Research Paper

Sanitary quality (bacteriological and physical-chemical) of drinking water in urban slums in Rio de Janeiro, RJ, Brazil

Natasha Berendonk Handam, José Augusto Albuquerque dos Santos, Antonio Henrique Almeida de Moraes Neto, Maria de Fátima Leal Alencar, Caroline Ferraz Ignacio and Adriana Sotero-Martins

ABSTRACT

Water must meet the drinking water standards in order not to cause disease. In urban slums the infrastructure (water supply, sewage) is more precarious, leaving the population susceptible to health problems. The objective was to analyze drinking water consumed by the population in Manguinhos slums, Rio de Janeiro, Brazil, based on the standards established in the Brazilian Regulation, and based on socioenvironmental indicators related to the health of the slums population. Bacteriological and physicochemical parameters were analyzed according to *Standard Methods for the Examination of Water and Wastewater*, compared with socioenvironmental data through spatial statistics. The results revealed that water, for the most part, exceeded the limits of drinking water quality standards, which places the population's health at risk and reinforces the urgency of public policies. Spatial and drinking water analysis indicated that the regions with the highest population density were the regions with the highest socioenvironmental vulnerability. These areas are priorities for government action to reduce health inequities, such as education, access to health services and access to sewer and water treatment.

Key words | coliforms, drinking water, Manguinhos slums, physicochemical analysis, water quality

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INTRODUCTION

According to the last Demographic Census of 2010 (IBGE 2010), 11,425,644 people in Brazil, corresponding to 6% of the Brazilian population, live in one of the 6,329 slums. The city of Rio de Janeiro is one of the cities with the largest number of people living in slums, with 1,393,314 residents in 763 slums, constituting 22% of the city's population (IBGE 2010). In general, in urban slums, the infrastructure (water supply, sewage, solid waste collection and drainage)

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is more precarious, leaving the population more susceptible to social injustices. This demonstrates the inability of public officials to meet and supervise social demand for adequate housing and sanitation (Lopes *et al.* 2011). The diseases that occur in the slums are largely related to the absence of adequate sanitation; agglomerated populations without planning, and consequently precarious conditions of personal hygiene and housing (Ferreira 2009). In addition, the lack of sanitation favors higher financial costs for the National Health System, due to the increase in hospitalizations and the excessive use of medicines. However, studies indicate that most waterborne diseases can be reduced by implementing an adequate sewage system and drinking water supply for the population (Eshcol *et al.* 2009; Renwick *et al.* 2009; Datasus 2016).

In Brazil the water quality standards are described in Consolidation Ordinance No. 5 of 2017. According to the legislation, drinking water must not contain total coliforms or *Escherichia coli* (*E. coli*). This regulation also establishes the maximum permitted values (MPV) for the physicochemical parameters of water (Brazil 2017) (Table 1).

The drinking water from commercial gallons, also called bottled water, must be in accordance with the National Health Surveillance Agency (ANVISA), of the Brazilian Ministry of Health, Collegiate Board Resolution No. 275/2005 (Brazil 2005). The quality is appropriate when there is absence of *E. coli*, and when it has less than 1.0 CFU (colony-forming units) of total coliforms per 100 mL of water (Brazil 2005).

Table 1 | Bacteriological and physicochemical standards – Brazilian drinking water standard described in Consolidation Ordinance No. 5 of 2017, Brazil

Parameters	Bacteriological and physicochemical standards
Total coliform	Absence
Escherichia coli	Absence
Total alkalinity (mg/L $CaCO_3$)	250 mg/L
Total hardness (mg/L $CaCO_3$)	500 mg/L
pH	6.0–9.5
Residual chlorine (mg/L Cl)	5 mg/L
mg/L N-ammonia	1.5 mg/L
mg/L N-nitrite	1 mg/L
Chloride (mg/L Cl^-)	250 mg/L
Conductivity (uS/cm)	ND
Sulfate (mg/L SO_4^-)	250 mg/L
mg/L TDS	1,000 mg/L
Turbidity	5.0 uT

With the conditions of contaminated water and low immunity, people who drink water can acquire diseases such as diarrheal diseases, hepatitis A, rotavirus (Brazil 2006), giardiasis, and amoebiasis (Neves 2009).

In Brazil, drinking water that is distributed by sanitation companies to homes can be contaminated along the way due to the clandestine connections used by residents to obtain water. Generally, the material used for clandestine water connections in slums are made with materials with low durability and without safety mechanisms, and may also be exposed to irregular sewage pipes through which the sewage was discarded (Barcellos *et al.* 1998). Due to tubes damaged by rupture, in periods of intermittency or lack of water supply, negative pressure favors the entry of biological and chemical contaminants present in the soil into the tubes, polluting the water (Carmo 2009). Another form of contamination is storing drinking water, including containers such as water reservoirs. When this is not carried out properly, pathogens and/or vectors may proliferate, such as arbovirus-transmitting mosquitoes, intestinal parasite cysts and bacteria that cause gastroenteritis (Sotero-Martins 2015).

In this context, the objective was to analyze the drinking water consumed by the population living in Manguinhos slums, Rio de Janeiro, Brazil, based on the standards established in the Brazilian Regulations, and based on socio-environmental indicators related to the health of the slum population.

METHODS

The study was developed in the 13 slums of Manguinhos, with 38,461 people living in 12,528 residences, located in Rio de Janeiro, RJ, Brazil (–22°52′47.04″S; –43°14′57.18″W) (Brazil 2017). The territory has one of the lowest human development indexes (HDI) (IBGE 2010). The study area is characterized by serious social and environmental problems, such as: clandestine electrical and plumbing connections; poor ventilation, shaded and overpopulated houses; contamination of water reservoirs by poorly channeled sewers.

Sewage is discarded in septic tanks built by the residents, either on the streets or directly into rivers. These slums, as in other Brazilian slums, suffer from high levels of violence associated with drug trafficking (Ignacio 2017; Ignacio et al. 2017; Handam et al. 2018).

A systematic sampling of the slum households was performed to collect water samples, representing 1% of households in each Manguinhos slum, from the list of households in each slum obtained from the Primary Care Information System – SIAB (2013). In systematic sampling, for every 20 households one was selected at random from each Manguinhos slum. The 1% sample size was determined due to the availability of financial and human resources for this study to represent the Manguinhos slums. To analyze the quality of different sources of drinking water, water samples were collected from: taps, which is supplied by the sanitation company (the resident described that he did not treat water at home, and used tap water directly); filters (the resident tried to treat water at home); and bottled water (the resident bought it, usually because he did not trust the quality of the water provided by the sanitation company). In all residences selected by the study, samples of tap water were collected and, if used, samples of filter and bottled water were also collected. Among all houses, 69% also had a commercial water filter and/or bottled water, 31% of homes use water to drink and wash food directly from taps. In total, 134 samples of water were collected from taps, 87 from filters and 10 samples from bottled water (among the houses, 10 had a bottle of water), totaling 231 analyzed samples (Table 2).

Bacteriological parameters (total coliforms and *E. coli*) and physicochemical parameters (turbidity, pH, free residual chlorine, total alkalinity, total hardness, nitrogen ammonia, nitrogen nitrite, chloride, conductivity, sulfate and total dissolved solids) were analyzed. Therefore, due to limited human and material resources, physical-chemical analysis was performed only on water samples from taps in dwellings, as this was the main source of drinking water used in all dwellings in the communities.

Appropriate aseptic laboratory and biosafety practices were used to avoid external and biological contamination. The materials used for analysis were previously sterilized in an autoclave at 121 °C/1 atm for 20 min (APHA 2012). For the bacteriological analysis, sterile 50 mL bottles (falcon type) were used, containing 50 μL of 10% sodium sulfate solution to neutralize the residual chlorine in the supplied water. In the physicochemical analyses, 500 mL sterile plastic bottles were used.

The methods for bacteriological and physicochemical analysis were based on Standard Methods for the

Table 2 | Number of water samples collected from tap, filter and bottled water sources; number of residents (population); number of population and selected houses for study (1%, $n = 123$); demographic density (hab./ha²) in the Manguinhos slums, Rio de Janeiro, RJ, Brazil ($n = 231$)

Slums	Population	Houses	Demographic density	Houses (1%)	Tap	Filter	Bottled water
CAH	3,551	1,122	6,777	11	11	5	3
Amorim	2,641	941	2,379	9	10	8	0
POC	2,684	939	2,631	9	9	8	0
Nova Vila Turismo	2,853	1,017	2,432	10	10	8	0
Vila Turismo	3,140	979	5,065	10	10	7	0
CHP2	3,538	1,040	4,921	10	15	12	0
Parque João Goulart	3,159	1,076	3,191	11	11	6	1
Parque Carlos Chagas	2,729	925	4,231	9	11	3	1
Vila União	2,726	841	3,200	8	9	8	0
Nelson Mandela	2,953	932	3,333	9	8	3	3
Samora Machel	3,141	989	6,828	10	10	5	0
Mandela de Pedra	3,378	1,005	4,176	10	10	9	1
DESUP	2,268	722	0.995	7	10	5	1
Total	38,761	12,528	–	123	134	87	10

Examination of the Water and Wasterwater, and within 24 hours of being collected, the samples were analyzed (APHA 2012). For the bacteriological analysis, 50 mL of sample was diluted, which consisted of 5 mL of the sample in 45 mL of phosphate buffered water (Handam 2016; Sotero-Martins *et al.* 2017), and samples were also analyzed without performing dilution.

Then, the filter membrane method was used with chromogenic indicator culture medium, Chromocult® Coliform Agar (Cat. No. 1,10426,0100/500 Merck), in which 10 mL of the diluted and undiluted samples were filtered (Sotero-Martins *et al.* 2017; Handam *et al.* 2018).

The results of the water analysis of taps and filters were compared to the standard of Consolidation Ordinance No. 5 of 2017, which establishes the quality standard for drinking water (Brazil 2017). For bottled water, the results were compared to the Resolution of Collegiate Board (RDC) No. 275/05 of ANVISA (Brazil 2005).

A heat map spatial analysis was used to identify the areas with the highest concentration of individuals most vulnerable to water quality, considering bacteriological and physicochemical parameters and population density, using the Kernel spatial density estimator (Oliveira & de Oliveira 2017). For data manipulation the software geoprocessing tool QGIS version 2.18.13 was used. For this, the following classification was used: meeting of the drinking water standard (white points) and exceedance of the limits of the quality standard (black points). In order to obtain data that corroborate the results on water quality, analysis was made of the socioenvironmental indicators of the Manguinhos slums. Socioenvironmental data were obtained from the database of the Programa Território Integrado de Atenção à Saúde (Teias) – Escola Manguinhos da Escola Nacional de Saúde Pública Sergio Arouca (ENSP/Fiocruz), Brazil. The present study is part of this program. Data from each favela was used in the study. The information from socioenvironmental indicators was as follows: population density; percentage without access to family health strategy (No_FHS); without adequate cleaning of water reservoirs (No_adequate_water_reservoirs); frequency of illiterate residents (Illiteracy). They were also used to build the database to be analyzed in spatial statistics in the Quantum Geographic Information System (QGIS) software 2.18.13 version.

After the analysis the results were delivered to residents, along with an environmental health education guide on caring for water for human consumption. This guide aims to work with the population on the importance of water quality for human consumption. The guide to environmental education in health was developed through this work in group meetings, with contributions from researchers, students and also residents living in the slums, with a simple and illustrative language to facilitate understanding, highlighting the importance of the disinfection of water reservoir and water filters (Sotero-Martins *et al.* 2014).

The study was approved and registered by the Research Ethics Committee with Human Beings of the Oswaldo Cruz Foundation/RJ/SISNEP under No. 548/2010.

RESULTS AND DISCUSSION

The physical-chemical analysis of the water samples ($n = 134$) showed that 114 samples (85%) presented with acidic pH below 6.0, with an average pH level of 5.49 (±0.26 standard deviation), which does not meet the drinking water quality standards determined by the Brazilian Consolidation Legislation 5/2017. In addition, one sample was also inadequate due to the chloride parameter (285.95 mg/L), being 1.14 times above the maximum allowed value, according to the law (Table 3).

The acidity of the water is mainly due to the presence of free carbon dioxide, which can result from the decomposition of organic matter by sewage contamination and industrial waste (Funasa 2014). For human health, water with acidic pH can cause irritation to the skin or eyes of individuals who come into contact (Morais *et al.* 2016). In addition, if consumed for a long period, 10–20 years, it can cause gastric problems such as gastritis, ulcers and stomach cancer. The high concentration of chloride causes an unpleasant taste in the water and can cause laxative effects in individuals. Generally, the concentration of chloride in water is caused by the dissolution of minerals by the intrusion of seawater, and can also be caused by the presence of domestic and industrial sewage (Funasa 2014). Therefore, this indicates that the water that supplies homes is not suitable for human consumption and can cause damage to public health.

Table 3 | Number of residential water samples collected from taps ($n = 134$) of Manguinhos slums with the results of the analysis of pH and chloride parameters that were not within the maximum permitted values according to the Ordinance of Consolidation No. 5 of 2017, expressed in absolute values and in percentages

Slums	Houses (1%)	Tap	pH		Chloride	
CHP2	10	15	4	27%		
Vila União	8	9	6	67%		
Samora Machel	10	10	9	90%		
Nova Vila Turismo	10	10	10	100%		
Comunidade Agrícola de Higienópolis	11	11	11	100%		
Vila Turismo	10	10	9	90%		
Parque João Goulart	11	11	11	100%		
Nelson Mandela	9	8	9	100%		
Amorim	9	10	8	89%	1	10%
Parque Oswaldo Cruz	9	9	8	89%		
DESUP	7	10	10	100%		
Mandela de Pedra	10	10	8	80%		
Parque Carlos Chagas	9	11	11	100%		
Total	123	134	114 (85%)		1 (10%)	

The results of total hardness, free residual chlorine, total dissolved solids, total alkalinity, ammonia, nitrite, sulfate and turbidity were in accordance with the maximum allowed values described by the Ordinance of Consolidation No. 5 of 2017. The slums that presented the highest mean levels of the parameters were: total hardness in the Amorim slum (41.42 ± 17.18); pH in the Vila União slum (5.85 ± 0.25); conductivity in the Nelson Mandela slum (315.75 ± 145.16); TDS in the Nelson Mandela slum (158.32 ± 72.69); free residual, in the CAH slum (2.05 ± 1.77); chloride, in the Amorim slum (65.68 ± 99.52); total alkalinity ($40.99 \pm 1{,}857$) and N-nitrite (0.037 ± 0.018), in the Samora Machel slum; N-ammonia (0.055 ± 0.024) and sulfate (21.32 ± 4.92) in the CHP2 slum; and turbidity in the V. turismo slum (1.4 ± 1.06) (Table 4).

The results of the bacteriological analysis of the water samples, considering both bioindicators, total coliforms and *E. coli*, showed that 27% (26/97) of the water samples collected from filters and bottled water met the drinking water quality standard, and that 73% (71/97) exceeded the limits of the drinking water quality standards of the legislations: Consolidation Ordinance No. 5/2017 and Collegiate Board Resolution (RDC) No. 275/05 of ANVISA. For water samples collected from taps, 31% (42/134) met the quality criteria and 69% (92/134) exceeded the limits of the drinking water quality standards of the Consolidation Ordinance No. 5/2017.

Regarding the samples collected from taps, 91 of the 134 samples (68%) were positive for total coliforms, with the highest level found at 21 CFU/mL; and 11 samples of the 134 samples (8%) were positive for *E. coli*, with the highest level found at 1.44 CFU/mL (Figure 1).

Regarding the samples collected from filters and bottled water, 69 of the 231 samples (30%) were positive for total coliforms, with the highest level found at 14.89 CFU/mL; and 10 samples (4%) were positive for *E. coli*, with the highest level found at 1.37 CFU/mL (Figure 2).

The simultaneous evaluation of bioindicators – bacteriological and physical-chemical parameters – of samples collected from the taps showed that the quality worsened because only 10% (13/134) met the drinking water quality standards, and 90% (122/134) exceeded the limits of the quality standards, according to the Ordinance of Consolidation No. 5 of 2017. The number of samples from taps that exceeded the limits of the quality standards increased from 92 to 122 samples.

The socioenvironmental analysis through spatial statistics showed that the Manguinhos slums were the most socioenvironmentally vulnerabe. The study showed that 61% (8/13) of the places with the highest percentages of residents do not adequately clean water reservoirs (No_adequate_water_reservoirs), also do not have access to the family health strategy program (No_FHS) (Figure 3(a)). The Manguinhos slums, which had a higher percentage of residents who did not clean water reservoirs adequately, 54% (7/13), also had the highest frequency of illiterate (illiteracy) and the lowest levels of education (Figure 3(b)). The associations were statistically significant with *p*-values <0.05.

The spatial statistical analysis through the Kernel compared the quality of the water with the population density of the slums. These areas receive water from the same sanitation company, however they are clandestine connections. The associations between water quality and population density were statistically significant with *p*-values <0.05. The spatial statistics analysis confirmed the expected in the

Table 4 | Physicochemical results of residential tap water samples ($n = 134$) of the slums Manguinhos, RJ, Brazil, expressed as mean ± standard deviation

Parameters	Standard	V. Turismo	J. Goulart	N. Mandela	DESUP	Mandela de Pedra	Amorim	POC	CHP2	Vila União	PCC	Samora Machel	N. Vila Turismo	CAH
Total hardness (mg/L $CaCO_3$)	500	29.10 ± 6.54	25.62 ± 8.45	20.20 ± 5.62	24.55 ± 3.83	34.09 ± 7.80	41.21 ± 17.18	31.55 ± 12.12	39.74 ± 7.58	28.61 ± 3.37	20.81 ± 4.41	21.94 ± 3.34	25.31 ± 3.96	20.92 ± 3.54
pH	6.0–9.5	5.61 ± 0.33	5.28 ± 0.20	5.17 ± 0.18	5.59 ± 0.31	5.54 ± 0.35	5.70 ± 0.24	5.64 ± 0.36	6.06 ± 0.24	5.85 ± 0.25	5.30 ± 0.32	5.68 ± 0.17	5.32 ± 0.13	5.30 ± 0.11
Conductivity (uS/cm)	*	62.31 ± 14.84	99.72 ± 20.78	315.37 ± 145.16	126.52 ± 142.33	99.71 ± 106.16	99.72 ± 14.14	110.74 ± 20.76	93.91 ± 24.50	67.78 ± 16.07	42.36 ± 6.18	44.21 ± 7.52	57.71 ± 12.51	64.08 ± 21.65
mg/L TDS	1,000	30.78 ± 7.20	48.95 ± 10.32	158.32 ± 72.69	34.56 ± 17.07	44.12 ± 13.25	50.87 ± 7.00	56.02 ± 11.24	48.17 ± 4.34	35.22 ± 9.00	22.64 ± 3.60	23.32 ± 3.70	29.42 ± 6.66	32.19 ± 11.05
Residual chlorine (mg/L Cl)	5	1.65 ± 0.71	1.09 ± 0.49	0.81 ± 0.30	0.22 ± 0.06	1.00 ± 0.00	0.26 ± 0.32	0.86 ± 0.88	0.99 ± 0.78	0.47 ± 0.71	0.95 ± 0.57	1.31 ± 1.52	0.76 ± 1.51	2.05 ± 1.77
Chloride (mg/L Cl^-)	250	51.92 ± 28.88	23.28 ± 17.12	47.01 ± 37.14	59.18 ± 39.85	65.30 ± 59.46	65.68 ± 99.52	50.42 ± 41.80	57.45 ± 32.16	23.16 ± 9.22	33.60 ± 21.16	38.92 ± 19.99	55.99 ± 41.28	58.03 ± 9.91
Total alkalinity (mg/L $CaCO_3$)	250	32.50 ± 7.10	26.23 ± 9.97	20.92 ± 13.47	35.63 ± 10.23	38.13 ± 11.20	9.98 ± 14.50	27.15 ± 18.38	35.00 ± 7.01	36.81 ± 6.59	27.58 ± 17.72	40.99 ± 18.57	41.88 ± 8.36	16.63 ± 16.67
mg/L N-ammonia	1.5	0.001 ± 0.002	0.003 ± 0.004	0.000 ± 0.000	0.003 ± 0.007	0.011 ± 0.020	0.013 ± 0.020	0.006 ± 0.009	0.055 ± 0.024	0.041 ± 0.016	0.018 ± 0.032	0.015 ± 0.023	0.023 ± 0.046	0.009 ± 0.024
mg/L N-nitrite	1	0.013 ± 0.010	0.006 ± 0.006	0.002 ± 0.001	0.004 ± 0.003	0.009 ± 0.013	0.002 ± 0.005	0.005 ± 0.005	0.001 ± 0.001	0.002 ± 0.002	0.034 ± 0.013	0.037 ± 0.081	0.018 ± 0.037	0.005 ± 0.004
Sulfate (mg/L SO_4^-)	250	12.48 ± 4.82	16.96 ± 5.66	1.59 ± 2.21	12.63 ± 8.46	10.22 ± 6.44	16.96 ± 8.14	13.86 ± 5.42	21.32 ± 4.92	18.72 ± 4.58	3.65 ± 1.31	4.89 ± 1.62	10.10 ± 7.28	6.66 ± 1.99
Turbidity	5.0	1.40 ± 1.06	1.01 ± 0.70	1.21 ± 1.18	0.29 ± 0.33	0.62 ± 0.44	1.33 ± 0.62	0.76 ± 0.23	SD	SD	SD	SD	SD	SD

SD = No data for turbidity in these slums; CHP2 = Provisional Housing Center 2; PCC = Carlos Chagas Park; CAH = Higienópolis Agricultural Community; TDS = total solids dissolved; POC = Oswaldo Cruz Park; CaCO3 = calcium carbonate; (mg/L SO_4^-) = milligrams per liter of sulfate; and (mg/L Cl-) = milligrams per liter of chloride. * = undefined.

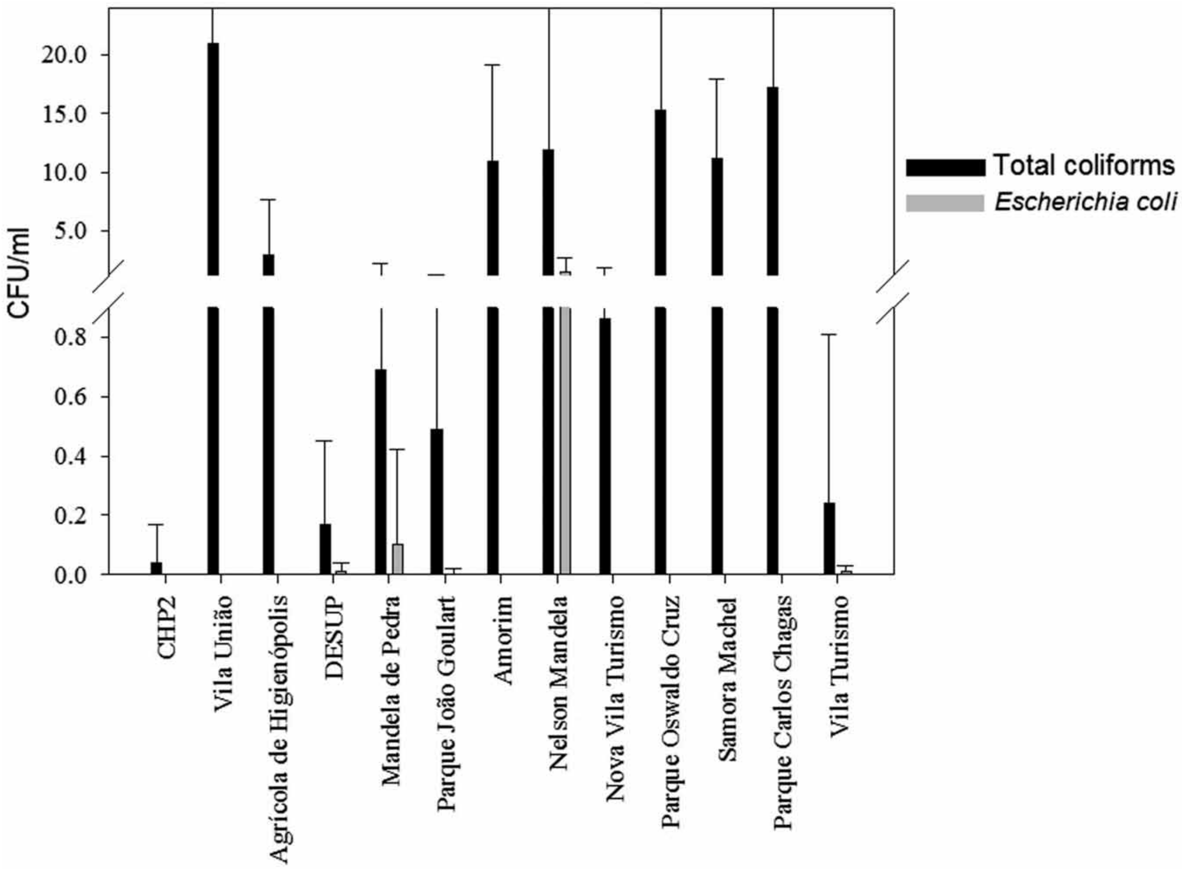

Figure 1 | Mean levels of contamination by total coliforms and *E. coli* in samples of tap water in the Manguinhos slums, RJ, Brazil ($n = 134$). The break interval used in the graphic was: 0.9–1.2.

regions with the highest population density in the territory, such as slums 1, 2, 8, 10, 11, 12, which were the regions that presented the largest cluster of residences (clusters) and where the water samples exceeded the limits of the drinking water quality standards. This spatial pattern can be observed and corroborates with the pattern for regions with higher illiteracy rates, and regions where people do not clean reservoirs properly. Therefore, in spatial analysis it is possible to confirm the most vulnerable slums within the territory. The regions that presented a spatial pattern with residences in better sanitary condition of drinking water were mainly in 5, 6 and 9 (Figure 4).

The results of water samples that exceed the limits of the quality standards were similar in samples collected from faucets, filters and bottled water, demonstrating that the water supplied to the residences in this territory is unreliable, and the quality needs to be improved to eliminate contaminants for human consumption, mainly for drinking and washing food in order to avoid possible health problems, such as diarrheal diseases.

The reasons for water contamination may be due to domestic conditions, such as: lack of cleanliness of the water tank; unchanged filter refills; and inadequate water pipe installation (i.e. next to sewerage) (Belo *et al.* 2012). This contamination may also be due to the water distributed by the sanitation company (TrataBrasil 2015), and contamination during the distribution, which was provided by residents through clandestine connections without guarantees of quality to the home (Fernandes & Costa 2009; Cedae 2014). The clandestine connections are made with materials with low durability and without safety mechanisms, and may also be exposed to irregular sewage pipes through which the sewage was discarded. When there is a lack of water in Manguinhos slums, which happens

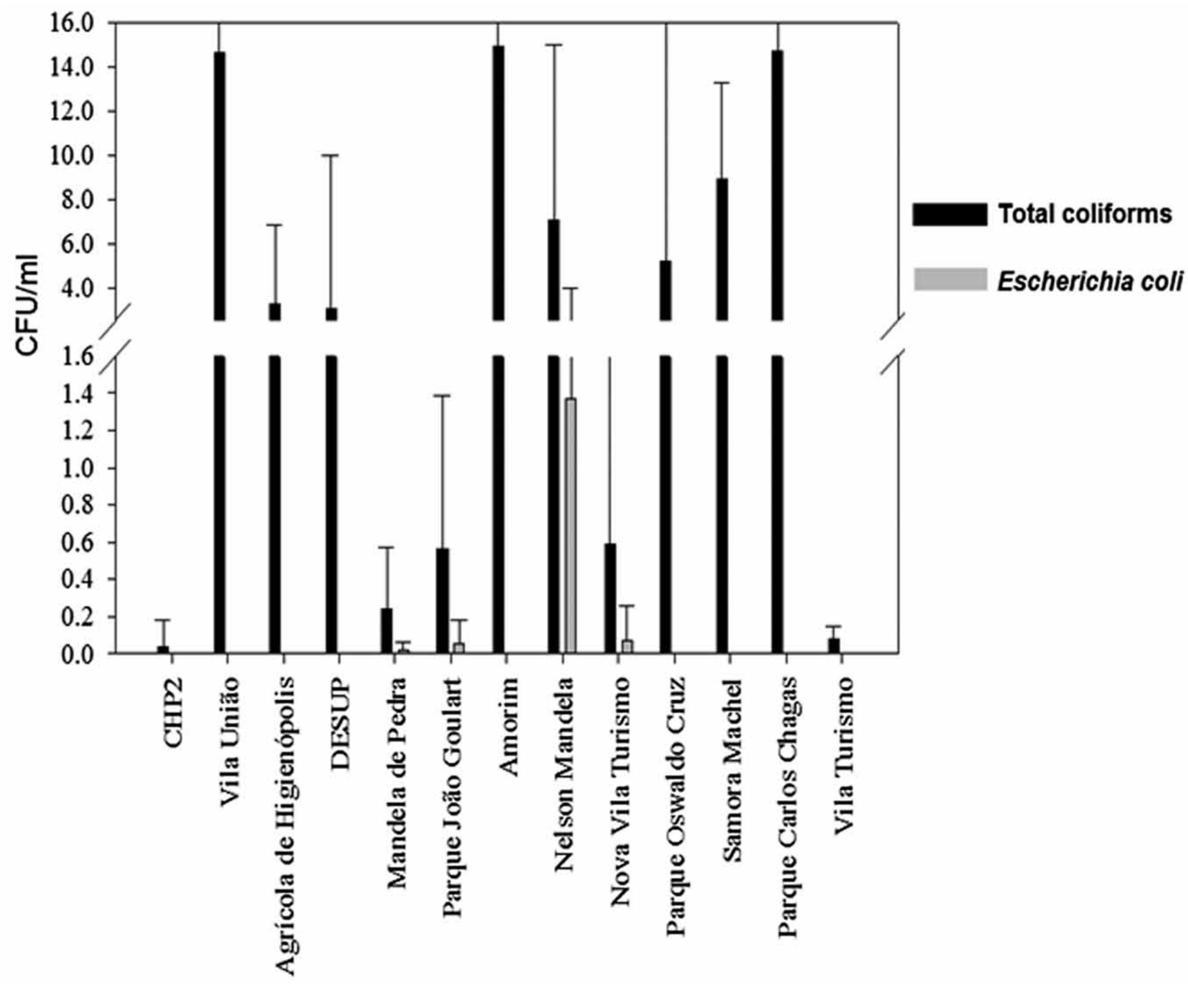

Figure 2 | Mean levels of contamination by total coliforms and *E. coli* in the water samples of filters and bottled water in the Manguinhos slums, RJ, Brazil ($n = 97$). The break interval used in the graphic was: 1.6–2.5.

monthly, for 3–4 days, it can cause negative pressure, which favors the entry of contaminants in clandestine connections, polluting the water (Carmo 2009; Fernandes & Costa 2009).

According to the sanitation company that supplies the region (Cedae 2014), problems of non-conformities can occur in the distribution network and are associated, mainly, with the presence of sewage contamination, which in more than 95% of cases is due to clandestine connections that provide the infiltration of sewage into the network. Clandestine connections are an illegal act and put collective health at risk.

In addition, in 2015 it was identified that the water distributed by the Rio de Janeiro sanitation company (CEDAE) was contaminated by thermotolerant coliforms in the piped water of the Guandu system (TrataBrasil 2015). Recently, the water distributed by the company had a high presence of potentially toxic algae, which give bad conditions of turbidity, odor and taste in the metropolitan region of Rio de Janeiro (Alencar 2020).

Regarding the quality of bottled water, the cause of the contamination is not known. However, it is known that this type of water can possibly be contaminated by the source, in the filling or during transport and storage, according to Inmetro (2009). When the packaging is not adequately sealed and the temperature is high, these factors allow the passage of oxygen, favoring the entry and proliferation of bacteria in the water, as well as the release of nutrients from the plastic (Rosenberg 2003). Residents used bottled water as an

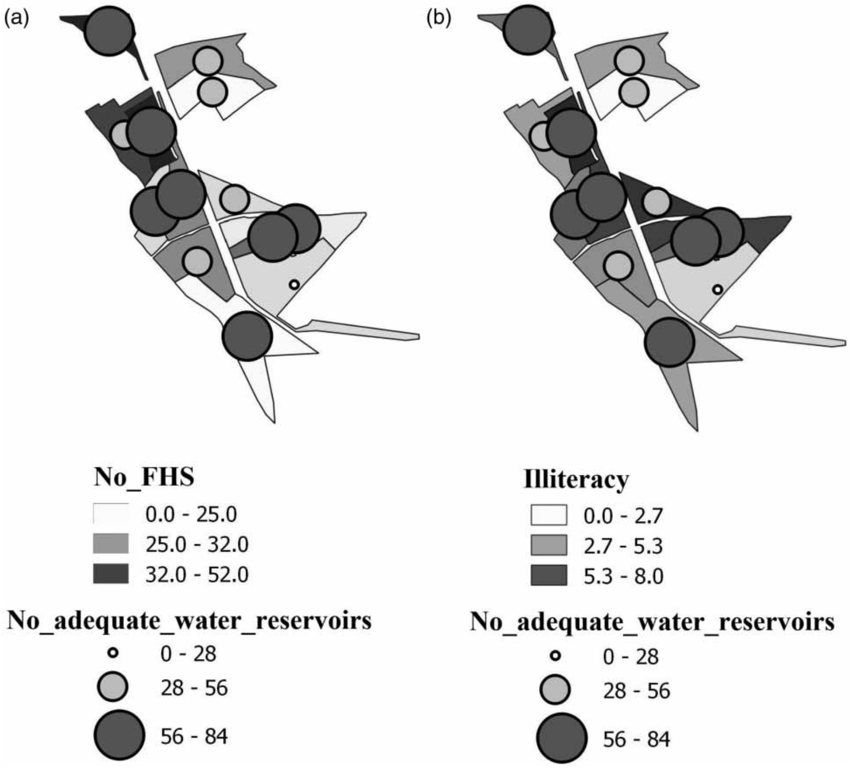

Figure 3 | Spatial representation of the socioenvironmental analysis of the Manguinhos territory. (a) Without access to the family health strategy program (No_FHS) × residents do not adequate clean water reservoirs (No_adequate_water_reservoirs). (b) Frequency of illiterate residents (Illiteracy) × No_adequate_water_reservoirs.

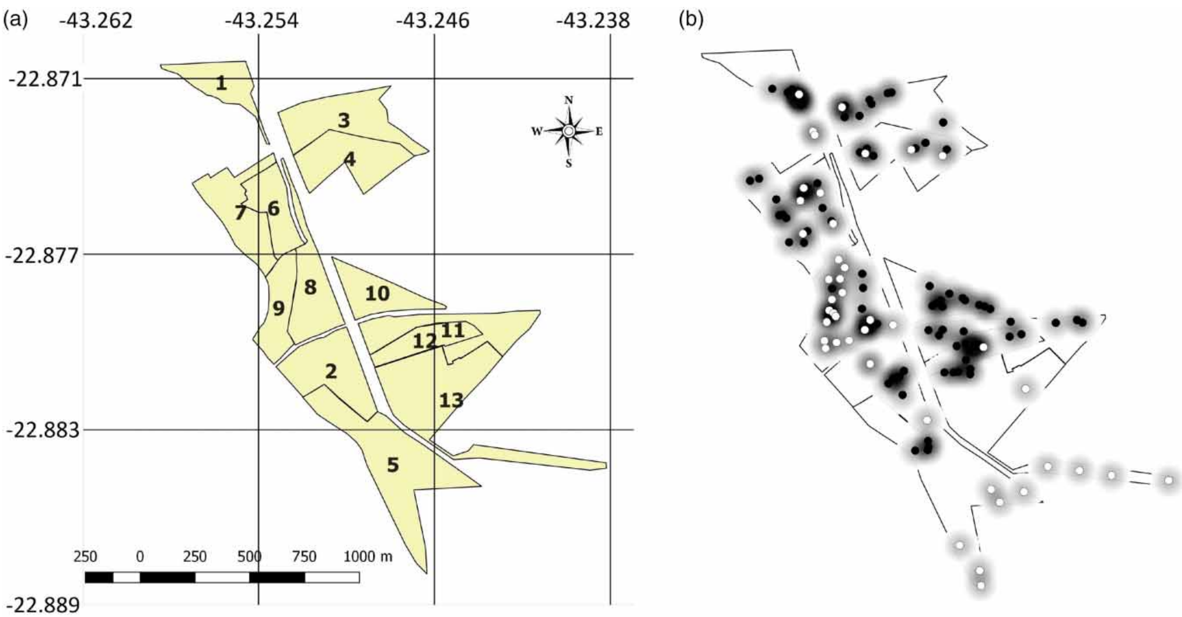

Figure 4 | Region of the Manguinhos slums, RJ, Brazil. (a) Region subdivided into 13 slums for Family Health Strategy (FHS) actions. (b) The circular points represent the total tap water collection points, corresponding to 1% of the relative population present in each slums, the black points correspond to the locations that exceed the limits of drinking water quality standards and the white points indicate the residences that meet drinking water quality standards.

alternative to the water supplied in the region where they live, because they considered it to be healthier and safer, however the study showed that bottled water may also be contaminated. Commercial establishments present in the slums are generally not registered, therefore, the quality of the bottled water that is sold is not supervised, and the quality may be inadequate according to the water quality standard.

Pereira *et al.* (2015) also showed that residents in the slums of Rio de Janeiro, Brazil, consumed water directly from the tap and most water samples (58.8%) exceeded the limits of the quality standards due to total coliforms and *E. coli*. This study verified that the contamination of water reservoirs can occur through animal feces present inside the reservoirs, in addition to the lack of periodic cleaning of the water reservoirs. The reason for the lack of cleaning can be due to the difficulty of access to the place where the water tank is installed and the lack of information about the periodicity and cleaning procedure. FUNASA (2014) and Sotero-Martins *et al.* (2014) recommend that cleaning the water tank, as well as changing the filter refills, should be carried out every six months. In Manguinhos slums, the residents reported having difficulties cleaning the water reservoirs, because to get to the reservoirs the resident needs to climb stairs that are outside the residence, with the risk of an accident. As a result, a large number of residents, mainly the elderly, hire people to clean the water reservoirs, and therefore the cleaning may not be done properly.

Regarding the quality results of the filter water samples, it is not possible to know the cause of the water contamination of each sample that presented coliforms, however, it is known that contamination can be caused by the lack of exchange of the filter unit. When the filter refill is not replaced properly, the filtering function loses its efficiency allowing the passage of microorganisms. Water filtration in the residences is strongly related to the reduction of diarrheal diseases caused by helminths, protozoa and bacteria in all age groups (Belo *et al.* 2012). Therefore, health education for the use of water filters in homes is important, especially in areas where sanitation is precarious. In the Manguinhos slums, residents may not be using the filter properly or according to the manufacturer's recommendations. In addition, residents reported about the color of the water, which was dark and, to improve water quality, they changed the filter refills before six months. Furthermore, the high cost of filters is an important barrier, especially in these vulnerable socioeconomic communities.

The storage of drinking water due to intermittent water in slums is a risky process for health because used containers, such as pools and buckets, which are not appropriate, can be sites of proliferation of disease vectors, such as arboviruses. Therefore, adequate storage must be made in order to guarantee water quality, for example, adding chlorine in the appropriate amount per mL (Sotero-Martins 2015). The environmental health education guide 'Drinking Water: Care and Tips' was explained in the houses participating in the study on how to treat water that may be contaminated by biological agents (bacteria, viruses, protozoa, helminths); care with filters and storing water safely. A sheet was also provided to remind the resident of the replacement and cleaning dates for the filter and water tank. In view of the results of water quality, the residents of the slums of Manguinhos were advised not to consume water directly from the tap, but to use a filter, to boil or chlorinate the water, as well as the cleaning of the water tank and the exchange filter refill periodically. This guiding material can also be used in residences in other regions of Brazil and the world with characteristics similar to those of the present study.

CONCLUSIONS

This study revealed that the health of the favela population is at risk due to the quality of drinking water, which in general exceeds the limits of water quality standards determined by the Brazilian legislation. Spatial and drinking water analysis indicated that the regions with the highest population density in the territory were the regions with the highest socioenvironmental vulnerability. These regions are priorities for government action to reduce health inequities, such as education, access to health services and access to sewer and water treatment. Further research is also needed to reinforce the need for public policy changes in these areas.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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