



Drinking water quality in schools of the Santarém region, Amazon, Brazil, and health implications for school children

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ABSTRACT

The quality of drinking water and its health implications for school children were examined at schools in the Santarém region, Amazon, Brazil. In this region, the population is fully supplied by groundwater from the voluminous Alter do Chão aquifer. Drinking water samples from three schools in Santarem city and from one school at the rural Mojuí dos Campos town were subjected to microbiological and physicochemical compositional analyses. The health risk of human exposure to chemical compounds through water intake was also evaluated. The results indicated that most water samples were contaminated with total coliform and with *E. coli*, which could cause serious intestinal disorders for school children. Drinking water was acidic and most of the chemical element concentrations were within Brazilian water potability recommended levels. One exception was the high aluminium content in schools from Santarem served by shallower wells, suggesting that further epidemiological studies are necessary and the monitoring of exposed school children should not be discarded. Elevated nitrate concentrations were also noted in schools from Santarém with shallower wells, indicating lack of sanitation and the importance of periodic monitoring of drinking water to prevent adverse health effects. Quantification of human health risk indicated a hazard in schools served by shallower wells, with aluminium as the main pollutant, followed by nitrate. The results showed that most drinking water quality parameters are in accordance with Brazilian legislation. However, microbiological contamination, water acidity, aluminium and nitrate concentrations must be taken into consideration for local governments in order to prevent related diseases among school children.

Keywords: Amazon, drinking water, groundwater, health, pollution.



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Qualidade da água de consumo em escolas na região de Santarém, Amazônia, Brasil e implicações para saúde dos escolares

RESUMO

Qualidade da água de consumo e implicações em saúde de escolares foram avaliadas em escolas na região de Santarém, Pará, Amazônia. Nessa região, a população é abastecida totalmente por água subterrânea do volumoso aquífero Alter do Chão. Amostras de água de consumo de três escolas na cidade de Santarém e uma escola no município rural de Mojuí dos Campos foram submetidas a análises microbiológicas e de composição físico química. O risco à saúde por meio da exposição a contaminantes químicos pela ingestão da água, também, foi avaliado. Os resultados indicaram que a maior parte das amostras estiveram contaminadas por coliformes totais e *E.coli*, o que poderá ocasionar distúrbios intestinais importantes nos escolares. A água é ácida e as concentrações dos elementos químicos estão de acordo com os níveis recomendados pela legislação brasileira. Uma exceção foi observada para o alumínio, que apresentou concentrações superiores ao recomendado na água das escolas de Santarém com poços mais rasos, sugerindo que novos estudos epidemiológicos devam ser realizados e o monitoramento de crianças expostas não deverá ser descartado. Concentrações elevadas de nitrato também foram encontradas na água das escolas de Santarém com poços mais rasos, indicando deficiências sanitárias e a importância do seu monitoramento visando evitar efeitos em saúde. A avaliação quantitativa de risco em saúde evidenciou perigo somente nas escolas com poços mais rasos, sendo que o principal contribuinte foi o alumínio, seguido do nitrato. Os resultados mostram que a maioria dos parâmetros de qualidade da água das escolas estão de acordo com os limites recomendados pela legislação brasileira, entretanto, a contaminação microbiológica, a acidez e as concentrações elevadas de alumínio e nitrato na água devem ser consideradas prioridades visando a prevenção de doenças relacionadas com consumo de água pelos escolares.

Palavras-chave: água de consumo, água subterrânea, Amazônia, saúde, poluição.

1. INTRODUCTION

Water is essential to sustain life, and a satisfactory water supply must be available to the human population. According to the World Health Organization (WHO), in 2017, access to safe drinking water can result in tangible benefits to health (WHO, 2017). Safety of the water supply is key to public health, especially for children, who generally require greater protection. School children can spend five to eight hours a day in public elementary schools in Brazil. In this sense, it is essential that this communal space presents favourable environmental conditions to ensure good health practices and quality of life for children.

Adequate quality of drinking water is a human right (WHO, 2017). Unfortunately, the supply of safe drinking water has been compromised by the absence of adequate sanitary infrastructure in some regions of developing countries like Brazil, where this vital resource is vulnerable to pollution. In the case of groundwater supply, over the past 20 years it has become increasingly apparent that groundwater sources are being contaminated by hazardous microbiological agents and chemicals derived from a variety of social, economic and urban activities; therefore groundwater protection has become essential for governmental agencies (Palamuleni and Akoth, 2015; Llopis-González et al., 2014).

Groundwater is an important source of drinking water and often requires little or no treatment. Nevertheless, diseases caused by contaminated groundwater consumption are reported from countries at all levels of economic development (WHO, 2006). In general,

groundwater has good microbiological quality, but may become rapidly polluted if protective actions are not implemented and well maintained. Some studies highlight microbiological contamination due to the proximity of septic tanks to artesian wells in countries with precarious basic sanitation infrastructure (Dahunsi et al., 2014; Mendes et al., 2017). Fecal-derived pathogens are the principal concerns in setting health-based targets for microbial safety and diarrhea is the most common disease in school children that is associated with water contaminated by pathogens through the fecal-oral route (WHO, 2006). The control of the microbial quality of drinking water should be the first priority in all countries, given the immediate and potentially devastating consequences of waterborne infectious disease.

The health concerns associated with chemical constituents of drinking water differ from those associated with microbial contamination and arise primarily from the ability of chemicals to cause adverse health effects after prolonged periods of exposure, as evidenced by Kim et al. (2016). There are many inorganic and organic compounds that naturally occur in groundwater which may originate from the rocks and soil percolated by the water. However, chemicals from anthropogenic sources (i.e., urban or agricultural activities) can reach groundwater from diverse sources arising from the use and disposal of materials and products containing toxic elements in high concentrations, such as trace elements and nitrates (WHO, 2017).

Assessing groundwater quality and the risk for human health has become an important task in public health concerns. Studies of the quality of drinking water collected by wells have been developed worldwide, and are of great importance (Majumdar and Gupta, 2000; Nalbantciar and Pinarkara, 2016; Lapworth et al., 2018). In the Santarém region, there is a lack of research involving groundwater quality and health. Some studies (Azevedo, 2006; Aguiar et al., 2014) have been carried out investigating surface water quality in the Amazon region and, in general, the implications for ecosystems, such as the effects on fish development and other living aquatic organisms. For these reasons, in this study we investigated the quality of drinking groundwater in four schools in the Amazon region, three located in an urban area, Santarém city, and one in a rural area, Mojuí dos Campos, during two seasons (dry and rainy). We compared the results with reference values from Brazilian legislation Ordinance 2914 (Brasil, 2011), which provides the standards for drinking water in Brazil based on the guidelines of the WHO. The health risk for children associated with ingestion of chemical compounds through drinking water was also quantified in schools, following the United States Environmental Protection Agency (USEPA) guidelines (USEPA, 1989; 1996).

2. MATERIALS AND METHODS

2.1. Study area

The study area is located in the Santarém region, in the west of Pará State, in the Brazilian Amazon. The region of Santarém includes the urbanized city of Santarém and the rural Mojuí dos Campos town, 30 km southeast of Santarém city (Figure 1). This region has a seasonal climate with two distinct periods (*i*) dry season (July to November) and (*ii*) rainy season (December to May), with June considered a transition month (Gomes et al., 2016). The climate in the Santarém region is tropical humid, and is classified as Am3 in the Köppen climate classification system (Köppen, 1936). In the last two years, according to the Brazilian National Institute of Meteorology (INMET), 95% of recorded values of temperature were in the range of 32.7°C - 22.5°C in the dry season and 31.2°C - 22.3°C in the rainy season. In 2016, the total precipitation and average relative humidity in the dry season were 371.5 mm and 84.6%, and in the rainy season these were 986.0 mm and 87.4%, respectively (INMET, 2017).

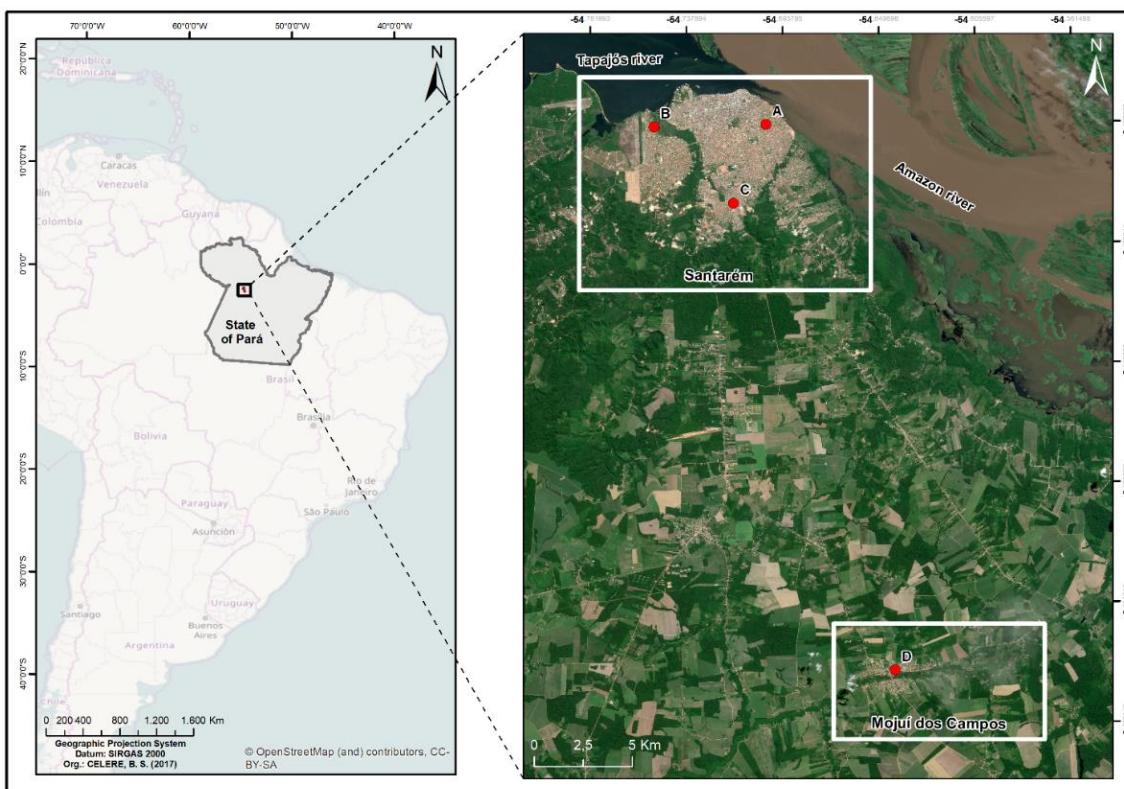


Figure 1. Location map of the State of Pará and Santarém region indicating the Schools A, B and C in Santarém and the School D at Mojuí dos Campos, State of Pará, Amazon, Brazil.

The city of Santarém had an estimated 294.447 inhabitants in 2016 according to the Brazilian Institute of Geography and Statistics (IBGE, 2016), and is the second most important urban region in the State of Pará, with economic activity based on local commerce, and it is located at the intersection of the Tapajos and Amazonas Rivers (Figure 1). These two rivers are important routes for regional transport; however, surface water is not used for human consumption. The Sanitation Company of Pará (COSANPA) and the Municipality of Santarém distribute drinking water in Santarém. COSANPA takes advantage of its own deep-water wells (> 250 m) that intercept the Alter do Chão aquifer and distributes water to 61% of the population; of these, 49% receive chlorinated water, whereas 12% of the population is not served by treated and disinfected water (COSANPA, 2013). The voluminous Alter do Chão aquifer is the major groundwater supply for most of the State of Pará (Tancredi, 1996). The Municipality of Santarém captures drinking water from shallower wells at 18 to 30 m deep. Households and other areas that are not served by either of these two water systems use groundwater from private shallow wells. According to the Sanitation Ranking published by the Trata Brazil Institute (2016), Santarém is among the ten municipalities in Brazil with the poorest drinking water treatment system.

The town of Mojuí dos Campos has 15.548 inhabitants (IBGE, 2016), and the main economic activity is the agricultural cultivation of soybeans, corn and black pepper. Agriculture plays a key role in supporting the rural population of the area. At Mojuí dos Campos, there is an important main water microsystem which captures water for human consumption from the Alter do Chão aquifer at a depth of 202 m without treatment and water disinfection.

2.2. Overview of schools and water sampling

A total of 36 drinking groundwater samples were collected at three elementary schools in Santarém (denominated in this study as Schools A, B and C) and at one school at Mojuí dos

Campos (denominated in this study as School D) (Figure 1). An overview of the characteristics of these schools is shown in Table 1. The water at the schools is used for food preparation, washing of household utensils, in the toilets and as drinking water by school children and employees. The supply of drinking water after its underground capture is provided by tanks (water tanks) with a capacity of up to 1.500 L, which are located inside the schools and made of polyethylene and fitted with a lid. Water was sampled from a drinking fountain over a period of three months (one sampling day in February, March and April) in the rainy season and in another three months (one sampling day in September, October and November) in the dry season, between 2015 and 2017. Immediately preceding water sampling the drinking fountains were cleaned with 70% alcohol and then tapped and allowed to drain for one to two minutes, following specifications established by the Brazilian Ministry of Health – National Health Foundation of Brazil (FUNASA, 2006). The volumes of the collected samples were 100 mL for the bacteriological analyses, 1 L for the parasitological analyses, 200 mL for the physicochemical parameters, and 100 mL for chemical analyses. After collection, the samples were conserved in a cold thermal box (4°C) until the analyses were conducted.

Table 1. Overview of schools in Santarém (A, B and C) and in Mojuí dos Campos (D) in the western region of the State of Pará, Amazon, Brazil.

Characteristics	School A	School B	School C	School D
Location	Santarém city	Santarém city	Santarém city	Mojuí dos Campos
Number of students in 2017	823	306	1069	376
Drinking water source	Groundwater (30 m deep) – private well	Groundwater (200 m deep) – COSANPA	Groundwater (18 m deep) – private well	Groundwater (202 m deep) municipal microsystem
Water storage after underground collection	Water tank	Water tank	Water tank	Water tank
Sewage treatment	Septic tank	Septic tank	Septic tank	Septic tank
Distance of septic tank of school to groundwater well	Approximately 15 m	More than 50m	Approximately 15 m	More than 50 m

2.3. Water analyses

The drinking water samples from the schools were analysed for microbiological characteristics (total coliform, *E.coli*, heterotrophic bacteria and parasites), physicochemical parameters (pH, turbidity, conductivity and alkalinity) and chemical composition (anions and trace elements).

The microbiological analyses for total coliforms, *E. coli* and heterotrophic bacteria were carried out using a vacuum pump and the method of membrane filters following standard methods of FUNASA (2006), which consists of filtration of 100 ml of the water sample through a sterile membrane with 47 mm in diameter and a porosity of 0.45 µm. The membranes were then placed in Petri plates with a Rapid HiColiform Agar (Himedia®) culture media for growth of total coliforms and *E.coli*. Petri plates were incubated at 35°C for 24 ±2 hours in order to count Colony Forming Units (CFU) of total coliforms; after incubation, the colonies that grew

with blue-greenish coloration were considered as total coliforms. The Petri plates were incubated at 44°C for 24 ± 2 hours for *E. coli* counting and after incubation, the Petri plates were exposed to ultraviolet light (366 nm, 6W) at a distance of 6 to 8 cm in a dark environment. A positive result was considered for *E. coli* when colonies in the fluorescent staining were detected. For the reading of heterotrophic bacteria, the result was considered positive when there was CFU present on the membrane after the pre-established conditions of incubation. Heterotrophic bacteria Petri plates were incubated for 35°C for 48 ± 3 hours with de media Plate Count Agar (Himedia®) for counting the colonies. The counting of heterotrophic bacteria includes the entire group of microorganisms that is capable of growing in a nutrient-rich solid medium agar.

Parasitological analysis was performed using the spontaneous sedimentation method, for a determination of eggs, cysts and larvae of helminths and protozoa. For this analysis, 1L of the water sample was arranged in a sedimentation chalice, where it remained for a period of 24 hours. Afterwards, 1 ml of the sediment material was deposited on a slide and stained with a drop of lugol solution (Neves, 2005; Ferreira et al., 2008; Julião, 2011). The material was then analysed under an optical microscope NIKON Model E200.

The pH of the water was measured by the potentiometric method using a portable pH meter, Model HI 991 003 (Hanna®), at a temperature of 25-30°C, and water turbidity and conductivity were measured with the same equipment. Alkalinity was determined by titration measuring the amount of sulphuric acid used, and the calculation indicated the amount of carbonate and bicarbonate ions involved in the reaction expressed as mg.L of CaCO₃ (Brazil, 2006).

Samples intended for chemical composition analyses were filtered through a 0.2 µm syringe filter and kept cooled (4°C) until analysis. Additionally, samples intended for trace-element analysis by Inductively Coupled Plasma Mass Spectrometer (ICP-MS) were preserved with two drops of concentrated HNO₃ at a pH of less than 2.

The anion contents in water were analysed by Ion Chromatography in a Thermo Scientific Dionex ICS-5000 spectrophotometer. All the samples were analysed for fluoride (F⁻), chloride (Cl⁻), nitrite (N-NO₂⁻), nitrate (N-NO₃⁻), sulphate (SO₄²⁻), bromide (Br⁻) and phosphate (PO₄³⁻). For the anions, the following components were used: an IonPaC AS19 Capillary Column (0.4 x 250mm) in combination with the AG19 Guard Column (0.4 x 50 mm), Anion Capillary Electrolytic Suppressor (ACES™ 300) and Eluent Generator Cartridges for the generation of potassium hydroxide (KOH) with concentrations between 2 and 50 mmol L⁻¹. The runs lasted 30 min with a flow of 0.010 mL min⁻¹ with the following concentrations' slope: 0-10 min (2-10 mmol L⁻¹); 10-20 min (10-45 mmol L⁻¹) and 21.1-30 min (2-2 mmol L⁻¹). For cations, the components were as follows: IonPac CS12A Capillary Column (2 x 250 mm) in combination with the CG12A Guard Column (2 x 50 mm), Cations Capillary Electrolytic Suppressor (CCES™ 300) and Eluent Generator Cartridges (EGC) for the generation of methanesulfonic acid (MSA) at a concentration of 20 mmol L⁻¹ and a flow 0.25 mL min⁻¹ throughout the 17 minutes of the run. For both determinations, the injection was made by the Automatic Sampling System (Dionex AS-AP) with a high-performance conductivity detector. Data were analyzed with the Chromeleon 6.8 software. For the equipment calibration, analytical curves were constructed for each of the ionic species, obtaining seven concentration points (in triplicate) for each curve at the following concentrations: 0.2; 0.4; 0.6; 0.8; 1.0; 2.0 and 3.0 mg L⁻¹. The detection limits in mg L⁻¹ were estimated to be 0.001 for F⁻; 0.015 for Cl⁻ and PO₄³⁻; 0.005 for NO₂⁻ and Br⁻; 0.003 for NO₃⁻ and 0.010 for SO₄²⁻.

The concentrations of the 57 trace elements were determined in all water samples by ICP-MS equipped with collision cell technology (CCT) (Xseries II Thermo Scientific), but only 16 elements were quantified in this study: aluminium (Al); arsenic (As), boron (B), barium (Ba),

calcium (Ca), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), sodium (Na), nickel (Ni), lead (Pb) and zinc (Zn). For quality control, all analyses were performed in triplicate and quality control of the measurements was carried out by the analysis of the reference material: River Water Reference Material for Trace Metals (SLRS-5). The detection limits in ng mL⁻¹ were estimated to be 0.4 for Al, 0.005 for As, 1.2 for B, 0.009 for Ba, 9.3 for Ca, 0.004 for Cd, 0.01 for Cr, 0.05 for Cu, 29 for Fe, 47 for K, 0.2 for Mg, 0.03 for Mn, 2 for Na, 0.04 for Ni, 0.002 for Pb and 0.1 for Zn.

2.4. Data analysis

Element concentrations were examined by descriptive statistics and compared with the maximum values recommended by Brazilian Ordinance 2914 that provides guidelines for controlling and monitoring the quality of drinking water for human consumption in Brazil (Brazil, 2011).

USEPA guidelines were used to quantify risk for human health considering the exposure through ingestion of groundwater in the schools (USEPA 1989; 1996). Human health risk assessment has become a widely applied methodology to quantify the risks derived from exposure to environmental pollutants (Turdi and Yang, 2016). The health risks include non-carcinogenic and carcinogenic agents in drinking water for school children.

The non-carcinogenic risks were assessed by estimating the Hazard Quotient (HQ) and Hazard Index (HI) for each school during six months. The HQ was calculated as the quotient between the environmental Daily Exposure (DE) dose and the Reference Dose (RfD), which was obtained from the Integrated Risk Information System (IRIS) in mg.Kg.day (USEPA, 2014). The non-carcinogenic risk was calculated for chemicals that had their reference doses established by IRIS using the following Equation 1:

$$DE = C * Co * EF * ED / Bw * AT \quad (1)$$

In the equation, DE is the daily exposure doses through oral intake (mg Kg – day⁻¹); C is the chemical concentration in water (mg L⁻¹); Co is the volume of drinking water consumed by the children in one day (L); EF is exposure frequency in days; ED is the exposure duration in years; Bw is the average body weight in kg and AT is averaging time in days. Adopted values and description of the different parameters are shown in Table 2.

The Hazard Quotient (HQ) values were obtained for a number of elements (Al; As; Ba; B; Cd; Cr; Cu; Mn; Ni; Zn) and for nitrate by the ratio between DE and their respective reference doses from IRIS (RfD). When the ratio exceeds the unit, it is characterized as a danger to human health, with the possibility of non-cancerous effects of human exposure to substances. Subsequently, the Hazard Index, defined as the total risk, was obtained by summing the HQ of each element. Values of the Hazard Index (HI) under unity are considered as safe.

2.5. Ethical aspects

The Research Ethics Committee of the State University of Pará (UEPA) approved this study in September 2015 with the register number 1.318.594.

Table 2. Input data for calculating the non-carcinogenic risk for school children from drinking water in schools in Santarém (A, B and C) and in Mojuí dos Campos (D) in the Santarém region, Amazon, Brazil.

Parameters	Values adopted	Unit	Reference data
Mean concentration of chemical in drinking water (C)	Results of present study	mg L ⁻¹	Present study
Daily water consumption by children (Co)	1.26	L day	USEPA (1996)
Exposure frequency (EF)	275	days	USEPA (1996)
Exposure duration (ED)	06	years	USEPA (1996)
Body weight children (Bw)	15	kg	USEPA (1996)
Averaging time for non-carcinogenic exposure (ATnc)	ED x 275 (1650 days) Al = 0.018 As= 0.0003 Ba and B= 0.2 Cd = 0.0005 Cr = 0.003 Cu= 0.04 Mn = 0.14 Ni = 0.02 Zn = 0.3 N - nitrate = 1.6	days	USEPA (1989)
Reference Doses (RfD) from IRIS		mg kg day	USEPA (2014)

3. RESULTS AND DISCUSSION

3.1. Microbiological contamination

Table 3 shows the results of microbiological analyses of 36 water samples from schools corresponding to dry and rainy seasons and indicates the growth of Colony Forming Units (CFU) per 100 ml water. The results showed the presence of heterotrophic bacteria in all samples whereas total coliforms were detected in 28 samples and *E. coli* in 16 samples. Cysts and parasites in water samples were not found. The concentrations of heterotrophic bacteria agree with Brazilian Ordinance 2914 (Brasil, 2011). The highest values were found in School A during the rainy season (240 to 1144 CFU/100 mL) and in School C during the dry season (396 to 1694 CFU/100 mL). These heterotrophic bacteria have no effects on human health, but are a good indicator of the quality of water (i.e., the lower the concentration of heterotrophic bacteria in drinking water the better its quality) (Brasil, 2011).

Detection of total coliforms in schools was accentuated during the rainy season with 17 positive samples compared to 11 samples in the dry season. Values of CFU varied widely between schools. The schools with shallower wells are more susceptible to the infiltration of soil contaminants that may increase during rainy periods. Some explanations can be raised for the growth of total coliforms in water samples. The proximity between wells and the septic tanks and the shallower depth of the wells in Schools A and C may favour the presence of coliforms and the higher value of CFU/100 mL. Septic tanks should be constructed in the lowest part of the area and at a minimum horizontal distance of approximately 16 m from the wells (USEPA, 2002). However, this criteria is not always followed at schools with shallower wells. Another explanation is the inadequate maintenance of water tanks in schools. The maintenance of these reservoirs in schools often does not follow a cleaning routine.

Table 3. Microbiological analyses of drinking water samples from Schools A, B and C in Santarém and D in Mojuí dos Campos during the dry and rainy seasons, Santarém region, Amazon, Brazil, and the reference values from Brazilian Ordinance 2914.

Microbiological Parameters	School A				School B				School C				School D				Reference value Ordinance 2914
	Samples with microbial growth	CFU/100 mL															
Dry season	<i>n</i> =6				<i>n</i> =3				<i>n</i> =6				<i>n</i> =3				
<i>Heterotrophic bacteria</i>	All samples	73 -724	All samples	220- 484	All samples	396 – 1694	All samples	132 -643									< 50.000 CFU/100 mL
<i>Total coliform</i>	3 samples	04 -512	3 samples	01 - 06	2 samples	02 – 146	3 samples	01 – 14									Absence
<i>E. coli</i>	Absence	--	2 samples	01- 02	Absence	--	3 samples	01 -02									Absence
<i>Parasites</i>	Absence	--	Absence	--	Absence	--	Absence	--									Absence
Rainy season	<i>n</i> =6				<i>n</i> =3				<i>n</i> =6				<i>n</i> =3				
<i>Heterotrophic bacteria</i>	All samples	240 -1144	All samples	18 – 360	All samples	17 – 189	All samples	51 – 308									< 50.000 CFU/100 mL
<i>Total coliform</i>	6 samples	02-348	2 samples	300- 973	3 samples	04 – 280	6 samples	01- 69									Absence
<i>E. coli</i>	4 samples	02 - 07	1 sample	15	2 samples	01 - 163	4 samples	02 – 33									Absence
<i>Parasites</i>	Absence	--	Absence	--	Absence	--	Absence	--									Absence

The number of samples with *E. coli* was also higher during the rainy season, with 11 positive samples but just 5 during the dry period. The presence of *E. coli* in water samples from schools is in disagreement with the Brazilian standards for potability as delineated in the Decree 2914 (Brasil, 2011). *E. coli* is an excellent indicator of fecal contamination in water because it is a microorganism belonging to the intestinal microbiota of mammals and birds (Hunter, 2003). The origin of *E. coli* in water samples may be the same as that of the total coliforms, due to the proximity of the shallow well to the septic tank and the lack of adequate maintenance of the water tanks. The presence of these microorganisms in water suggests contact with fecal material and highlights the possibility that other fecal microorganisms could be present in the water (i.e., Cryptosporidium and hepatitis virus), indicating that the water is inadequate for human consumption and could cause health risks to school children, such as diarrhea, hepatitis and other gastric intestinal disturbances. More detailed research on this region also is recommended, since most studies in the Amazon region have been conducted to evaluate the presence of total coliforms and *E. coli* in surface waters such as rivers and streams (Aguiar et al., 2014; Azevedo, 2006).

3.2. Physical chemical parameters and chemical composition of drinking water

The mean, minimum and maximum values of some physicochemical parameters in water from schools are presented in Table 4. Drinking water at temperatures between 25 - 30°C was acidic with pH ranging from 4.2 to 5.2 at Schools A, B and C and 4.7 to 5.0 at School D. The values found for pH in all schools are below the recommended minimum of 6.0. The low pH of local groundwater may result from natural processes, such as partial solubilisation of siliciclastic rocks (e.g., sandstone of the Alter do Chão formation). Alternative processes like pyrite oxidation or acid rain, commonly found in industrial areas (Edmunds and Smedley, 1996), are unlikely to occur in the region. Other studies have detected low groundwater pH (around 4.5 – 5.0) as a common feature in different places in the Amazon (Medeiros et al., 2016; Mendes et al., 2017).

The health effects of acidic water intake remain unclear. The WHO (2003) reported about skin and mucous irritation after exposure to acid water, but some gastric and intestinal disturbances are likely to occur. The acid drinking water may contribute to adverse health effects, since many minerals are soluble in acid water, thus releasing some toxic trace metals such as Al, Cd and Pb (Edmunds and Smedley, 1996). The solubility of Al is strongly pH-dependent and significant environmental concentrations could be found below pH 5.5, where increasing concentrations are related to the solubility of microcrystalline gibbsite (Bache, 1986).

Water turbidity was very low for all samples and yielded no great variations between the schools. Potable water normally registers turbidity up to 5.0 NTU (Brasil, 2011).

The highest water conductivity found in Schools A and C, with shallower wells, suggests a greater susceptibility to water contamination. There are no recommended values for conductivity in Brazilian legislation. Natural waters, in general, according the Environmental Company of the State of São Paulo (CETESB), show conductivity of 10 to 100 µS cm and the values increase in more-polluted waters when solid particles are added to water (CETESB, 2009). Tancredi (1996) showed conductivity ranging from 11 to 28 µS cm in groundwater from Santarém. These figures are similar to those found in School D and lower than those found in Schools A and C.

The alkalinity of water presented a wide variation among schools in the range of 3 to 40 mg L⁻¹ of CaCO₃. There is no recommendation for water alkalinity in Ordinance 2914; however, in general, water for human consumption should not exceed 120 mg/L of CaCO₃. Below this limit, alkalinity has no sanitary significance, although at higher levels it can cause an unpleasant taste for consumers (CETESB, 2009).

Table 4. Mean, Minimum (Min) and Maximum (Max) of some physicochemical parameters in drinking water from Schools A, B and C in Santarém and D in Mojuí dos Campos.

Parameters	School A			School B			School C			School D		
	Mean	Min	Max									
<i>Dry season</i>												
pH	4.2	3.8	4.8	4.6	4.3	5.0	4.5	4.0	5.0	5.0	4.3	5.8
Turbidity (NTU)	0.2	0.1	0.5	0.5	0.4	0.6	0.1	0.1	0.2	0.6	0.2	1.5
Conductivity ($\mu\text{S cm}$)	99	88	131	57	32	81	67	22	126	27	16	59
Alkalinity (mg L ⁻¹ of CaCO ₃)	13	10	18	06	04	10	04	03	07	13	07	20
<i>Rainy season</i>												
pH	4.3	4.1	4.8	5.2	4.6	6.0	4.6	4.0	5.4	4.7	4.4	4.9
Turbidity (NTU)	0.2	0.1	0.6	0.7	0.2	1.7	0.1	0.1	0.2	0.3	0.1	0.7
Conductivity ($\mu\text{S cm}$)	144	118	166	48	23	95	91	78	104	18	14	26
Alkalinity (mg L ⁻¹ of CaCO ₃)	08	03	11	30	15	40	24	13	35	11	10	12

The mean, minimum and maximum concentrations of the most abundant anions in groundwater and the maximum value allowed by Brazilian Ordinance 2914 are shown in Table 5. Concentrations of N-NO₂⁻, PO₄³⁻ and Br⁻ were below detection limits in all samples and were not registered in Table 5; the mean concentrations of F⁻ were very low as well, but were included in the table. All anion concentrations were below the maximum limits of Ordinance 2914.

Table 5. Mean, Minimum (Min) and Maximum (Max) values of anions (mg L⁻¹) in water samples from Schools A, B and C in Santarém and D in Mojuí dos Campos and the reference values (mg L⁻¹) from Brazilian ordinance 2914.

School A			School B			School C			School D			Maximum limits Ordinance 2914
Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	
<i>Dry season</i>												
0.02	0.02	0.04	LD	LD	LD	LD	LD	LD	0.01	0.01	0.03	1.5
11.2	11.1	11.4	1.8	1.7	2.2	4.0	1.3	9.2	2.0	2.0	2.0	250
5.8	5.7	6.0	0.5	0.2	0.8	1.9	0.06	5.6	0.1	0.09	0.1	10
6.8	6.7	7.2	0.3	0.1	0.6	0.2	0.1	0.4	0.75	0.7	0.8	250
<i>Rainy season</i>												
0.02	0.02	0.03	LD	LD	LD	0.03	0.03	0.05	0.01	0.01	0.04	1.5
14.2	12.5	15.1	2.5	1.5	4.4	9.1	7.4	12.6	2.3	2.3	2.3	250
8.0	7.1	8.7	0.3	0.04	0.8	5.4	4.3	7.4	0.1	0.1	0.2	10
8.6	7.6	9.5	0.8	0.1	2.0	0.5	0.4	0.51	0.6	0.6	0.6	250

LD = below detection limit.

The anion Cl⁻ presented the greatest anion concentration in drinking water at all schools, in the range of 1.3 to 15.1 mg L⁻¹, and SO₄²⁻ yielded concentrations well below the recommended maximum. These findings are consistent with those reported by Tancredi (1996). Cl⁻ and SO₄²⁻ are widely distributed in the environment, including in waters, and no health-based guideline value is proposed for chloride in drinking water (Tancredi, 1996).

The concentrations of N-NO₃⁻ were higher in drinking water from Schools A and C (mean values 1.9 and 8.0 mg L⁻¹) than at Schools B and D (mean values between 0.1 and 0.5 mg L⁻¹)

with deeper wells, and the highest concentrations were found in the rainy season. Contamination by N-NO₃⁻ in groundwater is possible due to deficient sanitation systems, based on increasing use of septic tanks in areas of high population density (Vanier et al., 2010). The proximity (less than 16 m) between the wells and the septic tanks in Schools A and C may explain this finding. In the Santarém region, Tancredi (1996) found low values for N-NO₃⁻ up to 3.32 mg L⁻¹ in groundwater. These values are greater than our results for drinking water from deep wells (Schools B and D) and lower than those found from shallow wells (Schools A and C). Medeiros et al. (2016) found high concentrations of N-NO₃⁻ in shallow wells (7.7 – 61.35 mg L⁻¹) in riparian communities that were exposed to domestic and industrial pollutants elsewhere in the Amazon region.

The toxicity of N-NO₃⁻ is mainly attributable to its reduction to nitrite in the human body and the major biological effect of nitrite is its involvement in the oxidation of normal Haemoglobin (Hb) to methaHb (haematological disturbance), which is unable to transport oxygen to tissues (WHO, 2011). The Hb of infants is more susceptible to conversion to metHb and the reduced oxygen transport becomes clinically manifest; the condition, called “methemoglobinemia”, causes cyanosis. In addition, nitrite was shown to react with nitrosatable compounds in the human stomach to form N-nitroso compounds, which have been demonstrated to be carcinogenic in tested animal species, although some of the most readily formed compounds, such as N-nitrosoproline, are not carcinogenic in humans (WHO, 2011).

Mean concentrations of trace elements as well as maximum and minimum contents in drinking water from the schools are shown in Table 6.

The concentrations of cations in the samples of Schools A and C were, in descending order, Na> Ca> K> Mg> Al; and in the samples of Schools B and D the order was Na> K> Ca> Mg> Al. Cations are commonly found in compounds in acceptable concentrations in the chemical constitution of natural waters (Edmunds and Smedley, 1996), and these elements are essential for human health, since they play important roles in cellular metabolism and physiology (Bowman et al., 2003). Water is an important source of these elements, and Ordinance 2914 does not set recommended maximum limits for Ca, K and Mg, but only for Na and Al. The acceptable limit of Na in water is based on the taste it can confer, since water with high concentrations of Na becomes brackish and is not recommended for human consumption. The Na levels in the water samples are acceptable and at higher concentrations in Schools A and C. Similarly, concentrations of Ca, K, Mg and Al were higher in shallower well samples. The concentrations of these chemical compounds, with the exception of Al, in schools with deep wells (B and D) were very similar to those found by Tancredi in 1996. The results suggest that the shallow wells of the schools were more susceptible to contamination by these elements and it is recommended to conduct periodic monitoring of the quality of drinking water in these schools.

The concentrations of trace elements are below the maximum limits recommended by the Ordinance 2914, except for Al at Schools A (414-672 ng ml⁻¹) and C (71-1370 ng ml⁻¹). The concentration of Al exceeded the recommended concentrations in all samples of School A and in four samples (out of the six analysed) of School C. The rather high concentration of Al in water samples from Schools A and C could be associated with natural process, i.e., interaction between water and rocks in the upper portion of the Alter do Chão geologic formation; moreover, when the pH value of the water is below 5.5, the chances of solubilization of Al in water increases substantially (Bache, 1986). Soils rich in organic matter and acids (pH below 5.5) also favor Al mobility and solubility, especially in areas with acidic rainfall and mining (Bache, 1986).

Table 6. Mean, Minimum (Min) and Maximum (Max) concentrations of trace elements (ng ml^{-1}) in drinking water from Schools A, B, C and D in the Santarém region, State of Pará, Amazon and the maximum value allowed (ng ml^{-1}) by Brazilian Ordinance 2914.

Trace elements	School A			School B			School C			School D			Maximum value Brazilian Ordinance 2914
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	
<i>Dry season</i>													
Al	429	414	429	92	32	184	510	71	1370	39	37	41	200
As	0.04	0.02	0.06	0.008	0.008	0.02	0.01	0.01	0.04	0.01	0.01	0.02	10
B	8.4	7.5	9.3	LD	LD	LD	LD	LD	LD	LD	LD	LD	--
Ba	6.6	6.1	7.4	33.8	31.8	36.2	21.4	13.6	26.0	19.1	18.5	19.4	700
Ca	4271	4080	4387	234	158	383	1231	885	1691	130	121	153	--
Cd	0.004	0.002	0.007	0.01	0.01	0.02	0.007	0.004	0.01	0.02	0.02	0.01	5.0
Cr	0.02	0.02	0.04	0.05	0.04	0.07	0.14	0.04	0.3	0.04	0.03	0.05	50
Cu	6.1	4.8	7.6	32.2	24.6	58.0	1.9	1.5	2.2	9.3	2.8	27.1	2000
Fe	LD	LD	LD	8.3	6.2	11.5	9.6	8.0	12.0	LD	LD	LD	300
K	2177	2139	2217	1386	1333	1476	955	530	1778	144	138	152	--
Mg	593	585	612	172	150	207	564	469	679	116	115	119	--
Mn	10.8	10.5	11.0	5.5	5.0	6.4	7.9	6.2	11.2	4.2	4.01	4.2	100
Na	1034	10440	10055	1225	860	1832	3733	970	9257	853	832	870	200000
Ni	0.1	0.07	0.16	0.62	0.3	1.1	0.38	0.37	0.40	LD	LD	LD	70
Pb	2.9	0.4	10	2.8	1.6	1.8	0.9	0.2	2.2	0.38	0.17	1.08	10
Zn	11.3	9.68	16.89	50.5	18.4	93.7	4.3	3.2	5.7	11.1	6.9	23.3	5000
<i>Rainy season</i>													
Al	625.3	586	672	53.4	36.0	83.0	1045	868	1353	43	37	54	200
As	0.07	0.05	0.1	0.01	0.01	0.02	0.1	0.06	0.2	0.02	0.02	0.05	10
B	6.8	6.4	7.3	2.3	1.7	2.6	3.4	2.6	3.8	LD	LD	LD	--
Ba	6.6	6.1	7.1	35.4	32.7	39.7	11.0	9.2	13.7	19.3	17.9	20.2	700
Ca	5675	5395	6109	337	163	613	1579	1223	2240	156	146	178	--
Cd	0.013	0.008	0.01	0.02	0.01	0.03	0.03	0.01	0.04	0.006	0.003	0.006	5.0
Cr	0.06	0.06	0.08	0.06	0.05	0.08	0.11	0.10	0.12	0.03	0.03	0.04	50
Cu	6.9	6.02	7.8	67.4	23.8	137	5.0	2.1	10.1	9.3	4.27	14.8	2000
Fe	LD	LD	LD	5.0	4.1	6.3	4.2	2.5	6.9	LD	LD	LD	300
K	2661	2585	2840	1530	1378	1458	1503	1190	1977	168	162	185	--
Mg	771	744	811	202	153	289	437	375	561	140	134	144	--
Mn	11.4	10.5	11.9	6.3	5.1	8.0	9.4	8.1	11.6	4.5	4.4	4.6	100
Na	13087	12649	13817	1760	905	3456	8337	6400	11760	944	916	981	200000
Ni	0.3	0.2	0.3	1.1	0.9	2.0	0.2	0.2	0.3	0.1	0.1	0.1	70
Pb	0.74	0.55	1.1	5.4	1.8	9.5	5.9	3.2	9.6	0.3	0.29	0.34	10
Zn	11.9	10.6	14.8	110	42.6	222	3.7	3.3	4.1	9.5	7.2	11.8	5000

LD = below detection limit.

According to the Agency for Toxic Substances and Disease Registry (ATSDR), neurological effects and Alzheimer's disease have been associated with oral exposure to Al, (ATSDR, 2008). Although there is evidence for this association, as proposed over 40 years ago, it is still controversial. Studies indicated a weak association between elevated intake doses of Al and increasing risk of neurological dysfunction and Alzheimer's disease (Walton, 2014). Alzheimer's disease is a human form of chronic Al neurotoxicity (Walton, 2014). However, according to ATSDR (2008), the absorption of Al is low through the human intestinal system, generally in the range of 0.1–0.4%, and therefore oral exposure should be not be harmful. In children, the effects may be higher, especially in individuals with pathologies associated with the renal system. In these cases, bone damage may also occur, since excess Al may limit phosphate absorption, which is necessary for bone maintenance and is an important concern in growing children (ATSDR, 2008).

3.3. Human health risk assessment

Human health risk assessment associated with the ingestion of groundwater is important due to the increased demand for drinking water from the Alter do Chão aquifer in the Santarém region, and disorganized growth and lack of sound sanitary measures in the region could affect groundwater quality. With the values obtained from the environmental Daily Exposure and Reference Dose, we estimated the non-carcinogenic risks through the HQ and HI for each school during six months. Input values of exposure were assumed, aiming to quantify and indicate the contaminants as a priority for health in drinking water (Castilhos et al., 2014).

Table 7 shows the Hazard Quotient (HQ) for a number of metals and nitrate exposure through water consumption for children in schools and their respective Hazard Index (HI) (sum of the HQs). The non-carcinogenic risk associated with water intake in schools had a HI>1 for Schools A (2.84) and C (3.62). The drinking water in Schools B (0.48) and D (0.21) was considered safe according to the methodology adopted and does not show a risk for children. Aluminium presented HQ> 1 in Schools A and C and was the chemical compound that most contributed to the HI with 86.2% and 94.6%, respectively. The second chemical element with the greatest contribution to the HI in Schools A and C was nitrate with 12.7% and 4.9%, respectively. The values found for the non-carcinogenic daily exposure (DE) values for As, Cd and Cr were less than 3.9×10^{-6} mg kg day in schools due to the very low concentration of these elements in drinking water. Consequently, non-carcinogenic and carcinogenic risks were considered to be absent for these elements in the present study.

The methodology of health risk assessment has been used mainly due to exposure by contaminants from surface waters (USEPA, 1989; 1996), whereas groundwater is less frequently considered. In the Santarém region, to date, no reports of this type of methodology applied to chemical contaminants have been published. Castilhos et al. (2014) assessed the potential health risk to exposure groundwater for Ni, Hg, Zn, B and Ba in 12 groundwater wells in urban area of the city Capitão Gervásio (Piauí State, northeast of Brazil), and found a non-carcinogenic risk HQ>1 for Ni. The presence of Ni in regional geology may have favoured the occurrence of hydrogeochemical anomalies or contamination from the soil in inadequate well constructions. Turdi and Yang (2016) assessed exposure to chemical contaminants through groundwater wells in four agricultural and pasture regions of China for children and adults and found more severe (carcinogenic and non-carcinogenic) risks for children. The authors found that non-carcinogenic risk was primarily associated with Zn and the carcinogenic risk was due to Cr, As and Cd. The hazard ratio was higher in agricultural areas, especially because of the high concentrations of As and Cr in the sampled wells.

The methodology mentioned above deals with the generation of numerical indices of critical areas and should be prioritized in public health and environmental control programs. The current results showed that groundwater of the most superficial layers of the Alter do Chão

aquifer might be a matter of concern for local governments, especially for Al and nitrate contents.

Table 7. Hazard Quotient (HQ) due to oral exposure (ingestion) of some trace elements and nitrate in water in schools and the respective Hazard Index (HI).

	HQ School A	HQ School B	HQ School C	HQ School D
Al	2.45	0.33	3.40	0.19
B	0.003	0.0004	0.0009	0.0003
Ba	0.002	0.010	0.007	0.008
Cu	0.013	0.10	0.007	0.01
Mn	0.006	0.003	0.005	0.002
Ni	0.0008	0.003	0.001	0.0004
Zn	0.006	0.02	0.001	0.002
N-Nitrato	0.36	0.02	0.20	0.005
HI	2.84	0.48	3.62	0.21

4. CONCLUSIONS

These results for drinking water quality from schools in Santarém and Mojuí dos Campos, Brazilian Amazon, allow us to make a series of conclusions and recommendations about how the quality of the water in this region should be managed.

The bacterial contamination (total coliforms and *E. coli*), especially during the rainy season of water samples from urban Schools (A and C), with shallower wells, show inconsistencies with the Brazilian Ordinance 2914 and expose school children to risks such as acute diarrheal diseases. Furthermore, the detection of *E.coli* in water samples from all schools indicates fecal contamination, suggesting that new microorganisms should be investigated such as hepatitis A virus and Cryptosporidium. The lack of maintenance and correct sealing of water tanks is a probable explanation for bacterial contamination in some water samples from wells of different depths in these schools. These results suggest that, to avoid these implications, schools should use chlorine-diluting pumps in their water supply systems, as well as establish a cleaning routine for the water tanks based on recommendations of the Brazilian Sanitary Surveillance Agency (ANVISA).

Determination of physicochemical parameters indicates that the water consumed in schools is acidic and confirmed results found in other studies in the Amazon region. The acid water may induce gastric and intestinal dysfunctions for school children, and favour the solubility of other toxic substances at the water source and along the course of groundwater. The chemical analyses showed low concentrations for most chemicals at levels below the recommended values in the Brazilian legislation. However, aluminium concentrations in water yielded values up to 5 times higher than the reference values of Ordinance 2914 in samples from schools with shallower wells in Santarém (Schools A and C). The prolonged exposure to high concentrations of aluminium in water may lead to some neurological implications, and in this case, the results of this study are preliminary, and it is suggested that future epidemiological studies are necessary in schools in the Santarém region, especially those with shallow wells. These future studies will serve to expand this debate and promote future interventions in the field of public and environmental health in this region. The acidic pH of the drinking waters and the presence of aluminium is probably related to natural processes of interaction between rock and water from the shallower layers of the aquifer system Alter do Chão. Nitrate concentrations in water yielded higher values in shallower well samples, up to 62 times higher than water from samples from deeper wells, and the presence of nitrate indicates a deficiency in sanitation that may lead to adverse implications for children's health, such as infant

methemoglobinemia.

The evaluation of the health risk for children in schools, assessed through the ingestion of water, showed a non-carcinogenic risk only for schools with shallower wells located in Santarém. At these schools, the chemical compound that most contributed to risk was aluminium, followed by nitrate. In schools with deeper wells, the value of the hazard index remained below 1, evidencing the absence of risk for the evaluated elements. These results are preliminary for schools from the Santarém region, and they represent an important contribution to a necessary debate for future interventions in the field of public and environmental health in this region.

The current research shows unprecedented results related to the quality of groundwater from the Alter do Chão aquifer and its relation to human health in the region of Santarém. We emphasize the importance of implementation of control actions and monitoring of water quality, especially at localities where groundwater is collected from shallower wells that put the health of the population that use these waters at risk.

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