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Diagnostic of Groundwater Intended for Human Consumption in the Municipality of Abaetetuba, Pará - Brazil

Gilmar W. Siqueira[1], Andreza C. M. Leite[1], Assad J. Darwich[2] and Fabio Aprile[2*]

[1]*Pará Federal University, 66075-100 PA, Brazil.*
[2]*National Institute of Research in Amazonian, 69060-001 Amazonas, Brazil.*

Authors' contributions

All authors participated of the samples collection, date and statistical analysis and wrote the first draft of the manuscript.

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ABSTRACT

The objectives of this research were to evaluate the quality and to determine the degree of vulnerability and accessibility of groundwater destined to the public supply of the municipality of Abaetetuba (State of Pará - Brazil), allowing to establish an environmental management program based on the national legislation. Analytical procedures for temperature, dissolved oxygen, pH, alkalinity, hardness, electrical conductivity, ionic concentration [Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, Cl^-_{did}, SO_4^{2-}, HCO_3^- and CO_3^{2-}], TDS, BOD, total and fecal coliforms were applied in agreement with traditional standard methods in limnology and geochemistry. Collections were made between 2012 and 2016 in 20 wells located in priority areas such as schools, federal institutes of education, hospitals and clinics, water treatment plants, bus terminal and residences. The results obtained (in average) were: temp 23°C; DO 3 mg/L; O_2 saturation 35.1%; pH 5.3; alk 25.8 and hard 38.4 mg/L; EC 128 µS/cm; ions Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, Cl^-_{dpd}, SO_4^{2-} and HCO_3^- plus CO_3^{2-} were 14, 24, 42, 21, 19, 0.2, 1.3 and 29.5, respectively; TDS 91 mg/L;, BOD 2.4; total coliforms 279 MPN and fecal coliforms 20.4 MPN. The results indicate that, although from a physical-chemical point of view, the water meets the

*Corresponding author: E-mail: aprilefm@hotmail.com;

standards of supply and consumption presented in environmental legislation, in the biological aspect (BOD and coliforms) the samples presented different degrees of bacterial contamination. On the Water Quality Index of the groundwater, most of the samples indicated quality from acceptable to good to supply, with a certain degree of attention to possible sources of contamination, especially faecal coliforms. Cluster analysis indicated a strong association between the parameters [pH-Alk-Hard] and [BOD-tot coliforms-fecal coliforms]. Several factors have been identified as being responsible for contamination as from inadequate areas for good installation; lack of cleaning and maintenance; inadequate water storage; the presence of unauthorized personnel; and personnel unless proper training to handle the wells. Most of the wells in operation do not meet the minimum sanitary conditions to supply the population with quality drinking water.

Keywords: Groundwater; water supply; sanitation; faecal contamination; Amazon.

1. INTRODUCTION

The growing demographic and industrial expansion associated with the lack of financial resources, especially in developing countries, has lead to deterioration in the quality of surface waters for supply. As surface waters are continually being polluted by human activity, forcing the sanitation companies to fetch clean water more distant from the area of consumption, increasing the costs of treatment to distribution.

Brazil has one of the largest hydrographic networks in the world, with most of the water abstracted for supply from surface waters. The country has a surface water potential equivalent to 53% of the total found in South America, and 12% of the world total [1,2]. However, this apparent abundance condition does not reflect the real condition of availability, distribution and use of water resources. Amazon region holds 68% of Brazil's surface water resources and is occupied by only 4.5% of the total population [1,3]. Nevertheless, a significant number of communities, districts and municipalities do not have or only have part of their supply supplied by water treated by simple disinfection.

An alternative found to maintain the water supply in urban centres is the catchment and supply of groundwater. This applied practice without planning and adequate studies can cause intense contamination of the subterranean aquifers, with damage due to the lack of knowledge about the hydrogeological environment, and the difficulty in the control and treatment of these waters. The issue of contamination of soil and water has been of great concern in countries where this resource is restricted. In Brazil, the lack of quality surface water and the contamination of underground aquifers both have been aggravated by large urban and industrial centres, which currently supply almost all of their water needs through groundwater.

According to the IBGE Demographic Census [4], actually, in Brazil, 55% of the districts are supplied by groundwater, which represents the supply of 30-40% of the population [2,5]. Besides serving the population directly, these waters are used in industry and agriculture. Due to increasing demand, groundwater is under strong anthropogenic pressure, which can lead to intense exploitation of the aquifer. That situation can result in the exhaustion of the wells, as well as reduce the amount of water that supplies the rivers, causing a drought of springs, depletion of reservoirs, among other negative impacts.

In most of the municipalities of the Amazon, the water supply system is precarious and sometimes partially absent. An alternative found by the sanitation companies in the region was the supply of the cities of the interior through the supply of groundwater, which most often occurs without any kind of treatment, only capture, followed by storage and distribution to the consumption areas [6,7]. Abaetetuba is an example of a municipality that supplies the urban area with groundwater, often from shallow tubular wells (Amazonian wells), usually built without any standardization, environmental inspection or license, presenting a potential risk of biological and chemical contamination. Studies developed in the municipality by Almeida et al. [8], from the use of Georadar, have demonstrated that there is evidence of soil contamination by hydrocarbons, which increases the risk of contamination of the wastewater to the population. The objectives of this research were: 1) to carry out a quality assessment and determine the degree of vulnerability and accessibility of groundwater destined to human consumption in the municipality of Abaetetuba; 2) to contribute with data for the implementation of a planned public policy for decision-making in relation to groundwater management.

2. MATERIALS AND METHODS

2.1 Study Area

The municipality of Abaetetuba has a territorial area of 1610.11 km^2, with 56.9% of the total occupied by rural areas of various sizes. According to the Demographic Census, the population in 2010 was of 141,100 inhabitants, of which 58.8% were of the urban area and 41.2% of the rural area [4]. The population for 2017-18 was estimated at 153,380 inhabitants, a rate of increase of 8.7% in seven years, and a population density of 87.61 inhab/km^2 [9]. The municipality is located southwest of the city of Belém (01°43'05"S - 48°52'57"W, Fig.1), at an altitude of 10 meters, and with a distance of approximately 90 km in relation to the centre of the capital. The city is located in the watershed of the Pará River, presenting in the subsoil a significant reserve of water. Abaetetuba is a city-centre of a region that includes the municipalities of Moju, Igarapé-Miri and Barcarena (Fig. 1). The predominant economic activity in the municipality is the third sector (commerce and services), which counts on an ample network of establishments of the most diverse activities. Industrial activity has a smaller share in the local economy but has been showing great growth in recent years, especially in the food and agro-forestry products sectors [7,9]. There are five hydrogeological systems in the area of the municipality, formed by aquifers belonging to the stratigraphic units Pirabas, Barreiras and Quaternary Coverage. These systems are called Alluvial, Post-Barriers, Barriers, Upper Pirabas and Lower Pirabas, with a predominance of the Barreiras group [7,10]. The Municipal Human Development Index (MHDI) has grown over the last 25 years, with an estimated HDI of 0.628 in 2010 rising to 0.751 in 2013 [4,11]. Despite that, socioeconomic development is still modest, and taking into account aspects of basic sanitation, such as the supply of treated water, sewage, and rainwater and solid waste management, the municipality presents conditions that are still very precarious. According to information from the National Survey of Basic Sanitation – NSBS [12,13], less than 40% of active economies have a regular water supply. According to the NSBS 2008, the water supply situation has changed in

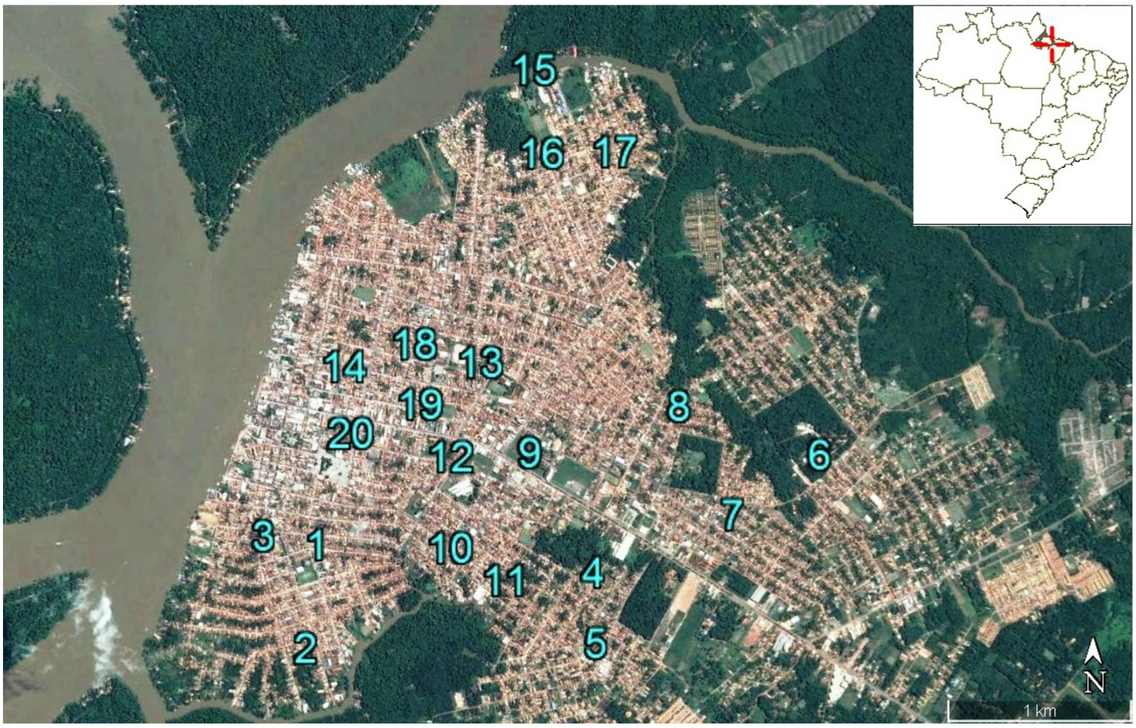

Fig. 1. Location map of the municipality of Abaetetuba (Pará, Brazil) scale 1:250,000 with an indication of the area of the wells monitored

Residence = 2-4-5-16-20; School= 1-6-8-10-11-13-15-17; Square= 3; Hospital= 12-7; Bus terminal= 9; water supply= 14- 18-19. (Source: CNES/©2018Google; SiAGAS/CPRM [14] modified). [9= 1°43'36.61"S/ 48°52'42.12"W]

Table 1. Abaetetuba city (PA): Geographic location of sampling points

1	School	1°43'52.87"S	48°53'19.73"W	11	School	1°43'50.34"S	48°52'48.53"W
2	Residence	1°44'2.31"S	48°53'21.71"W	12	Hospital	1°43'37.34"S	48°52'54.07"W
3	Square	1°43'46.91"S	48°53'25.10"W	13	School	1°43'20.65"S	48°52'44.72"W
4	Residence	1°43'57.75"S	48°52'30.87"W	14	Water supply	1°43'21.40"S	48°53'12.80"W
5	Residence	1°44'1.45"S	48°52'28.43"W	15	School	1°42'28.86"S	48°52'35.36"W
6	School	1°43'27.91"S	48°51'50.84"W	16	Residence	1°42'39.24"S	48°52'33.99"W
7	Hospital	1°43'38.75"S	48°52'4.32"W	17	School	1°42'43.43"S	48°52'29.20"W
8	School	1°43'28.41"S	48°52'15.79"W	18	Water supply	1°43'17.39"S	48°52'56.40"W
9	Bus terminal	1°43'36.61"S	48°52'42.12"W	19	Water supply	1°43'19.19"S	48°52'55.40"W
10	School	1°43'49.05"S	48°52'50.07"W	20	Residence	1°43'24.33"S	48°53'15.76"W

the last decades, with the evolution of demographic patterns and the type of economic growth observed. However, pressure on water resources has increased, leading to conflicts of use. During this period there was a worsening of the surface waters quality that crosses the region, due to anthropic activities such as urbanization, agriculture and mining.

2.2 Analytical Procedures

Twenty wells were sampled between 2012 and 2016, with annual frequency, located strategically in schools, institutes of higher education, hospital, dental centre, water treatment plants, bus terminal, square (community well) and residences supplied by public Cia. (COSANPA), in the districts of Santa Rosa, Centro, Algodoal, Cristo, São Sebastião, Mutirão, São Lourenço and Francilândia (Fig. 1 and Table 1). The survey of information on the wells, including technical aspects, was obtained through direct contact with owners and company of the public sector and complemented with data of the System of Information of Groundwater of the Company of Research of Minerals [14]. Additional information on the water use situation (residential, agricultural or industrial), and well location (UTM coordinates), their status (in operation, deactivated, dry, private or community), flow rate (m³/h), depth (m) and year of perforation were also obtained. The methodologies for collecting and preserving the water samples, as well as the physical-chemical and microbiological analyzes, were conducted using specific procedures, according to recommendations proposed by the Adolfo Lutz Institute and the Sanitary Surveillance Agency - ANVISA [15] and National Agency of Waters – ANA [16]. The analytical procedures were performed in the Laboratory of Chemical of UFPA, according to protocols described in [17-20]. The parameters analyzed were: temperature (°C), dissolved oxygen (DO mg/L), pH, electrical conductivity (EC μS_{25}/cm) and total dissolved solids (TDS mg/L), all determined by direct reading with multiparameter probe electrodes in-situ at sampling sites; alkalinity (HCO_3^-/CO_3^{2-} mg/L) by potentiometric titration; total hardness (mg/L), using EDTA 0.0004 M as titrant and eriochrome black as indicator; total iron (Fe_{tot} mg/L) by spectrophotometry with 4-aminoantipyrine (APHA Method 5530-C); Na^+, K^+, Ca^{2+}, Mg^{2+} (mg/L) by spectrophotometry (APHA Method 5910-B and 3120-B) [20]; chlorine (Cl^- mg/L) for automatic spectrophotometer with Hg thiocyanate (APHA Method 4500-CL - item F) [20]; chlorine DPD (mg/L), by the reaction of the free chlorine with N,N-diethyl-p-phenylenediamine; total sulfate (SO_4^{2-} mg/L) by ionic chromatography (APHA Method 4110-C) [20]; biochemical oxygen demand (BOD_{5-20} mg/L) for dilution and incubation at 20°C and 5 days (APHA Method 5210-B) [20]; total coliforms (MPN/100 mL) by incubation method in multiple tubes (CETESB NT L5.202) and membrane filtration technique (CETESB NT L5.214) [17,18]; fecal coliforms or thermotolerant (MPN/100 ml) by membrane filtration technique of cellulose acetate (0.45µm pore) followed by incubation for 24 hours at 44.5°C (CETESB NT L5.221) [17,19]. The results were analyzed based on the Brazilian legislation for the quality standard, procedures for control and monitoring of water quality, and permissible limits for the supply of water for human consumption: Administrative Rule N° 2914 of 12/12/2011 [21] and Ordinance N° 518 of 03/25/2004 [22] of the Ministry of Health; and CONAMA Resolution N° 396 [23]. The Water Quality Index (WQI) for groundwater was determined by applying the standards determined by the environmental sanitation agency of the São Paulo State [24]. The results were also analyzed statistically from the ANOVA, Cluster and PCA application, using Statistica StatSoft© 7.0 and Microcal Origin© 9.0 softwares.

3. RESULTS AND DISCUSSION

3.1 Physical-chemical and Biological Parameters

Most of the world's population still die from water-borne diseases (childhood diarrhoea, *amebiasis*, *schistosomiasis*, hepatitis) due to lack of basic sanitation, especially lack of sewage treatment. Over 30% of the deaths in developing countries is caused by the consumption of contaminated water, and on average, one-tenth of the productive time of each person is lost due to water-related diseases [25]. It is estimated that 95% of sewage from developing countries is disposed of without any treatment in surface waters, directly contaminating soil and groundwater aquifers [26]. This trend has been observed in the Metropolitan Region of Belém (MRB), as well as in the nearby municipalities. Abaetetuba is located near the MRB, whose capital Belém was considered in the last two decades the city with the greatest number of hospitalizations due to diarrhoea, and the municipality with more than 300 thousand inhabitants with the worst rate of sewage treatment in Brazil [26,27]. These indications, especially for surface waters, have also been observed in groundwater, more and more frequently, through the monitoring of public and private water supply wells. The diagnosis of the results presented in Fig. 2 is based on the standards established by the current national legislation [21-23]. A synthesis of the analyzed environmental parameters is presented in Table 2 of the 20 wells monitored, approximately 50% were outside the pH limit (Fig. 2A), including the mean values, which were close to 5.3±1.2. The pH of the Amazonian surface waters is quite variable. However, the groundwater of this region tends to be slightly acidic to acidic, which interferes with the mobility of several elements, such as trace elements. In groundwater, the acidic condition may facilitate the water erosion of rock metals. It is not uncommon to observe groundwater used for the public supply rich in dissolved iron due to this acidic characteristic of the waters. The very acidic values (<4.0) can mean an increase in the CO_2 content dissolved in the water resulting from the microbial decomposition or the dissolution of the carbonate and calcareous rocks. The presence of carbonic acids may also interfere with pH, and may even be indicative of contamination by organic compounds (total coliforms). The pH had a direct correlation with the alkalinity, and this with the hardness (Fig. 2B). In this study, the correlation between pH and alkalinity was P=0.983 [equation 1: Alk=10.659pH – 49.612] and between alkalinity and hardness P=0.999 [equation 2: Har=2.315Alk + 10.031]. The alkalinity had an important function of buffering the slightly acidic waters, especially by the dissolution of the carbonates (CO_3^{2-} and HCO_3^-) of the matrix rock. In waters destined for human consumption, total alkalinity has no sanitary significance. However, at high levels it can have an unpleasant taste [28]. The hardness of the monitored groundwater was within the standards established by the legislation (Fig. 2B), with an average of 38.4±30.1 mg/L, suggesting the presence of alkali elements such as dissolved Na, K, Ca and Mg. Chlorine values ranged from 1.8 to 69.0 mg/L (mean 18.9±17.3 mg/L), always being below the established limits, so there is no restriction of water for human consumption parameter. The low natural values of Cl^- are due to the low values in the igneous and sedimentary rocks. Sodalite [$Ca_5(F,Cl,OH)$-$(PO_4)_3$] and apatite [$Na_4(AlSiO_4)_3Cl$] are the minerals more frequents in igneous rocks, which contain chlorine as the fundamental constituent. On the other hand, the higher Cl^- values were observed close the treatment stations due to the administration of chlorine dioxide or hypochlorite in the water by COSANPA, as a method of disinfecting the water before the public distribution. The DO contents ranged from 2.5 to 3.5 mg/L (mean 3.0±0.3 mg/L), suggesting low consumption by the oxidation processes. However, such results do not exempt groundwater from contamination by organic compounds. The occasional decrease of DO can be attributed to the presence of chemical reducing agents such as sulfides and ferrous salts, which alter the organoleptic properties of water [29].

An environmental parameter of great importance in the analysis of the chemical composition of water is the electrical conductivity (EC). From this it is possible to discuss aspects of the ionic composition, the capacity of buffering equilibrium and to establish a degree of conservative state for the system. EC values ranged from 35.5 to 299.0 (128.1±71.9). However, 40% of the sampling sites (1, 3, 11, 13, 17, 18 and 20) had EC above of the average, suggesting the enrichment of waters with mineral salts, especially sodium. That can mean moderate to heavily leached environments containing alkaline and alkaline earth metals, as well as carbonate sources. The Ministry of Health establishes values of up to 1000 µS/cm, therefore, although there is an occasional increase in conductivity, it remains within the standards accepted by the legislation for public supply. The total dissolved solids (TDS) are the sum of the contents of all the mineral constituents present in the water. The TDS values determined in the wells ranged from 20 to 217 mg/L (91±54 mg/L), remaining all sites within the standards established by law (Fig. 2C). The ratio of EC/TDS was on average 1.4 well above the average ratio found in the literature for groundwater, ranging from 0.5 to 0.7. This was due to higher conductivity values. Environmental parameters of biological interest include biochemical oxygen demand (BOD), total coliform and fecal coliform. BOD ranged from 0.9 to 3.6 mg/L (2.4±0.9 mg/L) with 60% of the samples analyzed above the values allowed by the legislation (Fig. 2D), suggesting contamination by organic compounds. In fact, total coliform (Fig. 2E) and fecal (Fig. 2F) contents ranged from 21.4 to 585.1 (mean 279.0±182.5 MPN/100 mL) and from 2.3 to 41.5 (20.4±12.7 MPN/100 mL), respectively. In this case, all the sampling sites remained above the limits established by law, indicating faecal contamination in all wells monitored. In most of the cases, the contamination occurs for the lack of cleaning and maintenance of the area around the wells or for the people's and animals approach in the place. But in some cases, contamination was noted by the presence of untreated sewage flowing near the sampling site, contaminated soils by infiltration, and consequently contaminating the wells and even the aquifer. These unsatisfactory sanitary conditions do not seem to disturb the population, which uses the water from the wells without prior disinfection. Those results should be concern cause, once the monitored wells are in schools and hospitals. In general, the presence of total coliforms in groundwater may be associated with soil characteristics, since the soil texture, the thickness and permeability of the unsaturated zone influence the filtration capacity of the water. Information on the survival of bacteria in groundwater is still relatively limited. In general, it has been accepted that the survival period is higher in groundwaters than in surface waters, mainly due to lack of sunlight and little competence for available nutrients [30]. Temperature is also an important factor, in this case for the survival of bacteria, which at slightly lower temperatures (20 to 24°C) survive a longer period of time. The chemical nature of groundwaters affects the survival capacity of bacteria. In general, enteric bacteria (*E. coli*) do not support well the extremes of pH and salinity, having low survival rates in acid environments as well as in slightly saline conditions. Aspects related to grain size and texture of adjacent soils also interfere with the life time of enteric bacteria. Soils with coarse sand and gravel, in addition to allowing a greater distance from the liquid path have a lower purifying power [31,32] allowing an increase in the dispersion degree of organic pollutants and inorganic contaminants.

3.2 Water Quality Index (WQI)

The availability of groundwater resources for certain types of use depends fundamentally on physical-chemical, biological and radiological quality. Until some time ago, there were no legal provisions in Brazil that delegated competence for management and protection of the groundwater. In that way, the knowledge and information on exploitation, control, protection, use and granting, or did not exist or were limited to scientific and governmental institutions, making it difficult to establish an adequate scientific analysis that would guarantee the

Tab 2. Summarized environmental parameters analyzed in wells from Abaetetuba city (PA)

	Max	Min	Ave	SD		Max	Min	Ave	SD
Temp (ºC)	24	22	23	0.4	Σcati (mg/L)	200	14	102	69
DO (mg/L)	3.5	2.5	3.0	0.3	Cl^- (mg/L)	69.0	1.8	19.0	17.3
O_2 (%)	41.9	29.0	35.1	3.5	Cl^- dpd (mg/L)*	1.0	0.0	0.2	0.3
pH	7.4	3.9	5.3	1.2	SO_4^{2-} (mg/L)	2.9	0.6	1.3	0.5
Alkali (mg/L)	65.0	2.0	25.8	23.2	HCO_3^- (mg/L)#	77.0	2.4	29.5	27.4
Hard (mg/L)	87.0	7.4	38.4	30.0	Σani (mg/L)	98	10	49	28
EC (μS_{25}/cm)	299	36	128	72	TDS (mg/L)	217	20	91	54
Na^+ (mg/L)	44	2	14	11	BOD (mg/L)	3.6	0.9	2.4	1.0
K^+ (mg/L)	73	2	24	19	total Fe (mg/L)	1.2	0.0	0.3	0.3
Ca^{2+} (mg/L)	103	3	42	38	total Coli (MPN/100ml)	585	21	279	183
Mg^{2+} (mg/L)	44	2	21	15	Fecal coli (MPN/100ml)	41.5	2.2	20.4	12.7

Max=maximum; Min=minimum; Ave=average; SD=standard deviation
**Cl^- dpd is residual chlorine; # HCO_3^- + CO_3^{2-}*

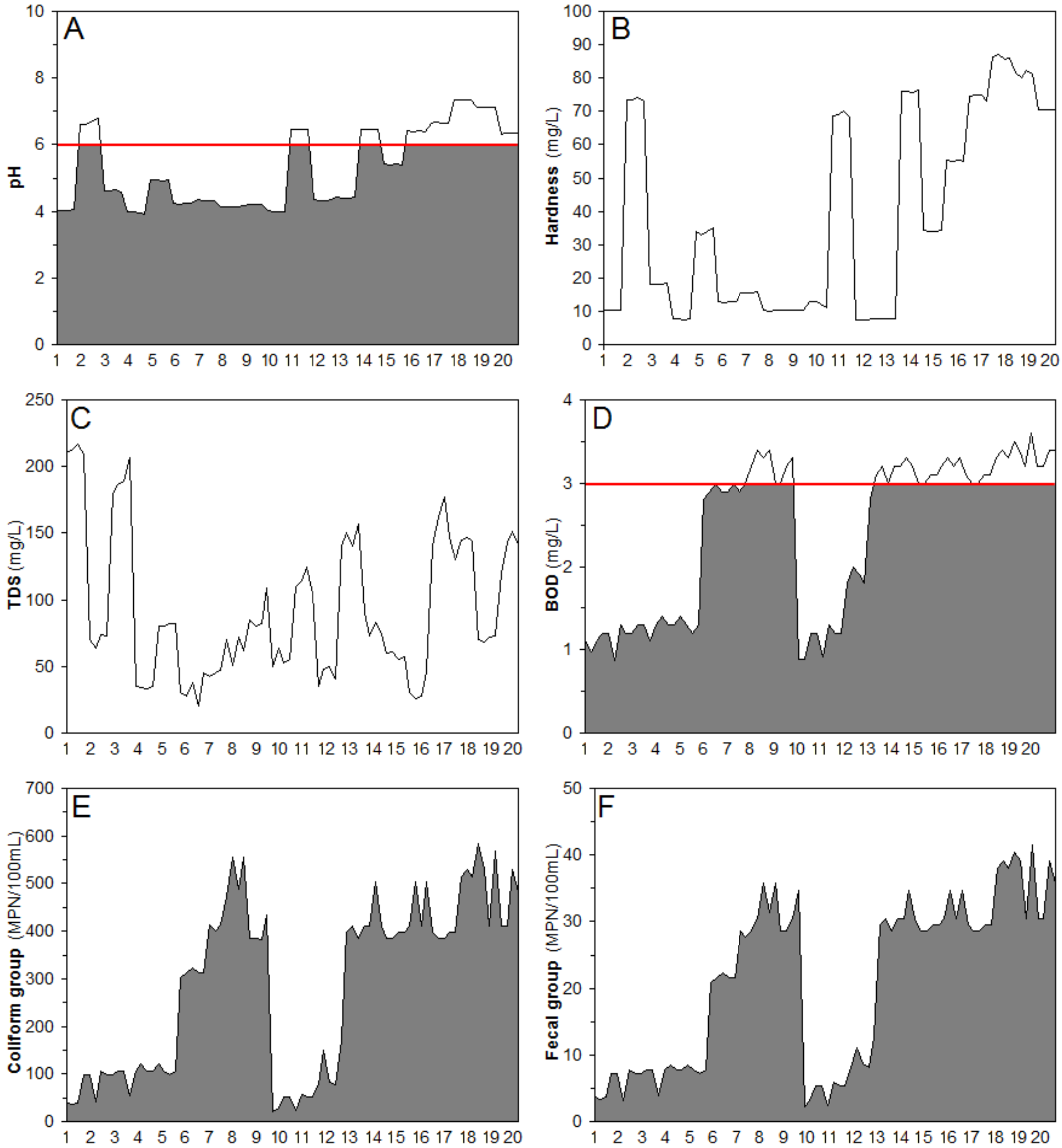

Fig. 2. Water quality of the wells of the municipality of Abaetetuba (PA, Brazil), according to the actual legislation [21-23]

Legend: white area = allowable values; gray area = unfit for consumption; red line = permissible limit.

preservation and protection of that resource. Even today, many of the criteria for analyzing groundwater quality are based on criteria for surface waters, such as the Water Quality Index (Fig. 3). The results suggest a water quality of the wells for moderate to good supply, but with a certain degree of attention to possible sources of contamination, especially faecal coliforms. Approximately 55% of the wells monitored showed acceptable and good water quality for human consumption (green area), and 45% presented regular quality (yellow area), suggesting attention to the sanitary patterns around the wells.

3.3 Statistical Analysis

Assuming that the contamination of the soil and wells, as well as the water erosion by anthropic activities, have both low influence on the electrical conductivity, this parameter was used as an indicator of the conservative state of the water. In this way, the standard of distribution of the cations (Na^+, K^+, Ca^{2+} e Mg^{2+}) and anions (Cl^-, SO_4^{2-}, HCO_3^- e CO_3^{2-}) were analyzed from linear regression analysis (Fig. 4). The results indicated a slight regression between conductivity and Σ cations (Fig. 4A), with R=0.288, suggesting that only 8.3% of the

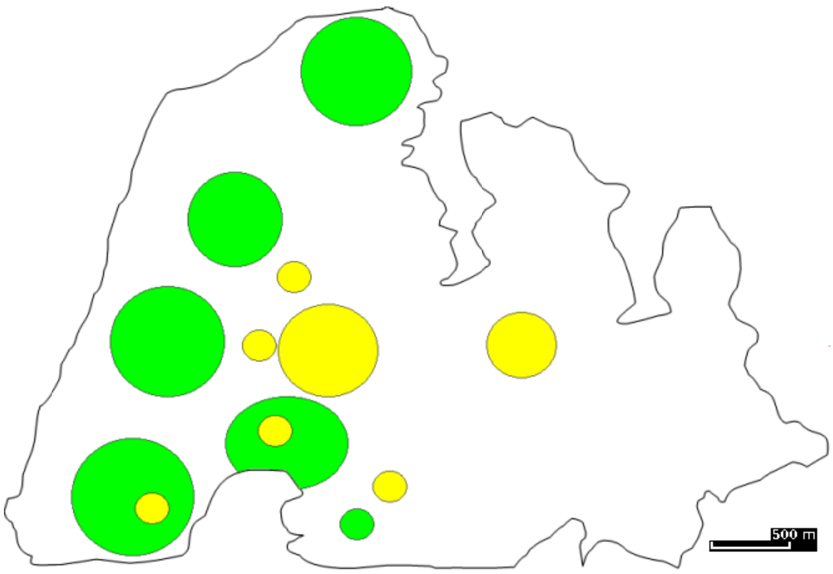

Fig. 3. WQI of the tubular wells monitored in the municipality of Abaetetuba (PA, Brazil) between 2012 and 2016

Legend: yellow = regular; green = acceptable to good. (Source: Golden Surfer© 9 with Kriging dispersion model).

variable defined as a dependent was explained by the predictive variable, and all the rest being part of the residual values. The analysis of variance determined from the application of the F test indicated F_1=7.03 > F.05(1;79), suggesting a difference in the treatment of the samples or in the behaviour of the environmental parameters. It is important to note, however, that this difference was not significant, demonstrating some dependence on the variable 'y'. Regression analysis between conductivity and Σ anions (Fig. 4B), with R=0.674, suggests that 45.5% of the dependent variable was explained by the predictive variable. In this case, the F testindicated an F_2=65.05 > F.05(1;79), rejecting the hypothesis of the events presenting similar behaviours. The cations should be being liberated gradually for water column from erosion processes of the matrix rock, what explains the conservative state of the ions. Especially in the Western Amazon, the white water rivers, originating in the Andean and pre-Andean regions, present high calcium content due to the geological characteristics, both in dissolved and particulate form and higher sodium content in the Eastern Amazon region due to the proximity with the coastal zone and ocean. These components, especially Ca^{2+}, must be rapidly precipitated as $CaCO_3$ that is more insoluble. On the other hand, the anions may be continually renewed from the conversion of CO_2, especially between wells 14 and 20, where parameters such as pH and alkalinity were higher.

Fig. 5 shows the spatial similarity dendrogram for the sampling sites (Fig. 5A) and for the environmental parameters (Fig. 5B). In general, the results showed the formation of four distinct groups of sampling sites (Fig. 5A): the first group was formed by the sites {11, 14 and 18-20}, and with a matrix distance of fear than 100 units. In that group are the sampling sites located in the treatment plants of the Cia. COSANPA, and that in a certain way they must present a standard resulting from the simple disinfection system adopted (addition of hypochlorite). The second group was formed by the sites {4, 6, 7, 10, 12 and 16}. It is a very variable group from the point of view of sampling areas, presenting sites in residences, hospitals and schools. Despite this, it presented an aggregation with a matrix distance of fear than 100 units. The third group was formed by sites {2, 5, 8, 9, 15}, which is the one that least presents a spatial pattern, and the sampling sites are totally dispersed within the municipality. The fourth group was formed by the sites {1, 3, 13 and 17}, located within the same micro-region. In general, the aggregation of the sampling sites was associated with the geological conditions and to the use and occupation of the soil in each micro-region. The dendrogram established for the environmental parameters (Fig. 5B) suggested a greater association between the variables {pH, alkalinity and hardness} and between the variables {BOD, total coliforms, fecal coliforms and DO). The first subgroup presents as correlation pattern the

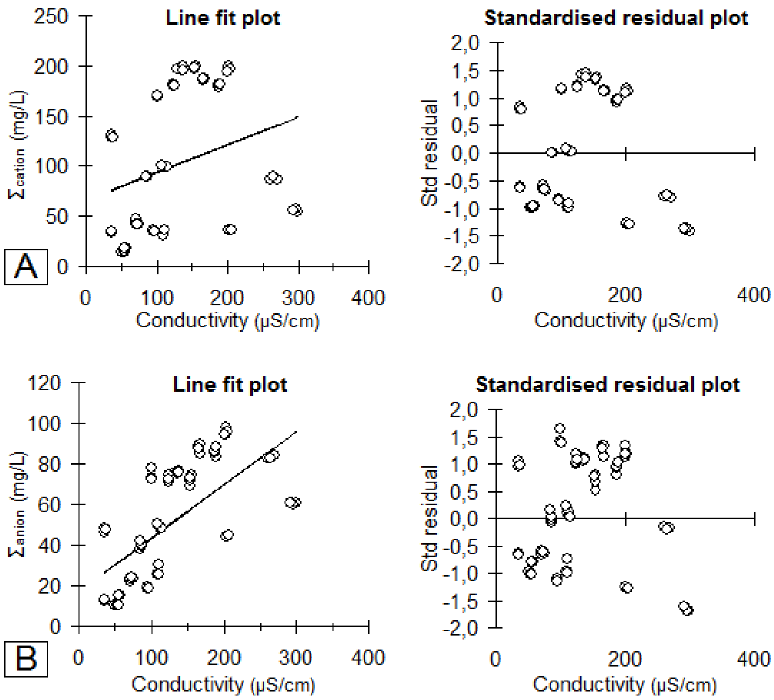

Fig. 4. Linear regression analysis of EC and A) Σ of cations and B) Σ of anions of wells monitored in the municipality of Abaetetuba (PA, Brazil) between 2012 and 2016.
Data: n=80.

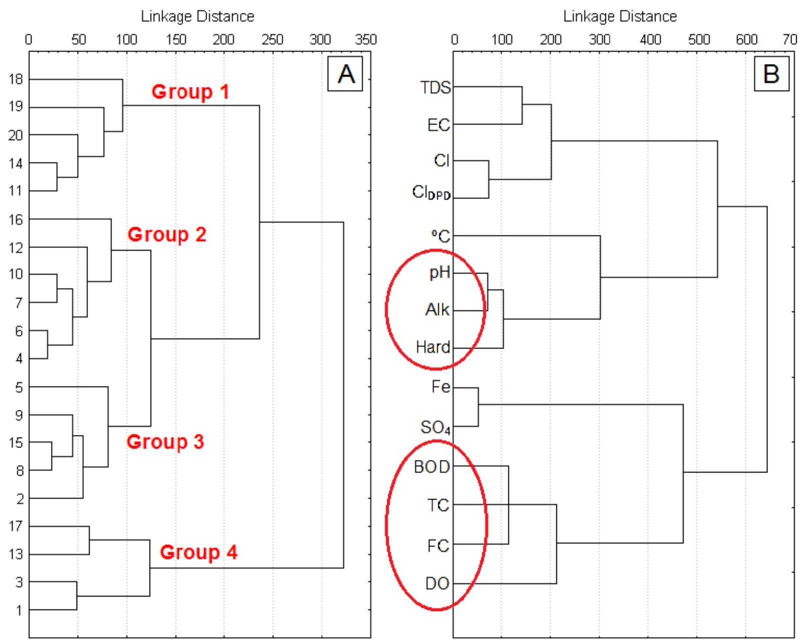

Fig. 5. Dendrogram of spatial similarity for A) sampling sites; B) environmental parameters of wells monitored in the municipality of Abaetetuba (PA, Brazil) between 2012 and 2016

capacity of buffering of the water system by the action of carbonate ions. The second group was correlated with the presence of organic compounds and the oxygen consumption in their oxidation.

The results suggest a low quality of the water intended for public supply, especially due to the high degree of bacteriological contamination present in the samples. In all wells monitored, the BOD, total coliform and faecal coliform values were out of the permitted standard by law. There is strong evidence that the maintenance need and the neglected manipulation of wells by unauthorized personnel are responsible for the biological contamination of water. Studies carried out by other authors in other wells in the municipality and in the Metropolitan Region of Belém suggest a significant discrepancy in the results of aquifer water quality evaluation, indicating degradation and low quality of groundwater used for both organic and inorganic pollution [6-8,10,33].

4. CONCLUSION

In general, the analytical results showed good water quality, staying within the limits established by environmental legislation [21-23]. However, when analyzed under the biological standard, the totality of the samples presented some degree of bacterial contamination, being outside the standards of supply described in the legislation. The presence of fecal coliforms in the water samples was indicative of contamination in the vicinity of the wells, due to diverse factors, such as: improper piping installation; lack of cleaning and maintenance of wells and cisterns; inadequate maintenance of the water distribution network in the treatment plants; wells installed in inadequate areas, with accumulating rainwater; inadequate water use, and presence of unauthorized personnel for handling of the wells. These were the main reasons identified during the monitoring, which should be contributing to the contamination of the waters destined for the public supply. The history of waterborne diseases, especially in the children of the region, corroborates the results obtained in this research. The final conclusion is that most of the wells in operation do not meet the minimum sanitary conditions to supply the population with quality drinking water.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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