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Assessment of the quality of water for consumption by river-bank communities in areas exposed to urban and industrial pollutants in the municipalities of Abaetetuba and Barcarena in the state of Pará, Brazil

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Abstract *In spite of the great technological advances in processes for treatment of water for human consumption, water actually used for supply has become a major public health challenge. This study assesses the quality of the water consumed in two riverside communities in the Brazilian state of Pará, in an area exposed to domestic and industrial pollutants. Four campaigns of sampling were carried out in the two communities. The variables used for the calculation of the water quality index – Índice de Qualidade da Água, or IQA – were: pH, total solids, chloride, fluoride, hardness and N-Nitrate. The waters used for human consumption in the* Maranhão Community, *where there is no contamination by industrial pollutants, presented adequate samples, with improvement in the dry season; on the other hand the waters of the* Vila do Conde, *a location close to the industrial activity, had quality that was unacceptable for human consumption in both the seasonal periods. The principal parameters affected were pH and N-Nitrate, with values up to 25 times the reference level of the Brazilian legislation for water for human consumption. These results indicated greater anthropic interference in the vicinity of Vila do Conde, in Barcarena. It is concluded that this population is in need of clinical assessments by specialized professionals on the state of its health.*

Key words *Index, Water quality, Water for human consumption, Environmental exposure, Health*

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Introduction

Water is an essential good that ensures the population's health, and is thus considered a priority for action in environmental health oversight in Brazil[1]. However, non-sustainable patterns of development have worked in favor of degradation of the environment, as a result of significant alterations in the natural environment, and destruction of various ecosystems (including especially aquatic systems), which lead to changes in the patterns of distribution of diseases and in the health conditions of various population groups[2].

Article 200 of Brazil's 1988 Federal Constitution attributes the duty of oversight and inspection of water for human consumption, and participation in policy and execution of basic water services, to the Brazilian Single Health System (*Sistema Único de Saúde,* or *SUS*)[3]. An enabling law under the Constitution, the Organic Health Law (Law 8080/1990), in its Article 6, also lays down specifications for the field of activity of the SUS in relation to oversight/inspection of water for human consumption in Brazil[4].

The debate on questions relating to water quality, and consequently, the activity of the Health Ministry in governing parameters of potability is not recent. The competency for preparing rules and standards for potability of water for human consumption has been a duty of the Health Ministry since 1977. And it was thus that Oversight of Quality of Water for Human Consumption was the first area of oversight in environmental health in Brazil[5].

This inspection and oversight of quality of water for human consumption is applicable to the various forms of supply of water – in public and private management; in city and rural situations; and in indigenous areas and isolated communities. The forms of supply of water can have very varied characteristics. For example, water may be distributed by a network or transported by vehicles; supply may be restricted to a single household or may be for various districts or municipalities; water tables from which water is collected may be on the surface or underground; the treatment may be complete, or may be simplified – with only disinfection. In all these, monitoring of water quality is the instrument of verification of potability of water for human consumption, according to a standard established in legislation. For monitoring or water quality, laboratory analyses of samples are required to be carried out, in accordance with specific sampling plans for this control, which are described in the Drinking Water Rules (*Norma de Potabilidade da Água*), and in accordance with the oversight sampling plans, described in the National Directive of the Oversight Plan (*Diretriz Nacional do Plano da Vigilância*)[6].

The standard of potability in Brazil is established in Ministerial Order GM/MS 2914, of December 12, 2011, which governs *Procedures for control, monitoring and oversight of quality of water for human consumption, and its standard of potability*, and also establishes the competencies and responsibilities attributed to the public health authorities (the Oversight function), in the three spheres of management of the SUS, and the people responsible for the system, or for providing an alternative collective solution for supply of water for human consumption (the Control function)[7].

The action of Vigiagua demonstrates and confirms that management of water resources in Brazil involves great difficulties. Waters collected for purposes of public supply are increasingly adversely affected in terms of quality and quantity, and even subterranean waters that have the barrier of the soil as protection are more vulnerable to the environmental pollutants arising from anthropogenic sources such as domestic waste, industrial waste, leaching of slurry from sanitary landfills, etc.[8,9].

There is no doubt that the productive economic activities of mining, hydroelectric power, timber, agribusiness and other sectors bring great benefits for the development of the country. On the other hand, there are many risks in the physical environment surrounding these productive areas – that is to say, the negative social and environmental effects of these activities can disorganize, and even destroy the feasibility of, human settlements and their interactions with nature, damaging the environment, causing disease and poverty. The production model of the municipality of Barcarena, in the state of Pará, suffered an intense impact from the Albras/Alunorte complex, which produces aluminum and some of its by-products, and had the support of the State in that approximately 40,000 hectares were compulsorily purchased for it to be built. Large areas were deforested and the local population which, prior to the construction of this industrial complex used natural resources such as fishing and hunting for its subsistence, needed to adopt other bases of production for its economic survival. There was intense migration of population to other areas of the municipality, and since this migration enjoyed no urban planning of any sort by the managers, the result was agglomeration of buildings in the form of slums and an overburden of population[10].

At present, the municipality of Barcarena (in the state of Pará), not unlike other Brazilian municipalities, faces problems of lack of adequate water services, absence of housing policies, precarious health services, etc. As well as these aggravating factors, there are frequently environmental accidents around the industrial area, resulting in pollution/contamination of surface and underground bodies of water and other elements of the environment, causing considerable damage to flora, fauna and the health of the population[11,12].

That is the context of this study which presents results of monitoring of underground water sources used for human consumption around the riverside communities that are exposed to pollution and environmental contaminants in the municipalities of Abaetetuba and Barcarena in the State of Pará.

Materials and methods

Description of the area of the study

Abaetetuba and Barcarena are large municipalities in the State of Pará with estimated populations (in 2014) of 148,873 and 112,921, and reported territorial areas of 1,610.108 and 1,310.588 square kilometers, respectively[13]. They are to the southwest of the city of Belém, about 90 km from its center, and are within the basin of the Pará River.

The hydrogeological systems of Abaetetuba and Barcarena were classified according to the classification criteria of Belém and Ananindeua, based on the proximity of the areas and similar geometric configurations identified in the lithological profiles. According to those authors, there are five hydrogeological systems in the area corresponding to these two municipalities, formed by aquicludes, aquitards and aquifers belonging to the stratigraphic units Pirabas, Barreiras and Quaternary Cover. These systems are referred to as Alluvium, Post-Barreiras, Barreiras, Upper Pirabas and Lower Pirabas, with predominance of the Barreiras group in these areas and other regions of the Pará River. Close to the principal surface bodies of water, however, the predominant systems are the Alluvium[14].

Maranhão and the Vila do Conde Community are in the municipalities of Abaetetuba and Barcarena, respectively, both in the State of Pará, at the geographical coordinates 1°40’ 10.58” S / 48°49’12.26” W and 1°34’3.17” S / 48°45’55.36” W (WGS 84). Maranhão Community (*Comunidade Maranhão*) is approximately 8.5 km (in a straight line) from the city of Abaetetuba, Pará, and 12 km from Vila do Conde, in Barcarena, Pará (as can be seen on Google Earth), with access by State Highway PA-252 and Ramal do Maranhão, a riverside community on the left margin of the river Guajará do Beja, which is a tributary of the Pará River. Vila do Conde is one of the districts of the municipality of Barcarena, and is located around the port area of Vila do Conde, where there are industrial companies that process and export kaolin, alumina, aluminum and electricity power cables, and several companies producing agribusiness products[10,11,13].

The water consumed in both locations originates from subterranean aquifers, and there is no type of treatment in these sources of supply – there is only capture of the source water, channeled or otherwise, storage in water tanks or raised reservoirs, and distribution to the points of consumption. The well that is used for the general supply in Vila do Conde – through piped distribution by the water service of the municipality – functions intermittently – i.e. not 24 hours per day.

Collection of data

Four campaigns of sampling of waters were carried out in 2012, two in the rainy period (January and April) and two in the dry period (August and November), aiming to portray the influence of rainfall and the change in the quality of the waters consumed in the area of study.

In the Maranhão Community, nine (9) individual wells of the open-mouth excavated type were monitored, and one (1) tubular or closed well. In Vila do Conde, the monitoring was carried out at one (1) individual open-mouth excavated well, and six (6) tubular or closed wells – five (5) individual and one (1) collective, administered by the water service of the municipality. Also monitored were waters stored in household recipients in the two locations: for example, clay pots, water filters, flasks in the refrigerator, etc. – these comprised ten (10) sampling points in Maranhão Community and thirteen (13) in Vila do Conde. The water distributed through the supply network was monitored at thirteen (13) sampling points in Vila do Conde – while in the Community this was not possible, because there is no public service of this type.

Analysis of data

The samplings and analyses were carried out respectively according to the recommendations of: (i) the Brazilian *Guide for Collection and Preservation of Samples: Water, sediment, aquatic communities and liquid effluents* (*Guia Nacional de Coleta e Preservação de Amostras: água, sedimento, comunidades aquáticas e efluentes líquidos*)[15] and (ii) the U.S. *Standard Methods for Examination of Water and Wastewater*[16].

The samples of water were collected: in 1-liter polyethylene flasks directly at the wells, using a stainless steel bucket; or in the suction tubing prior to the water tank or reservoir; or from containers used for household storage, considered in this study as household water; and in waters from the collective supply distribution network (taps).

The analyses of pH and total dissolved solids were carried out on Hanna® HI 769828 multiparameter equipment (methods SM 4500B and SM 2540C). Total solids in suspension were determined using a Hach® DR2800 spectrophotometer (UV-VIS, SM 2540D method). The variables chloride, fluoride and hardness ($CaCO_3$ and $MgCO_3$) and N-Nitrate were determined on the Dual Dionex™ ICS-2100 system manufactured by Thermo Scientific™ (USA SM 4110A method).

For the calculation of WQI in underground waters in this study, the variables pH, total solids (sum of total dissolved solids and total solids in suspension), fluoride, chloride, hardness and N-Nitrate were determined. These calculations followed the same criterion for WQI of the National Sanitation Foundation (NSF) and Cetesb (Environmental Water Technology Company of São Paulo State)[17]. The methodologies developed by Oliveira et al.[18], applied to subterranean water through the index of natural quality of subterranean waters (IQNAS) were taken as a point of reference.

This mathematical model developed by Oliveira et al.[18] and Silva et al.[19] was based on the same principle as the mathematical formulation used in the WKI of the NSF and Cetesb, which adopts the product of the values for quality of subterranean water based on the variables chosen through the opinion of specialists in the subject (qpH, q-total solids, q-chloride, q-fluoride, q-hardness and q-nitrate), raised to the weight defined by each variable in accordance with their importance, as per Equation 01:

$$GNQI = \prod_{i=1}^{n} qi^{wi} \qquad \text{(Equation 01)}$$

Thus, the GNQI (Groundwater Natural Quality Index) is represented by a number between 0 and 100, divided into four (4) categories and weightings, that is, from 0 to 36 classifies the waters as in the unfit for human consumption category, from 37 to 51 acceptable, from 52 to 79 good and from 80 to 100 very good; Q_i being the quality of the i-th variable, where i is a number between 0 and 100, obtained from the respective curve of average quality variation (Figure 2), as a function of its concentration or through mathematical equations for the curves of quality vs. concentration; and w_i is the weight corresponding to the i-th variable, a number between 0 and 1, attributed as a result of the importance for global quality compliance (Table 1).

The mathematical models built for the calculation of WQI in subterranean waters were prepared based on quality marks applied to each variable, the mark of 37 being used for acceptable quality at the end of the interval for each variable, taking the values recommended by Health Ministry Order 2914 of 2011 as reference.

For the descriptive statistics, Microsoft Corporation Excel 2013© was used, and the software Minitab 17 OnTheHub Inc.® was used for the Analyses of Principal Components, with rights to use under license.

Since there is no type of chemical treatment directly on the sources of capture of water, and they originate from subterranean aquifers, as a way of comparing the quality of the waters of the subterranean aquifers with the waters collected in households and in the distribution network, the calculation of the IQNAS was also carried out on the household waters and water from the distribution network with the same methodology applied for subterranean waters.

Ethical considerations

Complying with the specifications of Ministerial Order 466/2012, the plan of the study was approved by the Ethics Committee of the Evandro Chagas Institute.

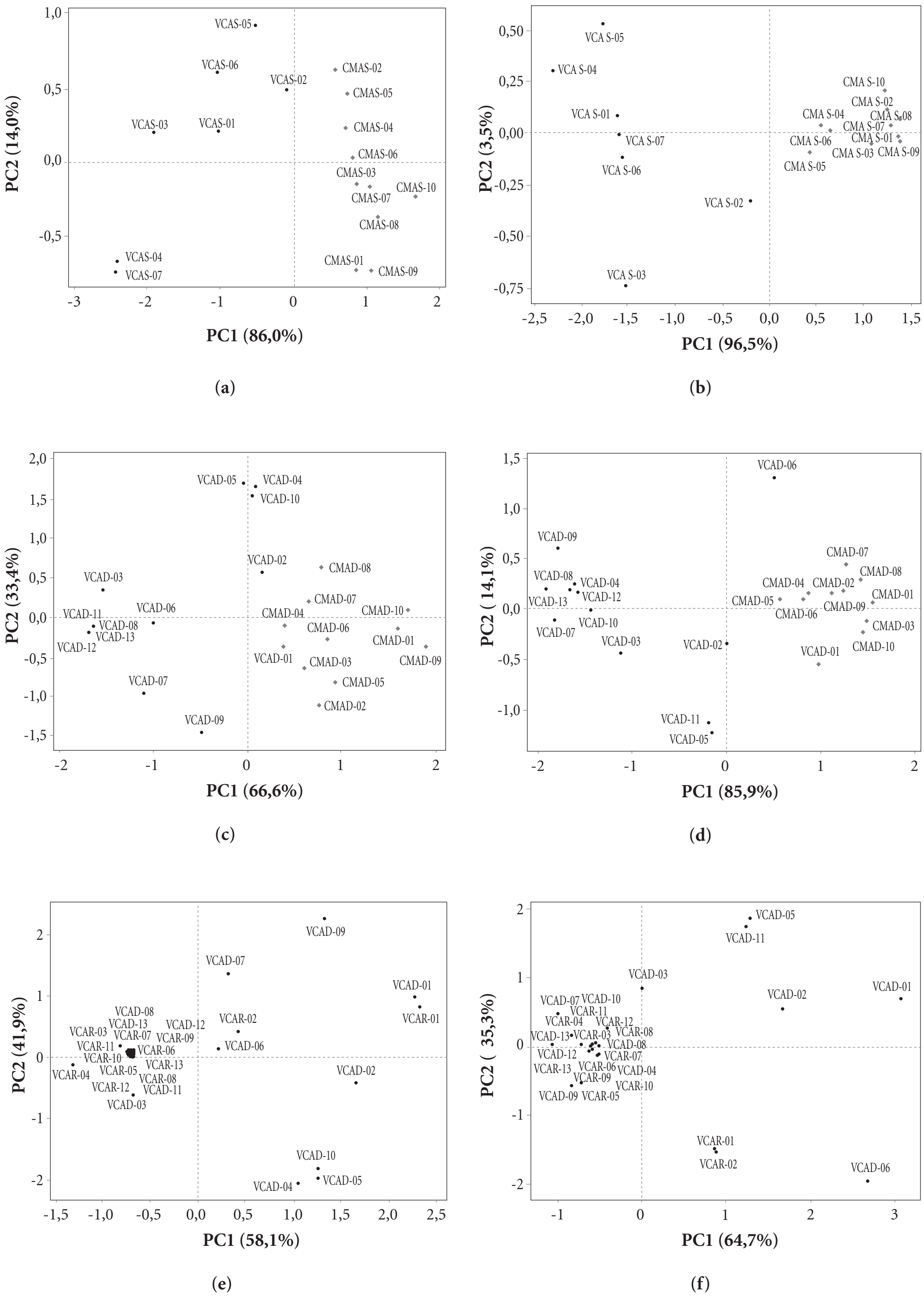

Figure 1. Score-plot analysis of principal components (ACP) on data for subterranean water in rainy period (a), dry period (b) and rainy vs. dry (c); of household water in rainy period (d), dry period (e) and rainy vs. dry (f); and household water and network water in rainy period (g), dry period (h) and rainy vs. dry (i) for the Maranhão Community and Vila do Conde.

Key: VCAS: Vila do Conde underground water; CMAS: Maranhão Community underground water; VCAD: Vila do Conde household water; CMAD: Maranhão Community household water; VCAR: Vila do Conde network water.

Table 1. Mathematical equations of quality curves of the variables pH, total solids, chloride, fluoride, hardness and N-Nitrate for determination of q_i.

Variables	Units	Mathematical equations (q_i)	Validity intervals	R^2	Weight (w_i)
pH	-	$qpH = 1.7354*(pH)^2$ $qpH = 16405*[(pH)^{-2.5}]-17$	[$2 \leq pH \leq 7.34$] [$pH \geq 7.35$]	0.990	0.05
Total solids (ST)					
	mg.L^{-1}	$qST = 79-0.167284*ST+EXP[(ST)^{0.228}]$ $qST = 27.7$	[$0 \leq ST \leq 1630$] [$ST > 1630$]	0.990	0.22
Chloride (Cl-)					
	mg.L^{-1}	$qCl = 100$ $qCl = 138.9*(Cl)^{-0.19561}-(Cl)^{0.42}$ $qCl = 0.0$	[$Cl < 4.86$] [$4.86 \leq Cl \leq 3000$] [$Cl > 3000$]	0.916	0.26
Fluoride (F-)					
	mg.L^{-1}	$qF = 80+21*F-(F)^{11.6263}$ $qF = 0.0$	[$0.0 \leq F \leq 1.5$] [$F > 1,5$]	0.924	0.16
Hardness (DZ)					
	mg.L^{-1}	$qDZ = 100$ $qDZ = 101.1*EXP(-0.00212*DZ)$	[$DZ < 5.4$] [$DZ \geq 5.4$]	0.949	0.16
N-Nitrate (N-NO_3-)					
	mg.L^{-1}	$qN\text{-}NO_3 = 100*EXP(-0.0994*N\text{-}NO_3)$	[N-NO3 $\geq$ 0.0]	0.993	0.15
			Sum of weights		**1.00**

Source: Adapted from Oliveira et al.[18].

Results

The analysis of the waters was carried out separated by source, into subterranean, households and distribution network. Data for distribution network water is presented only for Vila do Conde, because the Maranhão Community does not have this water distribution option.

Underground waters

In the rainy period, the WQIs calculated on the waters of the wells of the Maranhão Community showed acceptable quality (WQI = 46) in 5 % of the samples, good quality (WQI 53-78) in 80% of the samples, and very good quality (WQI 80- 86) in 15% of the samples. In the dry period, there was an improvement in the quality of waters of these wells, with WQI results varying from good (57-79) to very good (80-82) of 55% and 45% respectively. At Vila do Conde, in the rainy period, the waters of the wells presented unfit quality (WQI from 4-36) in 64.28% of the samples, acceptable quality (WQI = 39-50) in 14.28% of the samples and good quality (WQI 55-65) in 21.44% of the samples. In the dry period, the water quality of the wells assessed in Vila do Conde was unfit (WQI 2-34) in 78.57% of the samples, acceptable (WQI = 39-46) in 14.29% of the samples and good (WQI = 62) in 7.14% of the samples.

It is observed that the subterranean water in these two locations had very different quality conditions when compared between the rainy and dry periods (Figures 1a and 1b), with quality significantly better in the Maranhão Community – where results were less strong in the rainy season: its waters improved even more in quality in the dry period. The waters of Vila do Conde were unfit for human consumption in the two periods, including the well that is used for general supply of the population of Vila do Conde, which presented unfit quality with WQI values varying between 16 and 32. PC1 (86.0%) showed an excellent separation of two groups on the y axis in the rainy season, associated with the characteristics of the subterranean waters between the communities of Maranhão and Vila do Conde.

This result confirms a significant discrepancy in relation to the results of evaluation of the quality of the waters of these aquifers. In the Maranhão community the waters show a high-

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er standard reflected by higher WQI indices, in contrast to the results of Vila do Conde, whose WQI values show the degradation of the aquifers, being reflected in the quality of the underground water used for supply to the population. However, although PC2 (14.0%) did not show a good separation on the x axis where the samples collected in the Maranhão community are grouped, in the samples of Vila do Conde, two VCAS points, 4 and 7, stand out, denoting that in them there is a major differentiation in relation to the other points of this region, possibly due to the worse increase in the quality of the waters based on the WQI values of these sampling points.

These results were repeated in the dry period in which PC1 reached 96.5%, showing a greater distancing in relation to the quality of the underground waters in the communities assessed. This fact may be associated with lower percolation of other contaminants and nutrients that are normally more intense in the rainy period, that is to say, the characteristics of the waters have lower variation in the levels of the parameters assessed that are reflected in the WQI indices. However, it is also observed that in this period PC2 (3.5%) does not succeed in successfully separating any of the points of either region, these results being considered more homogenous for a single area.

Water in households

In the rainy period, the household waters of the Maranhão Community presented acceptably quality (WQI=45-51) in 10 % of the samples, good quality (WQI= 52-79) in 65% of the samples, and very good quality (WQI=80-87) in 25% of the samples. In the dry period, there was an improvement in the quality of the waters of these households, with WQI results varying from good (59-78), in 75% of the total, to very good (80-87), in 25% of the total. In Vila do Conde in the rainy period, the waters of the wells assessed showed unfit quality (WQI=12-34) in 65.39% of the samples, acceptable quality (WQI=43-47) in 7.69% of the samples and good quality (WQI 52-65) in 15.38% of the samples, and very good quality (WQI=82-85) in 11.54% of the samples. In the dry period, the quality of the waters of the wells evaluated in Vila do Conde was unfit (WQI=7-35) in 65.38% of the samples, acceptable (WQI=39-48) in 11.54% of the samples, good (WQI=54-65) in 15.39% of the samples, and very good quality (WQI=82-85) in 7.69% of the samples.

There were also differences in quality, in the households of the Maranhão Community and Vila do Conde, between the two seasonal periods (Figures 1c and 1d), and they had identical patterns to those of their sources (wells), that is to say, The Maranhão Community presented good quality in the majority of the samples assessed and Vila do Conde presented unfit quality in the largest percentage of the samples. This is evidenced in Figures 2c and 2d: PC1 (66.6%) showed a good separation of the two groups on the Y axis in the rainy period, associated with the characteristics of the household waters when compared between the Maranhão and Vila do Conde communities. This result confirms a significant difference in the quality of the waters collected in the household recipients of the two communities. In the Maranhão community, the waters had better WQI levels, but the results of Vila do Conde show degradation of the quality of the underground waters consumed, reflecting the same characteristics of the aquifers used to supply the population. PC2 (33.4%) did not present a good separation on the x axis. These results were repeated in the dry period in which PC1 (85.9%) and PC2 (14.1%) showed a greater distancing and separation on the y axis in relation to the quality of the household waters in the communities assessed.

Water of the distribution network

The waters of the distribution network were assessed only in Vila do Conde, and also maintained the same pattern of quality as the wells assessed in that district, including, indeed, the same level of quality of the well that is used for general supply to the population. The quality conditions of the water of the network were as follows: In the rainy period, 88.46% of the samples had unfit quality (WQI 9-30), 3.85% had acceptable quality (WQI = 39) and 7.69% had good quality (WQI = 55-61). In the dry period, the quality of the waters in the network in Vila do Conde deteriorated, presenting unfit quality in 92.31% of the samples (WQI 13-31) and good quality in 7.69% = (WQI = 54).

Finally, in Figures 1e and 1f, PC1 (58.1%) showed, in the rainy period, a separation of two groups on the y axis associated with the characteristics of the household waters and the distribution network of Vila do Conde. This result confirms a similarity as to the quality of the waters consumed in this community. The degradation of these waters reflects the same condition of quality of the aquifers of this region. PC2 (41.9%) did not show a good separation on the x axis. These results were repeated in the dry period in which PC1 (64.7%) and PC2 (35.3%) showed a greater distancing and separation on the y axis in relation to the quality of the household waters and the waters of the distribution network in the community assessed. Comparing the waters of the distribution network with the household waters in the two seasonal periods, an identical pattern of quality with small improvements of quality at some sampling points, probably due to boiling of water, addition of chemical products such as hypochlorite, etc., was observed.

Finally, Table 2 shows the applied descriptive statistics on the values of the variables and WQIs determined in this study in the subterranean waters, household waters and distribution network waters in the two locations, presenting values of geometric mean, standard deviation, minimum and maximum for the data of the rainy period and the dry period. It is seen that, according to the parameters evaluated, there is a better quality level for the Maranhão Community, with improvement of quality in the dry period, with predominance of good and very good quality. In opposition to this, Vila do Conde maintained a quality level varying from regular to bad in its waters – thus, unfit for consumption. It is worth remembering that the periods considered to be rainy are the months of January and April, and the dry periods are the months of August and November.

Discussion

The use of a a Water Quality Index (WQI) is a mathematical instrument used to transform large quantities of water quality data into a single

Table 2. Descriptive statistics applied to the data from the water samples by location and period.

Place	Period	Variables	Units	N	Underground water		
					M_G ± DP	Min	Max
Maranhão Community	Rainy	pH	-	20	4.62 ± 0.25	4.17	5.09
		Total solids	mg.L-1	20	30 ± 19	10	76
		Chloride	mg.L-1	20	9 ± 8.91	2.31	34.68
		Fluoride	mg.L-1	20	0.011 ± 0.009	0.005	0.030
		Hardness	mg.L-1	20	4.74 ± 7.70	0.02	35.32
		N-Nitrate	mg.L-1	20	11.21 ± 8.89	1.96	37.48
		WQI	-	20	69 ± 10	46	86
	Dry	pH	-	20	4.81 ± 0.57	4.01	5.69
		Total solids	mg.L-1	20	26 ± 20	10	83
		Chloride	mg.L-1	20	6.00 ± 7.77	1.66	34.18
		Fluoride	mg.L-1	20	0.014 ± 0.012	0.005	0.045
		Hardness	mg.L-1	20	0.83 ± 0.73	0.30	2.94
		N-Nitrate	mg.L-1	20	7.70 ± 5.13	2.68	20.11
		WQI	-	20	75 ± 8	57	85
Vila Do Conde	Rainy	pH	-	20	4.18 ± 0.50	3.56	5.02
		Total solids	mg.L-1	20	112 ± 50.41	40	247
		Chloride	mg.L-1	20	32 ± 16.56	12	70
		Fluoride	mg.L-1	20	0.020 ± 0.012	0.011	0.045
		Hardness	mg.L-1	20	7.27 ± 7.27	2.03	30.86
		N-Nitrate	mg.L-1	20	61.35 ± 48.74	17.46	186.88
		WQI	-	20	24 ± 20	4	65
	Dry	pH	-	20	3.96 ± 0.33	3.48	4.58
		Total solids	mg.L-1	20	109 ± 51.99	19	212
		Chloride	mg.L-1	20	29 ± 12.47	11	52
		Fluoride	mg.L-1	20	0.026 ± 0.021	0.006	0.068
		Hardness	mg.L-1	20	4.76 ± 8.05	0.75	32.60
		N-Nitrate	mg.L-1	20	77.52 ± 59.50	20.03	258.55
		WQI	-	20	19 ± 16	2	62

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number that represents the level of quality of the water. It is a tool very much used for planning of land use and management of water resources, especially in developing countries. It can be measured on the basis of different quantities and types of parameters, most frequently calculated considering the weight of each parameter. A study developed in Iran[20], which developed an WQI and validated its measures with the use of remote sensing, concluded that the index map that was created based on the index provides a wide-ranging vision that is easy to interpret for better planning and management.

Considering the references of the Brazilian legislation Ministerial Order 2914 of 2011, which governs procedures for control and oversight of water quality for human consumption and its level of potability[7], the waters assessed in this study, from capture up to the points of consumption, presented pH with acid characteristics in almost the totality of the two communities studied, not coming within the values recommended for human consumption (6.0-9.5).

The results for total solids showed low values when compared with the reference of legislation applied for total dissolved solids (1,000 mg.L^{-1}), but high in certain sampling points probably due to interference of rains and due to the lack of adequate protection of the capture wells. Also, the results of chloride, fluoride and hardness were all in accordance with the legislation (250, 500 and 1.5 mg.L^{-1} respectively).

Finally, the parameter that had the most influence in the quality of the waters assessed was N-Nitrate, presenting high levels in both communities, principally in Vila do Conde. The level on water for human consumption sets an upper limit of 10 mg.L^{-1}, but levels were found that were

Table 2. continuation

Place	Period	Variables	Units	N	Household water		
					M_G ± DP	Min	Max
Maranhão Community	Rainy	pH	-	20	5.12 ± 0.53	4.47	6.61
		Total solids	mg.L-1	20	24 ± 20	6	69
		Chloride	mg.L-1	20	10 ± 8.14	1.45	33.79
		Fluoride	mg.L-1	20	0.013 ± 0.008	0.005	0.030
		Hardness	mg.L-1	20	3.91 ± 5.80	0.15	22.51
		N-Nitrate	mg.L-1	20	10.78 ± 11.73	1.32	39.76
		WQI	-	20	67 ± 13	45	87
	Dry	pH	-	20	5.12 ± 0.53	4.00	5.95
		Total solids	mg.L-1	20	29 ± 20	12	86
		Chloride	mg.L-1	20	9.00 ± 8.16	2.54	39.24
		Fluoride	mg.L-1	20	0.015 ± 0.012	0.005	0.041
		Hardness	mg.L-1	20	1.02 ± 1.08	0.42	4.76
		N-Nitrate	mg.L-1	20	8.85 ± 4.73	2.34	19.22
		WQI	-	20	74 ± 7	59	87
Vila Do Conde	Rainy	pH	-	26	4.36 ± 0.67	3.56	7.03
		Total solids	mg.L-1	26	79 ± 48.59	18	181
		Chloride	mg.L-1	26	22 ± 13.69	3	53
		Fluoride	mg.L-1	26	0.035 ± 0.021	0.009	0.085
		Hardness	mg.L-1	26	6.52 ± 4.82	0.72	16.41
		N-Nitrate	mg.L-1	26	43.74 ± 37.68	1.75	124.22
		WQI	-	26	31 ± 23	12	85
	Dry	pH	-	26	4.11 ± 0.58	3.40	5.31
		Total solids	mg.L-1	26	92 ± 52.40	10	233
		Chloride	mg.L-1	26	20 ± 14.72	2	57
		Fluoride	mg.L-1	26	0.025 ± 0.020	0.006	0.089
		Hardness	mg.L-1	26	4.65 ± 4.85	0.52	17.99
		N-Nitrate	mg.L-1	26	46.06 ± 41.55	1.45	158.72
		WQI	-	26	29 ± 24	7	85

it continues

10 and even up to 25% higher than the Brazilian legislative benchmark. Nitrate is an important component for human health: in surface waters there are low concentrations, but they can reach high levels in deep waters. Their consumption in supply waters can cause adverse effects on health such as the induction of methemoglobinemia in children, principally in children under the age of three, who are more susceptible due to the alkaline conditions in their gastrointestinal systems, the formation of nitrosamines and nitrosamides present carcinogenic potentials.

The findings of this study are in line with the evidences shown in the literature on water pollution in locations with industrial activity. A study in an important province of subterranean water in the south of India[21], where there was a demographic explosion and intense growth of farming and industrial activities, found an increase in the concentration of weak acids, an increase in permanent hardness, and alterations in sodium adsorption, residual calcium carbonate and permeability, showing that in 56% of the samples collected in the region with industrial activity the water was considered unfit for human consumption.

Further, the pollution caused by emission of metals and other ions in effluents has an effect of creating an environment that is favorable for proliferation of microorganisms. A study in Pakistan[22], where the majority of people obtain potable water from subterranean water as a source, established the relationship between the bacteriological quality of water and socio-economic indicators with gastroenteritis in the study area. The results with the calculation of the WQI showed a supply of water that was unfit for consumption in terms of its physical-chemical parameters, and

Table 2. continuation

Place	Period	Variables	Units	N	Network water		
					M_G ± DP	Min	Max
Maranhão Community	Rainy	pH	-	-	-	-	-
		Total solids	mg.L-1	-	-	-	-
		Chloride	mg.L-1	-	-	-	-
		Fluoride	mg.L-1	-	-	-	-
		Hardness	mg.L-1	-	-	-	-
		N-Nitrate	mg.L-1	-	-	-	-
		WQI	-	-	-	-	-
	Dry	pH	-	-	-	-	-
		Total solids	mg.L-1	-	-	-	-
		Chloride	mg.L-1	-	-	-	-
		Fluoride	mg.L-1	-	-	-	-
		Hardness	mg.L-1	-	-	-	-
		N-Nitrate	mg.L-1	-	-	-	-
		WQI	-	-	-	-	-
Vila Do Conde	Rainy	pH	-	26	4.24 ± 0.50	3.64	5.66
		Total solids	mg.L-1	26	128 ± 25.44	65	192
		Chloride	mg.L-1	26	33 ± 7.03	15	47
		Fluoride	mg.L-1	26	0.048 ± 0.016	0.032	0.087
		Hardness	mg.L-1	26	11.53 ± 5.49	2.30	25.84
		N-Nitrate	mg.L-1	26	80.08 ± 26.73	19.86	139.86
		WQI	-	26	21 ± 12	9	61
	Dry	pH	-	26	3.95 ± 0.41	3.41	5.15
		Total solids	mg.L-1	26	124 ± 18.85	70	155
		Chloride	mg.L-1	26	27 ± 5.78	16	38
		Fluoride	mg.L-1	26	0.037 ± 0.047	0.006	0.150
		Hardness	mg.L-1	26	8.18 ± 3.57	1.00	16.81
		N-Nitrate	mg.L-1	26	72.86 ± 21.63	26.00	119.84
		WQI	-	26	25 ± 10	13	54

N: Number of data. MG: Geometric mean; SD: Standard deviation; MIN: Minimum; MAX: Maximum.

also with a significant correlation for concentration of fecal coliforms. It was also observed that the correlation was stronger in locations with a higher rate of illiteracy, evidencing a situation of environmental injustice.

Analogously to the industrial processes, the process of urbanization carried out in a disorganized way also contributed to the pollution of subterranean waters, as the results of this present study show. Chemical analyses made in India[23], adopting multivariate analysis techniques, similarly to this present study, found differences in the quality of water in accordance with the rainy period: the pollution index in the pre-monsoon period was greater (at 9.27) than in the post-monsoon period (8.74). Further, also similar to our study, the Water Quality Index was worse in the pre-monsoon period (217.59) than in the post-monsoon period (233.02). The study indicated, thus, that an extensive process of urbanization takes place when there is gradual development of various small and large-scale industrial companies, and this process, as a whole, is responsible for degradation of the quality of water, principally through processes like agricultural runoff, elimination of wastes, leaching and irrigation with waste water.

This result corroborates a prior study in a nearby region, also in India[24], which indicates that there is a change in the quality of the water in accordance with the period of the monsoons, which shows seasonal variation in the deterioration of the quality of underground waters.

In the same direction, a study on subterranean waters in Bangladesh[25] showed that, in spite of the influence of the geological process in reduction of concentration of dissolved oxygen and on the traces of metal present in the water, the route of mobilization of some metals, such as chromium, is spatially associated with the location of, for example, industrial companies dealing with leather.

Finally, to evaluate the effect of anthropogenic sources, a study in Morocco[26] evaluated the impact of three sources of pollution (slurry-producing activities, wastewater, and mining) on the physical-chemical characteristics of the surface and subterranean waters in the northern region of Marrakech. The analysis of principal components (PCA) enabled identification of the impact of the sources of pollution and the results showed that subterranean and superficial waters had alterations in their properties due to the pollution.

It is also important to point out that only six parameters were used for the assessment. It is believed that the inclusion of other parameters, such as thermotolerant coliforms, sulfate, betex (benzene, toluene, ethyl benzene and xylenes), mercury and other toxic elements in the panel could add sensitivity to the evaluation. It is known that these variables are associated with emission of untreated domestic effluents, and wastes resulting from industrial activities, principally through construction of wells without appropriate technical criteria and vulnerability of the subterranean aquifer of the region. However, the use of the parameters adopted has already been sufficient to observe differences in the regions studied. More recent studies indicate, further, the need for specification of chemical characteristics of the parameters used, such as which isotopes are involved in the process of pollution[27], which could help to identify the routes of exposure of the subterranean waters, and also to establish the levels of normality (which may vary in accordance with the geological formation, and not only due to anthropogenic sources[28]). For example, a study in Saudi Arabia[29] sought to establish the parameters for chemical indices such as chlorine and alkaline compounds, the sodium adsorption ratio, the percentage of sodium, concentration of residual sodium carbonate, and permeability index. The results show that the chemical composition of the underground waters of the study location is strongly influenced by the lithology of rocks of the country, rather than anthropic activities.

Conclusion

Monitoring of water quality aims to evaluate the quality of the water consumed by the population over time, assess the efficiency of treatment, and whether there are any breakages in the distribution system. The parameters used for the calculation of the index of subterranean water quality indicated a better level of quality for the Maranhão Community, presenting an improvement in quality in the dry period, with predominance of good and very good quality, while at Vila do Conde there was a low, adverse level of quality in its waters, that is to say, at the majority of the sampling points the conditions were unacceptable for human consumption.

The variables with the greatest negative influence on water quality were pH and N-Nitrate. For this reason a clinical assessment is essential in the near future, to evaluate whether the water quality conditions of these waters consumed by these populations could be contributing to the existence or worsening of illnesses, since this consumption has been going on for a long time.

This study will be able to serve as a complement to other investigations of other multidisciplinary areas, and alert the local authorities of these municipalities, especially in Vila do Conde in Barcarena, which requires extra efforts for attention to the water consumed in that district – while in the Maranhão community, in Abaetetuba, perhaps because it is further removed from the more intense anthropic activities, still shows better quality conditions in its waters for consumption. In any event, these populations should urgently be provided with treatment services able to provide water adequate for human consumption, and also frequent monitoring of quality of water for consumption.

Collaborations

AC Medeiros, MO Lima and RM Guimarães participated equally in all stages of preparation of the article.

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