba, in which they found a pH ranging from 5.0 to 6.3. Silva-Filho *et al.* [19] evaluated the physical-chemical quality of water from an artesian well in the city of Remígio, Paraíba (PB), Brazil, and found a pH of 6.52.

When compared to the values established by Consolidation Ordinance No. 5, of September 28, 2017, of the Ministry of Health, the pH is the standard for potability, and water for human consumption should have values between 6.0 and 9.5 [20], the vast majority of these waters do not fit within the recommended standards, which does not detract from drinking water, as the pH is also related to the region’s geology, vegetation cover, rapid recharge and the water-rock/soil interaction process.

CE of the samples collected in the wells ranged between 13.4 and 155.3 µS/cm (Table 3). The high values of CE found in wells 01 and 09 are atypical for groundwater of the Alter do Chão Formation, as, in general, these waters have low concentrations of dissolved elements (quartz, sandstone, arcsean sandstone, kaolin sandstone and kaolin), according to Silva

Table 3 Physical chemical parameters of the water samples evaluated (mg/L).

Sample	pH	CE (μS/cm)	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	NO_2^{-}	NO_3^{-}	SO_4^{2-}
Well 1	4.24	155.3	0.17	0.35	27.55	1.18	33.87	< LOD	50.99	0.16
Well 2	6.27	65.8	2.24	1.20	9.65	3.04	1.41	< LOD	0.23	0.30
Well 3	5.7	55.6	3.68	1.33	5.41	2.47	3.29	< LOD	0.45	0.13
Well 4	5.75	50.6	1.66	1.10	7.18	2.94	2.39	< LOD	0.32	0.50
Well 5	5.32	36.8	0.46	0.32	5.82	1.53	2.87	< LOD	1.04	0.15
Well 6	4.52	49.2	0.23	0.58	6.91	2.05	3.42	< LOD	19.78	< LOD
Well 7	5.76	88.0	1.87	1.26	14.21	3.29	10.06	< LOD	4.25	0.17
Well 8	5.17	89.8	0.81	0.55	16.66	1.41	29.40	< LOD	< LOD	0.06
Well 9	4.76	147.3	0.99	0.59	28.45	1.26	55.06	< LOD	16.36	0.37
Well 10	6.09	72.8	1.93	1.11	6.86	2.61	1.23	< LOD	0.91	0.42
Well 11	4.79	57.2	0.47	0.92	8.37	2.35	7.04	< LOD	15.96	0.006
Well 12	4.81	42.3	0.39	0.34	7.27	1.17	8.70	< LOD	2.56	0.17
Well 13	4.98	49.0	0.50	0.48	5.74	2.77	5.60	0.002	10.17	< LOD
Well 14	4.82	13.4	0.18	0.16	1.20	0.99	0.74	< LOD	0.30	0.04
Media	5.21	63.09	1.11	0.74	10.81	2.08	11.79	0.002	9.49	0.21

CE: electrical conductivity; LOD: detection limit.

[21, 22]. Normally, natural waters have a CE of less than 100 μS/cm, however, it can exceed these values when a high load of domestic and industrial effluents comes into contact with them [23]. This parameter is important to assess changes in the composition of water, however, it is not able to identify its origin [24-26].

Dissolved calcium contents ranged between 0.17 mg/L and 3.68 mg/L, with the general average of the wells being 1.11 mg/L. Magnesium contents ranged between 0.16 mg/L and 1.33 mg/L, with an average of 0.74 mg/L (Table 3). For waters from the Alter do Chão Formation, Silva [21] found, in Manaus, values for calcium and magnesium lower than 5.00 mg/L, and Silva [22] found an average value of 3.03 mg/L for calcium and 2.26 mg/L for magnesium in subsurface waters in Manacapuru, AM (a city close to Caapiranga). It shows that these indices are in the patterns found by the Alter do Chão Formation.

The hardness of water is expressed in mg/L of $CaCO_3$ equivalent and can be classified as soft (< 50 mg/L), mild (50-150 mg/L), hard (between 150 and 300 mg/L) and very hard (> 300 mg/L) of $CaCO_3$ [27]. This hardness is associated with presence in addition to Ca^{2+}, such as Mg^{2+} and a small contribution of Fe^{2+}, Mn^{2+}, Sr^{2+} and Al^{3+} [27, 28]. Water hardness is influenced by the geology of the drainage basin and by human activities. Generally, environments with pH close to neutrality have a soft hardness given by the low concentrations of carbonates, and the reaction with CO_2 for the production of bicarbonate is negligible [24]. Based on the classification mentioned above, the samples were presented as soft, all within the potability standards.

Potassium contents ranged from 0.99 mg/L to 3.29 mg/L, with an average of 2.08 mg/L while sodium contents varied between 1.20 mg/L and 28.45 mg/L, with an average of 10.81 mg/L (Table 3). M. L. Silva and M. S. R. Silva [18] found maximum potassium and sodium values of 110 mg/L and 110 mg/L in Iranduba groundwater, respectively. Dissolved chloride contents ranged from 0.74 mg/L to 55.06 mg/L, with an average of 11.79 mg/L (Table 3). All wells presented values below the maximum allowed by Ordinance No. 05/2017 of the Ministry of Health, which is equal to 250 mg/L of Cl^{-}. M. L. Silva and M. S. R. Silva [18] found average values of 84.33 mg/L for chloride in Iranduba's groundwater, values above those verified for most of the wells sampled in this work. Chloride is an important ion in ground and surface water as it has high mobility in the soil and can be leached from rocks, domestic and industrial sewage [28-30]. According to São Paulo State Environmental Company (CETESB) [31], a person expels approximately 4 g of chloride per day in the urine. Furthermore, it is important to emphasize that chloride participates in important physiological processes.

The nitrate contents found in wells 01, 06, 09, 11 and 13 were high (50.99 mg/L, 19.78 mg/L, 16.36 mg/L, 15.96 mg/L and 10.17 mg/L, respectively). These values are considered very high by Ordinance No. 518 of the Ministry of Health, which determines that the maximum allowed is 10 mg/L. These values found in these wells can cause serious illnesses in children and adults, methemoglobinemia known as blue baby syndrome and gastric cancer, while the ammonia value was not found in any of the researched wells (Table 3) [13, 32]. It is noteworthy that this nitrate contamination is a result of its leaching in soils contaminated with fertilizers as well as urban effluents, in addition, it may originate from the disposal of effluents from nitrifying biological treatment plants [17, 33, 34].

Sulphate had a low concentration in the analyzed waters, which ranged from 0.006 to 0.500 mg/L (Table 3). For waters from the Alter do Chão Formation in the city of Iranduba, M. L. Silva and M. S. R. Silva [18] found an average value of 3.71 mg/L and Silva [21] found values less than 1.0 mg/L in the city of Manaus for all sampled wells, values equal to those of Caapiranga.

Phosphate and ammonium ion contents were below the detection limit of the analyses for all samples. Phosphate has its natural origin (decomposition of biological and mineral material) as well as anthropogenic (agricultural fertilizers, animal feed supplements, food preservatives, pesticides, cosmetics, water treatment) [28, 35]. These results corroborate the results of Alves [36] who mentions that in natural waters its content does not exceed 1 mg/L (P_2O_5).

4. Conclusions

Most samples, with the exception of wells 2 and 10, had a very acidic pH and outside potability standards. The low pH in wells 1, 6 and 9 coincided with high levels of nitrate and CE, which indicates contamination of these wells, possibly by human effluents. Wells 11 and 13 also showed contamination by effluents, which is confirmed by the presence of high levels of nitrate. The absence of conservation practices in the watershed related to the protection of water quality, the lack of basic sanitation and adequate treatment of effluents, contribute to the contamination of these wells. It is essential that more studies be carried out in this area, as well as the implementation of more effective policies to avoid irregular or inadequate construction of wells.

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