International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-9, Issue-8; Aug, 2022
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.98.42

Spatial Characterization of Water quality for human consumption from well in the county of Barcarena - PA

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Received: 25 Jul 2022,

Received in revised form: 14 Aug 2022,

Accepted: 19 Aug 2022,

Available online: 24 Aug 2022

***Keywords*— groundwater, contamination, potability; index**

***Abstract*— *The exploitation of groundwater in the world assumes an important role due to its low cost, but this facility makes it more vulnerable to contamination. In this context, this study characterized the physical-chemical, toxicological and microbiological aspects of 165 samples of water for human consumption from wells from different sources of supply in the county of Barcarena-PA, which is divided into two regions: Barcarena headquarters and Industrial, in the period from 2017 to 2019. A water quality index was prepared to assess the water quality standard. Total Coliform bacteria were detected in 43.64% and E. coli in 15.76% of the water samples, most of which were untreated. Considering the physical-chemical and toxicological parameters, some, such as pH and aluminum, presented average values in disagreement with Brazilian legislation. Thus, a heterogeneity of contamination was observed in the Headquarters and Industrial regions, where the first presented alteration in the physical-chemical and microbiological parameters and the second, greater amount of metals and lower pH values. As for the index, only three categories of water quality were evidenced in the municipality: low, medium and high, which were distributed differently among the studied areas, supporting that environmental contamination occurs for different causes.*

I. INTRODUCTION

The groundwaters are formed by the precipitation that directly or indirectly infiltrates the soil surface. It can be collected for human consumption in a deeper confined or artesian aquifer which is located between two relatively waterproof layers, that hardens its contamination, or be collected in an unconfined or free aquifer next to the surface, which is susceptible to contamination[1].

In this sense, the groundwater exploration in the world assumes bigger proportions due to the uncountable advantages as the water quality, the costs of exploration and the simplified treatment for consumption, assuming an increasing importance as source of supply and being recognized as alternative to the users for the increasing use in last year's[2][3].

However, the anthropic influence about these water quality, due to the agricultural activities, urban and industry exceeds the natural capacity of the underground and underlying layers evidencing the contaminant effects of these activities[4].

In that way, Barcarena county fits with one of these cities, which economies was based in implantation of big projects that provides the implementation of a industrial complex, and, however, despite the increasing the county has no significant economic development, reflecting the lack of infrastructure, population growth, use and occupation of the soil and the water resources degradation [5][6]. As a result, the mining activity in this county has caused environmental impacts, which is related by population and local authorities[7].

Associated with the chemical pollutants from mining activities, it can't be ignored the biological water pollution due to the presence of pathogenic microorganisms, generally originated from fecal material, that reaching the supply network or others potable water sources consumed by population, it can be unchained a epidemic outbreaks of intestinal diseases, affecting a large number of people in short period of time[8].

Therefore, the water consumption security must obey the standards of potability, which demands important conditions to public health and well-being. It has to be as the Brazilian legislation demands to which states the maximum allowed values (MAV) to the bacteriological indicators, organoleptics, physical-chemical and toxicological of water could classify it as potable[09].

Thus, because of the factors previously cited, the creation of a water quality index through the potable indicators urges the necessity of an appliance which provides information and makes easy the interpretation about water quality due to the large number of variables related[10]. The determination of indices to characterize the springs quality, on surface or underground, to the many uses has a function to facilitate the communication with the public and also allow the general determination of the trend of evolution in water quality over time, as well as comparisons between different water sources[11].

Therefore, the mapping of the vulnerability of the aquifers to contamination helps the environmental planning and management, serving as a decision instrument[12]. In this way, the objective of this research was to identify the most vulnerable areas to the population supplied by water from underground wells, whose quality of physical, chemical, toxicological and microbiological parameters compromises and brings risks to the population health in the county of Barcarena/PA.

II. MATERIAL AND METHODS

Study area: The monitored area was Barcarena county, Pará state, located to 01°30'21'' of latitude south and 48°37'33'' of longitude west. 165 samples of water of 22 neighborhoods divided in Barcarena Headquarters and Industrial Area were analyzed (Figure 1), collected from 2017 to 2019, whose results are available in the data base of the Public Health Laboratory of Pará state.

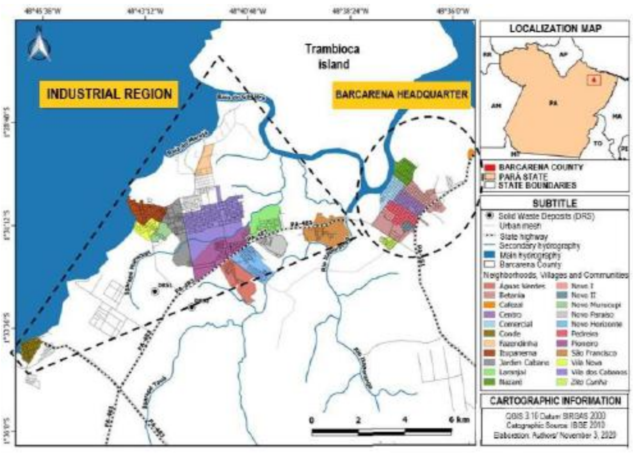


Fig. 1: Collection points of water samples of human consumption in the county of Barcarena-PA analyzed from 2017 to 2019. Source: Authors, 2021.

The evaluation criteria of the potable water supply system (WSS), alternative collective solution (ACS) and the alternative individual solution (AIS) of consumption water in Barcarena county, as well as the samples number, strategic sites of investigation, physical,chemical variables, microbiological and toxicological were evaluated according to Brazilian legislation to water potability[9].

Collection and analysis procedure: The collection was according to the technical rule NBR 9898 - Preservation and sampling techniques of liquid effluents and receptors bodies. The water samples volumes of the wells were collected directly using sterile bottles. This volume was fractionated in a nasco-type sterile collection bag with an identification stripe, as presented in figure 2[13].

Fig. 2: Collection procedures of water samples of human consumption in the county of Barcarena-PA analyzed from 2017 to 2019. Source: Authors, 2018.

A collector bag of 100 mL was used to pack the samples to microbiological evaluation with sodium thiosulfate tablets in cases of treated water, so the residual chloros could be neutralized.

A collector bag with 532 mL was used to pack the samples to the realization of pH, hardness, turbidity, apparent color, total dissolved solids, chloride content, ammonia content, nitrate content, nitrite content and sulfate content. To the analysis of heavy metals, 15mL of water from the sample was removed. These collectors' bags were transported under refrigeration conditions in a thermal box with recycled ice until its arrival in the laboratory. The physical-chemical, toxicological and microbiological variables were determined by the procedures and recommendations described in the *Standard Methods for Examination of Water and Wastewater*, whose methods are cited in the board 1[14].

Board 1: Methods to determine physical-chemical, toxicological and microbiological parameters in water for human consumption.

Parameter	Analytical Method
Nitrogen Series (nitrate, nitrite and ammonia) and sulfate	Colorimetric
Turbidity	Nephelometric
Total dissolved solids	Conductivity meter
Chloride and hardness	Titration
Apparent color	Spectrometry
pH	pHmetry
Heavy Metals (Al, Ba, Cd, Pb, Cu, Cr, Fe, Mn, Ni, Na and Zn)	Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES)
Total coliforms	Enzyme Substrate
E. coli	Enzyme Substrate with fluorescence

Index creation: The creation of the potability index (PI) was based in the mathematical model of change in binary basis values in decimal numeration, according to the calculations below, where n is the binary value of 0 and 1, whose 0 corresponds to the samples variables characterized as unsatisfactory and 1 the satisfactory to the microbiological, physical-chemical and toxicological parameters established in the Brazilian legislation[15].

$$IP = \sum_{i=1}^{23} 2^n * X_i \quad (1)$$

The variable X was the weight given to each variable, that was defined following from the higher weight to the most restrictive from the ordinance until the weight 0 for the more restrictive parameter. Thus, after the calculations of PI, a control diagram for the obtaining of the categorization of the samples was developed. Following, the water quality was estimated by comparison, a procedure of one rule of control which uses a single criteria that was the potability index and a Levey-Jennings graphic, with control limits calculated with μ ± 1DP (mean μ ± 1 standard deviation). Thus, it was possible to categorize the samples in 4 quality groups: low, medium, good and excellent. The mean of the Potability Index for each neighborhood was plotted in a map according to the localization of the collection point using the QGIS program.

Statistical Analysis: The data from the 165 samples were submitted to parametric test analysis as the descriptive statistic and qui-square (G test), with the data of physical-chemical, microbiological and toxicological parameters.

The descriptive statistic was used to evaluate the accordance in the legislation of the physical-chemical and toxicological parameters, obtaining the values of medium, minimum, maximum and standard deviation. To evaluate if the contamination distribute itself homogeneously in the two areas of the county, it was applied the Mann-Whitney test, and the statistical significance was accepted in 5%. The software used was the Bioestat 5.0 proposed by Ayres et al[16].

Table 1: Water categories for human consumption according to the Potability Index (PI) evaluated in the county of Barcarena - PA analyzed from 2017 to 2019.

Colors	Categories	Weighting
(red)	Low	≤ 4461311
(yellow)	Medium	> 4461311 ≤ 6726636
(green)	Good	> 6726636 ≤ 8991960

	Excellent	> 8991960

Source: Authors, 2019

III. RESULTS

This study analysis revealed that the samples of water for human consumption, 46.06% (76/165) was from the WSS, 17.57% (29/165) of ACS and 36.37% (60/165) of AIS. From these, 46.06% 976/165) was treated and 53.34% (89/165) non-treated. From the collected samples, 69.70% (115/165) was from the industrial area and 30.30% (50/165) of the Barcarena headquarters.

Microbiological, physical-chemical and toxicological parameters: Total coliforms (TC) was observed in 43.64% (72/165), and the E. coli in 15.76% (26/165) of the total quantity of analyzed samples. The figure 3 demonstrates the distribution of the presence of these microorganisms in treated and non-treated waters, with origins in WSS, ACS and AIS. TC presence was observed in 64.04% (57/89) in the samples of non-treated water, with origins in ACS and AIS, and in the treated water, from WSS, this bacteria was detected only in 19.74% (15/76). In relation to the E. Coli presence, it was detected in 1.32% (1/76) of the treated water, from WSS, as the detection percentage of this bacteria in the non-treated water samples reaches 28.09% (25/89), a proportion that differs significantly by the binomial test for TC (p<0.0001) and E. Coli (p<0.0001).

In relation to the physical-chemical and toxicological parameters, the non-treated water samples, the pH and aluminum presented differences in relation to the limits established by the Brazilian legislation. About the pH, this was below the range indicated for potable water, demonstrating values mean of 5.22, whose indication of satisfactory must be between 6.0 and 9.5. About the aluminum, the maximum allowed value (MAV) is 0.2 mg/L, however, the measure means demonstrate value of 0.39 mg/L.

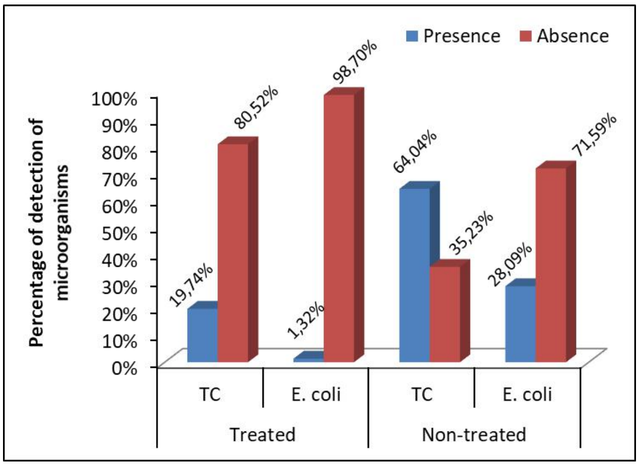


Fig. 3: Microorganisms frequency detected in water samples for human consumption collected from 2017 to 2019 in the county of Barcarena - PA.

Spatial distribution in Barcarena region: In relation to the spatial distribution of physical-chemical, toxicological and microbiological parameters, it was observed a heterogeneity of contamination in these waters for human consumption. The basic parameters, such as ammonia, chloride, hardness, pH and SDT presented higher concentrations in the region of Barcarena headquarters associated with the median. On the other hand, the industrial region demonstrates low quantities of these indicators and higher metal contents such as chromium, iron, manganese, sodium and zinc also in relation to the median. These distributions were significant between the headquarters and industrial regions by the Mann-Whitney test (Table 2).

In relation to the microbiological parameters, it was observed distribution statistically different in relation to the presence of E. Coli, when compared to the headquarters and industrial regions (χ^2 = 4.616; gl= 1; *p-value* = 0,0317), being more significant in the region of Barcarena headquarters where it was detected in 26% (13/50) against 11.30% (13/115) of the industrial region (figure 4). In relation to the presence of TC, the proportions verified between the regions do not differ (χ^2 =1.582; gl = 1; *p-valor* = 0,2085).

Table 2. Content comparisons of physical-chemical and toxicological parameters in water samples for human consumption between the headquarters and industrial regions of Barcarena - PA.

Parameter	Barcarena Region		Mann-Whitney test	
	Headquarters (N = 50)	Industrial (N = 115)	Z (U)	p-value
Ammonia				
Sum of ranks	4640.5	9054.5	1.7392	0.0410*
Median	0,12	0,09		
Chloride			2.9022	0.0037
Sum of Ranks	4968.5	8726.5		

Parameter	Barcarena Region		Mann-Whitney test	
	Headquarters (N = 50)	Industrial (N = 115)	Z (U)	p-value
Median	33.50	20.00		
Hardness				
Sum of Ranks	4855.5	8839.5	2.5015	0.0124
Median	50.00	40.00		
pH				
Sum of Ranks	4919.0	8776.0	2.7266	0,0064
Median	6.21	5.49		
SDT				
Sum of Ranks	5889.5	7805.5	6.1678	<0,0001
Median	119.35	51.24		
Chromium				
Sum of Ranks	2823.5	10871.5	4.7034	<0,0001
Median	0.01	0.03		
Iron				
Sum of Ranks	3424.5	10270.5	2.572	0,0101
Median	0.02	0.04		
Manganese				
Sum of Ranks	4670.5	9024.5	1.8455	0.0325*
Median	0.01	0.01		
Sodium				
Sum of Ranks	5414.0	8281.0	4.4818	<0,0001
Median	20.17	6.53		
Zinc				
Sum of Ranks	3311.0	10384.0	2.9748	0.0029
Median	0.01	0.02		

This study also showed that 63.64% (105/165) of the water offered to the population of the county of Barcarena came from the public supply system, whose main source of abstraction is groundwater, where 72.38% (76/105) come from WSS, which go through at least two treatment phases (filtration and chlorination) and 27.62% (29/105) come from ACS, they are only captured and distributed in the supply network without treatment. A good part of the population is still not assisted by the water concessionaire, this study estimated that 36.36% (60/165) of the residents obtain water from an individual alternative solution (Table3).

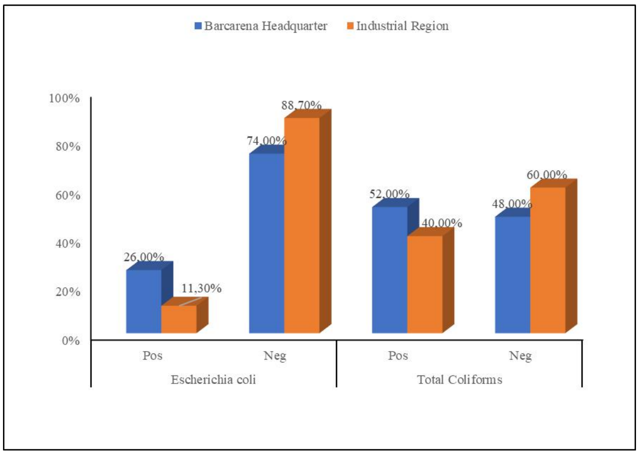


Fig. 4: Comparison of microbiological indicators between the Headquarters and Industrial regions of Barcarena-PA detected in water for human consumption.

Table 3. Distribution of water samples according to the quality categories between the headquarters and industrial regions according to water type.

Sample distribution	Low		Medium		Good		Total	
	N	%	N	%	N	%	N	%
Industrial	13	**11,30%**	33	**28,70%**	69	**60,00%**	115	69,70%
WSS	1	1,92%	8	15,38%	43	82,69%	52	45,22%
ACS	1	4,76%	13	61,90%	7	33,33%	21	18,26%
AIS	11	26,19%	12	28,57%	19	45,24%	42	36,52%
Non-treated water	12	19,35%	24	38,71%	26	41,94%	62	53,91%
Treated water	1	1,89%	9	16,98%	43	81,13%	53	46,09%
Headquarter	13	**26,00%**	13	**26,00%**	24	**48,00%**	50	30,30%
WSS		0,00%	5	20,83%	19	79,17%	24	48,00%
ACS	2	25,00%	1	12,50%	5	62,50%	8	16,00%
AIS	11	61,11%	7	38,89%		0,00%	18	36,00%
Non-treated water	13	48,15%	8	29,63%	6	22,22%	27	54,00%
Treated water		0,00%	5	21,74%	18	78,26%	23	46,00%
Total	26	15,76%	46	27,88%	93	56,36%	165	100,00%

The distribution of the water categories (low, medium and good) revealed significant differences in relation to the areas headquarters and industrial (x^2 = 9,443; GL = 2; p valor = 0,0239), where 74.19% (69/93) of the samples of good quality were detected in the industrial region against 25.81% (24/93) of the observed in the headquarter region, this proportional distribution was statistically significant (z = 6.5991; p-valor < 0.0001).

In relation to the treatment, most of the samples of good quality was treated (80.26%), significantly differing of the non-treated samples and of low quality (28.09) (x2 = 42.2803; GL = 2; p < 0.0001), however, when comparing the distribution of the supply of treated water in relation to the regions of Barcarena, no statistical differences were observed (Figure 6).

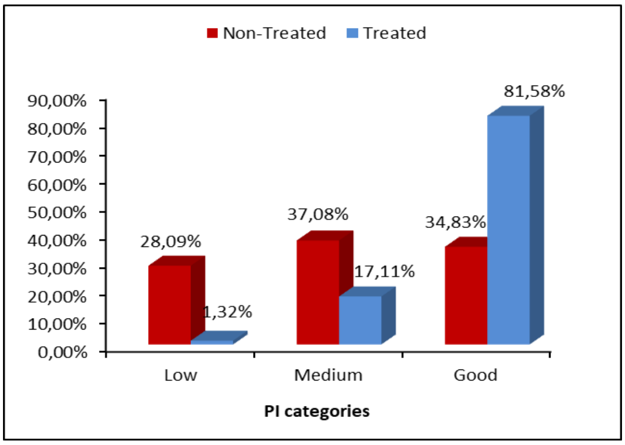
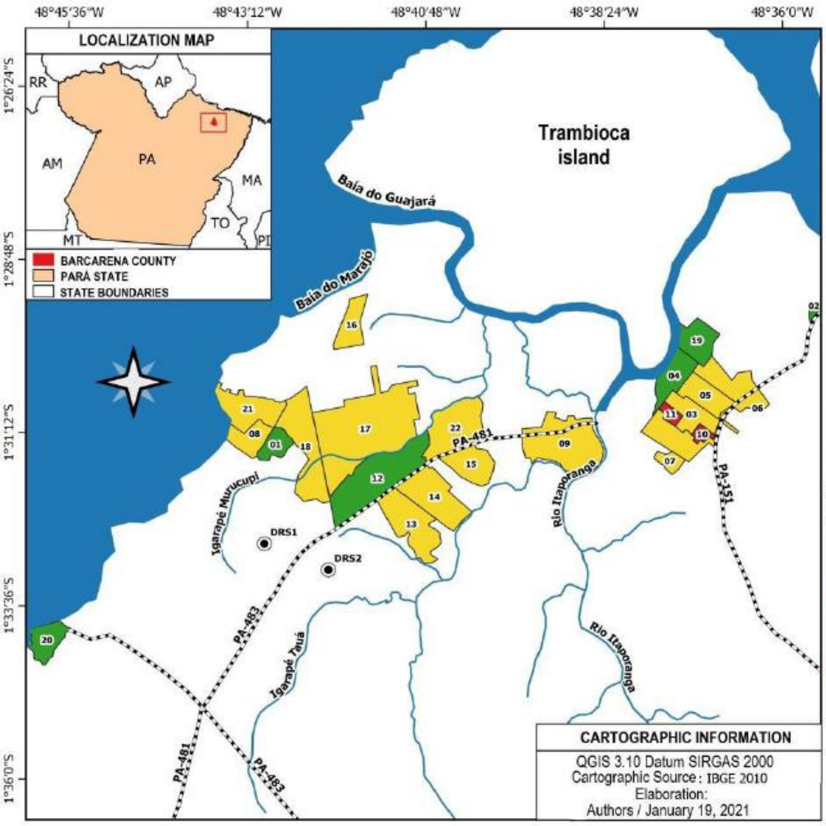


Fig. 6: Frequency of treatment of water for human consumption according to the quality categories in the county of Barcarena-PA collected from 2017 to 2019.

Potability index (PI): The mean of the potability index evidences that the county presented only categories low, medium and good of water quality (figure 5).



ID	NEIGHBORHOOD	CATEGORY	INDEX MEAN	SAMPLE N
01	Novo Murucupi	Good quality	8056616	4
02	Vila Cafezal	Good quality	6475511	6
03	Pedreira	Medium quality	5398809	4
04	Comercial	Good quality	6744989	9
05	Centro	Medium quality	6405801	18
06	Betânia	Medium quality	6375286	6
07	Zito Cunha	Medium quality	6481324	3
08	Vila Nova	Medium quality	5485669	6
09	São Francisco	Medium quality	6623135	13
10	Novo II	Low quality	1506302	1
11	Novo I	Low quality	2096126	1
12	Pioneiro	Good quality	6760532	15
13	Águas Verdes	Medium quality	5994464	5
14	Novo Horizonte	Medium quality	6419650	8
15	Novo Paraíso	Medium quality	5453421	2
16	Fazendinha	Medium quality	4508465	2
17	Vila dos Cabanos	Medium quality	6588061	21
18	Jardim Cabano	Medium quality	6475511	9
19	Nazaré	Good quality	8388606	1
20	Vila do Conde	Good quality	6789351	12
21	Itupanema	Medium quality	6521240	5
22	Laranjal	Medium quality	6690412	14

Fig. 5: Distribution of water samples according to quality categories in the Headquarters and Industrial regions in the county of Barcarena-PA.

IV. DISCUSSION

Microbiological, physical-chemical and toxicological parameters: The presence of microorganisms, total coliforms (64.04%) and E. coli (28.09%) in the wells waters that provide natural waters (non-treated), were categorized as unsatisfactory for human consumption according to the Brazilian legislation, being explained by the superficial wells (amazon wells) with depth minor than 50 meters, as the majority in this region. These aquifers unconfined are susceptible to contamination[7]. However, the depth of these wells wasn't evaluated in this study characterized as a limitation.

The studied wells from alternative individual solution, characterized as non-treated water, the results of physical-chemical parameters were different from the accepted by Brazilian legislation, for example the pH, whose samples was below from the accepted parameters between 6.0 to 9.5. The slightly acidic characteristic are due to the geological aspect of the region, where the natural tendency of the pH is slightly acidic to neutrality and/or the anthropogenic aspects which improved the organic matter decomposition, that results in acidic derivades as the humic acid, with pH reduction as consequence[18][19][20]. The low values of pH in amazon wells were also found in a study by Silva et al[7], that measured mean values for pH of 4.30 in wells in these same standards in this county. The toxicological aluminum parameter presented an increase in the maximum value, that according to Ferreira Filho[21] is explained by the fact that the pH around 4.8 to 6.0, this element becomes soluble in liquid phase.

Therefore, confronting this information with the pH medium value of 5.22 of non-treated water, with the medium value of Al of 0.39 mg/L, it can be noticed that the increase of Al are due to the pH value decrease, needing a correction strategy of pH for the population supply of treated water through prior alkalinization at source, as recommended by current Brazilian legislation

The presence of elevated concentrations of Al can be reflected by the contamination of the groundwater due to the existing mining activity in the region, which processes bauxite and kaolin. This increase is even more worrying in samples from non-treated water, whose average value was above that allowed by Brazilian legislation, corroborating studies carried out by Silva et al[22], who demonstrated high levels of metal in the soil of this same region at depths of up to 50m, one explanation being the detection of this metal in wells.

The production of red mud through alumina industries around the world and even in this region constitutes an environmental problem of considerable proportions, due to the volume of this generated passive and its causticity. Red mud is mainly formed by Al2O3, Fe2O3, TiO2 and SiO2. And additionally, by the oxides of K, Pb, Cu, Ni, V, Ga, P, Mn, Mg, Zn, Th, Cr, Nb that may be present as trace elements[23]. An alumina industry can generate 0.5-2 tons of dry solids of red mud for every ton of alumina produced. Furthermore, up to 2 tons of 5-20 g/L caustic liquor (as Na2CO3) can accompany each ton of dry mud solids due to the Bayer process used for the beneficiation of bauxite[24]. Therefore, it is a factor to consider in the detected increase of this element in the groundwater of this region.

Spatial distribution in the Barcarena Region: According to Souza et al[25] the aquifers around the industrial pole of Barcarena are highly vulnerable to contamination and this characteristic is mainly due to the fact that the aquifer is free, associated with the lithological characteristics of the unsaturated zone. Since residues are deposited in the area that have soluble substances in their composition, which, in case of leakage, can easily reach the groundwater aquifer, which may explain the results of this study, where the potability indices of the water consumed by this population showed heterogeneous distribution, in which most samples contaminated by metals are located in this Industrial region of Barcarena, differing from the pollution observed in the headquarters region, which concentrates a greater risk of contamination by domestic effluents (sanitary sewage), with the detection of microbiological indicators present.

Potability Index (PI): Through the PI, it was possible to observe that locations such as those found in urban centers such as Cabanos village, New Murucupi and Laranjal, which are mostly supplied by WSS, inserted within the Industrial region considered a more recently built and supplied by public systems with treatment based on aeration, filtration, and chlorination, had their categories, within the PI, between medium and good quality.

On the other hand, locations such as New I and II, located in the Barcarena headquarter region, whose supplies are mostly provided by AIS in Amazon-type wells, these samples had their indexes considered of low quality in relation to the criteria of potability, since microbiological indicators were the parameters with the highest weights within the PI calculation because they are considered more restrictive within Brazilian legislation and their presence consequently determines the intake of water outside the standards established for human consumption.

V. CONCLUSION

The determination of the Potability Index (PI) made it possible to identify that the most vulnerable areas are those that use alternative solution wells because these waters are not properly treated. On the other hand, the areas supplied by the public water system have better potable quality due to the treatment provided.

These vulnerable areas, supplied by groundwater, have high concentrations of Al, in addition to the presence of microorganisms of the total Coliforms group and E. coli, making them unfit for human consumption. These places are fragile due to frequent environmental accidents and the susceptibility to infiltration of domestic sanitary sewage, since little importance has been given to the drilling of wells in communities, with wells built using adequate techniques, thus compromising the quality of the water to be distributed to the population.

Thus, it is up to the health surveillance to guide users and other institutions involved about the need and, above all, the importance of adopting corrective measures, thus seeking greater protection at the source of water supply so that safer water is provided to the population.

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