Evaluation of the drinking water quality surveillance system in the metropolitan region of Rio de Janeiro

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ABSTRACT

The present work evaluated the surveillance of the drinking water quality information system database and correlated the findings of the microbiological analysis with the distribution of intestinal protozoa from the metropolitan region of Rio de Janeiro. From the database, we obtained 1,654 georeferenced monitoring stations that were used in the analysis. The results indicate that the minimum number of samples collected per parameter (free residual chlorine, turbidity, counts of total and fecal coliforms (*Escherichia coli*)) was not fulfilled, the collection of samples throughout the year was irregular and the representability of sampling points considered strategic was low (48% of municipalities). Besides, municipalities with a high prevalence for intestinal parasite protozoa were also the ones that had the highest counts for coliforms and the reverse can also be observed, indicating a transmission through contaminated drinking water. Despite the increased participation of municipalities in water surveillance actions during the studied period, it is necessary to implement managerial measures to improve the system, aiming to correct flaws and inconsistencies in the application of the water quality monitoring protocol.

Key words | Brazil, drinking water, health surveillance, intestinal parasitic infections, waterborne diseases, water parameters

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HIGHLIGHTS

- Analysis of the water surveillance protocol of Rio de Janeiro metropolitan area.
- First report to evaluate the surveillance of the drinking water quality information system database of RJ (Brazil).
- Possible transmission route of intestinal parasitic infections through drinking water contamination.
- Noncompliance with drinking water legislation.
- Need for urgent improvement in the drinking water surveillance program.

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INTRODUCTION

Water is essential to life and access to drinkable water is a crucial issue in public health. Drinking water legislation has the objective of ensuring the population access to water with quality and safety intended for human consumption.

In Brazil, the Secretary of Health Surveillance of the Ministry of Health (SVS/MS), through the General Coordination of Environmental Health Surveillance (CGVAM), started, in 2000, the implementation of the National Program for the Surveillance of Drinking Water Quality (VIGIAGUA) (Bevilacqua *et al.* 2014; Oliveira Júnior *et al.* 2019). In 2005, the model of action was published defining the field, the way of acting and the main activities necessary for the operationalization of the actions of surveillance of water for human consumption (VQACH) (Bevilacqua *et al.* 2014; Oliveira Júnior *et al.* 2019). The surveillance of the drinking water quality information system (SISAGUA) began to be consolidated from 2007, 7 years after the implementation of VIGIAGUA. For this purpose, the country used as reference the Guidelines for Drinking Water Quality established by the World Health Organization (WHO 2011).

VIGIAGUA program consists of continuous actions taken by the public health authorities to ensure the drinking water quality and the compliance of standards established in current legislation and to assess the risks that water from public and/or alternative sources may represent to human health (Brasil 2005). The standard of potability in Brazil is established in Federal Law number 5/2017 (PRC no. 5, annex XX) (Oliveira Júnior *et al.* 2019), which is being updated since 1990. It is in this ordinance that the physical, chemical, microbiological and radiological parameters necessary for monitoring are presented, as well as the definition of the three main supply systems: the water supply systems (SAA), the collective workaround (SAC) and the individual workaround (SAI).

The inventory of the water supply systems is carried out by the Unified Health System (UHS) and the body of Executive Power of the three spheres of government (Union, the States and the Federal District, and the Municipalities), which, through a feedback process of data provided by the Municipal Secretariats of Health, allows the maintenance of SISAGUA. Thus, SISAGUA stores information from alternative sources of water and official systems operated by public or private companies with recognized competence. The database gathers information on the geographic location or address, hydrological characteristics of the source, system classification, and main physical–chemical and microbiological parameters of potability.

Thereby, SISAGUA aims to inform decision-making process for health managers once the system classifies and identifies the most vulnerable areas (for waterborne diseases). As well, SISAGUA carries out direct and indirect interventions with public and private (concession) water companies, such as improvements in water treatment, identification of critical areas of water conduction and sources of contamination, among others.

Additionally, water is also a major vehicle for pathogen dissemination, and waterborne outbreaks caused by drinking water contamination occur worldwide (Yang *et al.* 2012; Efstratiou *et al.* 2017). A number of viral, bacterial and protozoan pathogens can spread via drinking water, causing illness in the population (Ashbolt 2015). Intestinal parasitic infections (IPIs) are considered as indicators of health and socio-environmental vulnerability and are associated with the precarious sanitation and water quality of a country (Pullan & Brooker 2012; Strunz *et al.* 2014; Speich *et al.* 2016; Faria *et al.* 2017). They continue to pose a serious public health problem, especially in developing countries where sanitation is not expanded in line with population growth, such that access to basic services becomes more difficult (Faria *et al.* 2017). The potential for waterborne parasite transmission is high, since infective helminth eggs and protozoa (oo)cysts are distributed through water in the environment. It is well documented that conventional water and sewage treatment processes are not completely effective in destroying protozoa (oo)cysts and helminth eggs (Betancourt & Rose 2004; Savioli *et al.* 2006; Hatam-Nahavandi *et al.* 2015).

Waterborne protozoan parasite infections are responsible for numerous outbreaks in the world (Efstratiou *et al.* 2017). The most common etiological agents are

Cryptosporidium spp. and *Giardia lamblia*, followed by complex *Entamoeba histolytica/Entamoeba dispar*, *Cyclospora cayetanensis*, *Toxoplasma gondii*, *Cystoisospora belli*, *Blastocystis hominis*, *Acanthamoeba* spp., *Balantidium coli* and *Naegleria fowleri* (Baldursson & Karanis 2011; Plutzer & Karanis 2016; Efstratiou *et al.* 2017).

In a previous work published by our group (Faria *et al.* 2017), we noticed a high frequency of protozoan infections in the metropolitan region of Rio de Janeiro state in contrast to helminth infections. Probably, regular deworming with the drugs reduced the prevalence of helminths. However, the deworming programs are not effective against protozoa infections. Our results indicate human exposure to fecal contamination, thereby pointing to the probable transmission of intestinal parasites via the supply of water for human consumption.

Despite the existence of a database, studies analyzing the information generated by SISAGUA are scarce (Queiroz *et al.* 2012). Some studies address the evolution of the norm of drinkability of water supply and the challenges of the program in the sense of transparency and access of the information generated to society (Freitas & Freitas 2005), and others explore quantitative aspects and goals reached by VIGIAGUA (Castro & Câmara 2004; Brasil 2009). So far, only one study (Vasconcelos *et al.* 2016) carried out in three states of Legal Amazon (Amapá, Amazonas and Maranhão) and analyzed the adhesion of the municipalities to VIGIAGUA program.

The present work analyzed the SISAGUA database, provided by the Ministry of Health, from the metropolitan region of Rio de Janeiro regarding the drinking water quality surveillance of the supply systems and correlated the findings of the microbiological analysis with the previously published distribution of intestinal protozoa.

METHODS

Study site

Rio de Janeiro state is composed of 92 municipalities. The metropolitan region of Rio de Janeiro is composed of 21 municipalities: Belford Roxo, Cachoeira de Macacu, Duque de Caxias, Guapimirim, Itaboraí, Itaguaí, Japeri, Magé, Maricá, Mesquita, Nilópolis, Niterói, Nova Iguaçu, Paracambi, Queimados, Rio Bonito, Rio de Janeiro, São Gonçalo, São João de Meriti, Seropédica and Tanguá (Table 1 and Figure 1). It is the second largest metropolitan area in Brazil with 11,812,482 inhabitants in an area of 8,147,356 km^2 (IBGE 2010).

According to the last census conducted in 2010, Rio de Janeiro municipality has a population of 6,320,446 inhabitants in an area of 1,197,463 km^2 (IBGE 2010). Most of the population (91.2%) has access to potable water, and 70.1% has sanitation coverage (Table 1) (IBGE 2010).

Water for the citizens of the metropolitan region of Rio de Janeiro is provided by two principal supply systems, called

Table 1 | Main characteristics of municipalities of the metropolitan region of Rio de Janeiro state

Municipalities	Population	Population density (inhab./km^2)	Drinking water coverage (%)	Sanitation coverage (%)
Belford Roxo	469,332	6,031.38	76.8	39.3
Cachoeira de Macacu	54,273	56.90	94.8	86.5
Duque de Caxias	855,048	1,828.51	85.1	41.6
Guapimirim	51,483	1,142.70	43.9	n.a.
Itaboraí	218,008	506.56	81.7	40.3
Itaguaí	109,091	395.45	86.4	37.0
Japeri	95,492	1,166.37	67.2	n.a.
Magé	227,322	585.13	79.7	40.6
Maricá	127,461	351.55	58	12.3
Mesquita	168,376	4,310.48	82.6	37.2
Nilópolis	157,425	8,117.62	98.3	95.9
Niterói	487,562	3,640.80	100	92.7
Nova Iguaçu	796,257	1,527.60	92.1	42.0
Paracambi	47,124	262.27	73.1	29.9
Queimados	137,962	1,822.60	79.7	37.0
Rio Bonito	55,551	121.70	87.2	n.a.
Rio de Janeiro	6,320,446	5,265.81	91.2	70.1
São Gonçalo	999,728	4,035.90	85.1	36.8
São João de Meriti	458,673	13,024.56	91.8	48.7
Seropédica	78,186	275.53	69.6	31.1
Tanguá	30,732	211.21	68.3	29.9

n.a., not available.
Source: IBGE 2010.

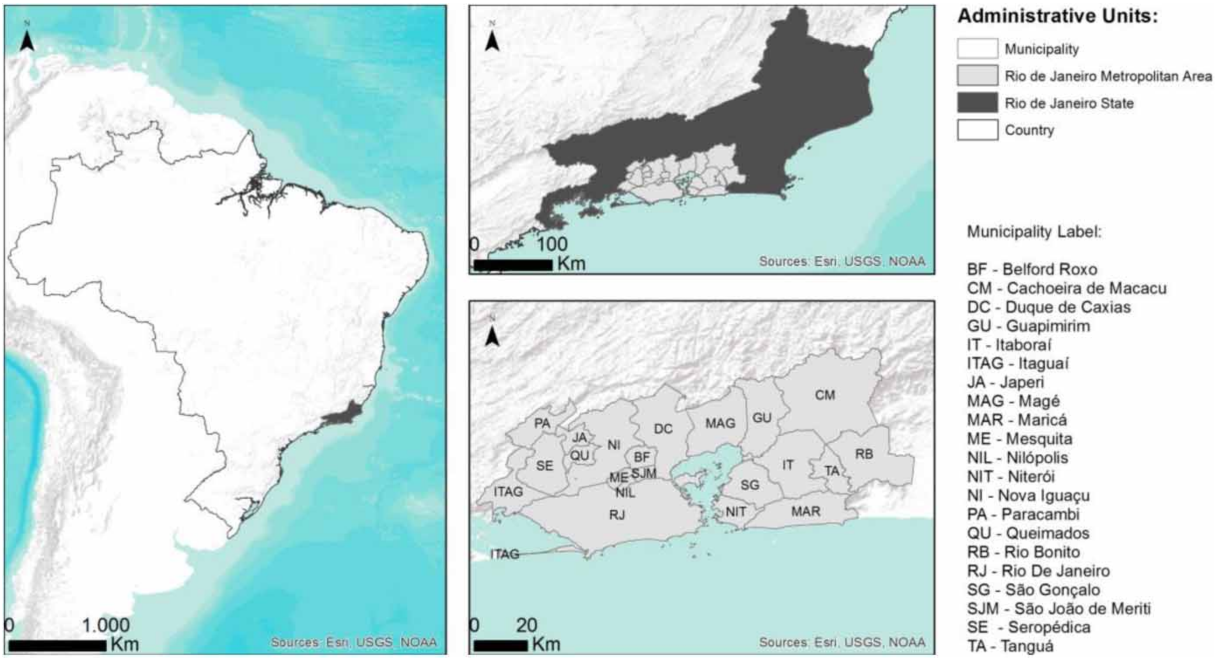

Figure 1 | Localization of the metropolitan region of Rio de Janeiro state, Brazil (Faria *et al.* 2017).

Guandu-Piraí and Imunana-Laranjal, that capture water from the Guapiaçu and Macacu rivers, respectively. Both of these undergo the conventional treatment process, including coagulation, flocculation, filtration (granulated active carbon), fluoridation and chlorination. Finally, water is pumped and distributed to reservoirs and the supply network.

Data source

The study was carried out from 2007 to 2013 using data obtained from the SISAGUA database, which is available through a System of Registration and Access Permission – SCPA (http://sisagua.saude.gov.br/sisagua/login.jsf), which can be done by any user who signs up in the system, although access may or may not be authorized. According to the spreadsheets provided by the Ministry of Health, the data for the most recent years (2014) have not yet been processed (personal communication). The spreadsheet provided by the Ministry of Health had information on (i) system address (address and geographic coordinates); (ii) type of supply source (water supply systems, collective or individual supply systems); (iii) description of the sampling point; (iv) sampling point (point at which water is effectively collected, that is, before or after reservation); (v) identification of the employee responsible for the water sampling; (vi) number of sampling samples and (vi) sampling date. Additionally, the SISAGUA database also records information on seven potability parameters recommended by Federal Law number 5/2017 (PRC no. annex XX) (Oliveira Júnior *et al.* 2019): (i) the presence of free residual chlorine (FRC); (ii) turbidity of the treated water; (iii) total coliform count; (iv) fecal coliform (*Escherichia coli*) count; (v) fluoride concentration; (vi) use of ultraviolet and ozone disinfection and (vii) other types of water disinfection. Only records with valid address were considered valid and suitable to integrate this study.

It is worth noting that in Brazil, unlike Europe and the United States, water is reserved before being consumed. This storage is performed to guarantee the regularity of the water supply in systems that have intermittency and low pressure in the network. According to the Federal Law, the sampling water must be performed before reserving the water, i.e. the first water outlet (faucet) after the water arrives.

The geographic distribution of intestinal parasites in the metropolitan region of Rio de Janeiro was obtained from a previously published database (Faria *et al.* 2017).

Monitoring stations identification

The SISAGUA database is not organized by the monitoring station. To overcome this limitation, the collection point of each sample was extracted from the database, validated manually and converted into geographic coordinates (latitude and longitude). Every sample with a new address was considered as a new monitoring station, while samples with duplicated addresses were considered as multiple records from the same monitoring station. Through this process, it was possible to georeference 95% of the samples (5,723) and cluster them into 1,654 monitoring stations.

Analyzed parameters

For the analysis of the surveillance protocol, consonantly to the Federal Law number 5/2017 (PRC no. 5, annex XX), we addressed the minimum number of samples collected during the year and the FRC, turbidity, counts of total and fecal coliform (*E. coli*) parameters; the uniformity of the sampling distribution throughout the year and the representativeness of the monitoring stations (or sampling points).

The analysis of the vulnerability areas for drinking water from supply networks was carried out through the detection of fecal coliforms in the water samples collected at the monitoring stations, which is an indicator of waterborne pathogens.

It should be noted that the parameters found in 2013 that presented better regularity were FRC, turbidity, total coliform counts and *E. coli* count. In the other years, there was not an adequate frequency of records for an annual analysis. Additionally, not all information was correctly filled out by employees (type of supply source, fluoride concentration; use of ultraviolet and ozone disinfection, or other types of water disinfection), thus rendering the analysis unviable.

Representativeness analysis

The sampling plan should present a representativeness of sampling points in the distribution system (water storage reservoirs and supply network), combining spatial coverage criteria and the presence of strategic points. Hence, monitoring stations should be located in (i) places where there is great circulation of people, such as road terminals, railways and airports; (ii) buildings that serve risk groups, such as hospitals, kindergartens and nursing homes; (iii) vulnerable parts of the drinking water supply systems just as network extremities, points where pressure is insufficient to maintain a constant water flow, sections affected by operational procedures (carried out in the network and in the reservoirs) subject to intermittent supply and (iv) regions with systematic reports of health problems with possible waterborne pathogenic causes (Brasil 2011).

The assessment of the representativeness of the monitoring stations was made manually.

RESULTS

The SISAGUA database began in 2007, and initially, only 43% (9 of 21) of the municipalities of the metropolitan region of Rio de Janeiro state joined the program (Table 2). As of 2010, the membership of SISAGUA was above 90%; however, the participation of all municipalities was never achieved. Only 33% (7 of 21) of the municipalities fully participated in water quality surveillance actions between 2007 and 2013, namely Itaboraí, Magé, Mesquita, Nilópolis, Nova Iguaçu, Rio de Janeiro and São Gonçalo.

According to the information mentioned above, our group opted for the analysis of the year 2013, since it was the year that all municipalities participated in the program, except for Tanguá, which was only in 2010 in the program. Despite the years 2010 and 2012 also present the same number of participating municipalities, the analysis of the spreadsheet revealed an irregular frequency of the information of the parameters, thus preventing a homogeneous analysis of the data. The year 2012 presented a regular frequency of information; however, it had locations of sampling points different from 2013, preventing a comparative study.

As mentioned earlier, the latest SISAGUA database (2014) is not available.

Description of the collection point

For the purpose of responsibility and competence in relation to water supply companies, the SISAGUA database contains an important analytical bias to be highlighted, related to the description of the sampling point, that is, the place

Table 2 | Participation of the municipalities of the metropolitan region of Rio de Janeiro state in SISAGUA between 2007 and 2013

Municipalities	Years 2007	2008	2009	2010	2011	2012	2013	Total
Belford Roxo	■	■	■	■		■	■	6
Cachoeira de Macacu				■	■	■	■	4
Duque de Caxias				■	■	■	■	4
Guapimirim	■			■	■	■	■	5
Itaboraí	■	■	■	■	■	■	■	7
Itaguaí				■	■	■	■	4
Japeri				■	■	■	■	4
Magé	■	■	■	■	■	■	■	7
Maricá		■		■	■	■	■	5
Mesquita	■	■	■	■	■	■	■	7
Nilópolis	■	■	■	■	■	■	■	7
Niterói			■	■	■	■	■	5
Nova Iguaçu	■	■	■	■	■	■	■	7
Paracambi		■		■	■	■	■	5
Queimados		■	■	■	■	■	■	6
Rio Bonito		■	■	■	■	■	■	6
Rio de Janeiro	■	■	■	■	■	■	■	7
São Gonçalo	■	■	■	■	■	■	■	7
São João de Meriti					■	■	■	4
Seropédica					■	■	■	3
Tanguá				■				1
Total	9	12	11	20	19	20	20	

where water is effectively collected (item (iv) of the description of the data source in the 'Methods' section). As previously described, the sampling water must be performed prior to reservation. Therefore, if this procedure is not described and executed, a bias related to the responsibility between supply (supply company) and storage (consumer) is generated on the maintenance of the quality of the water supply.

In 2013, of the 20 participating municipalities, only Niterói, Queimados and Seropédica carried out the collection of the water samples adequately and correctly filled the spreadsheet. In most of the municipalities, the information was collected with errors (e.g. the description of the sampling point written in the wrong field, performing the water sample after their reservation). Thus, most of the SISAGUA's spreadsheets were imprecise in fulfilling this criterion, which made it impossible to evaluate supplier and consumer with regard to the microbiological parameter (*E. coli*). So, this study considered that the positive results for fecal coliforms are relevant only for the construction of a vulnerability framework, taking into account the water that the population effectively consumes, but not operational aspects of quality and conservation.

Minimum number of samples collected during the year

In the year 2013, a total number of 6,044 samples collected were sent for the analysis of the following parameters: FRC (mg/L), turbidity (nephelometric turbidity units (NTU)), total coliforms (absence/presence in 100 mL) and *E. coli* (absence/presence in 100 mL) (Figure 2).

The information contained in SISAGUA's database shows that the number of samples collected monthly was

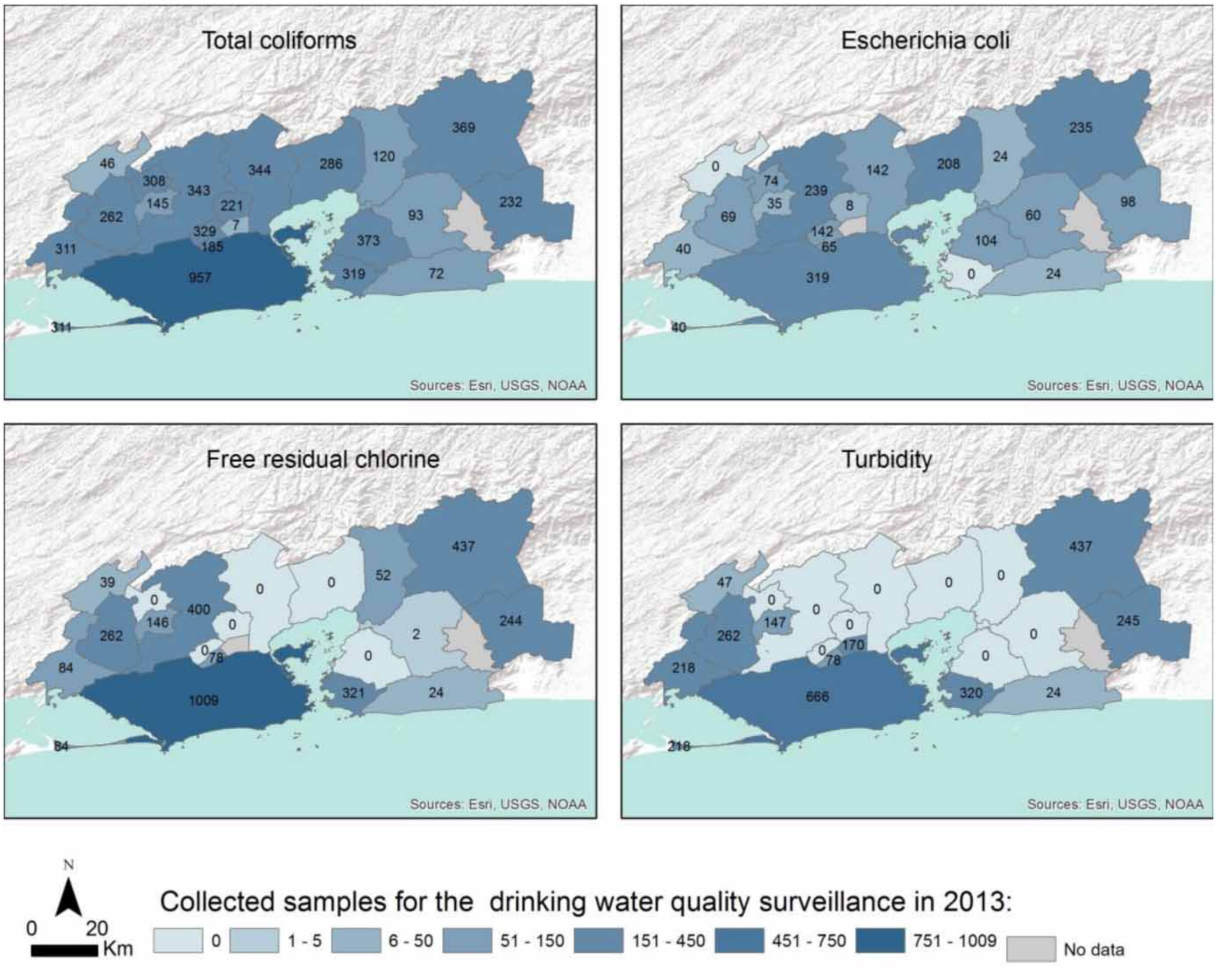

Figure 2 | Surveillance of drinking water quality in 2013 by municipalities of the metropolitan region of Rio de Janeiro attending several parameters: total coliforms, *E. coli*, FRC and turbidity.

performed irregularly, making it impossible to measure all the parameters. In addition, our group verified that all the participating municipalities presented sampling plans below what is recommended by Federal Law, regarding the total number of samples to be collected annually (Table 3).

The measurement of turbidity and FRC or other active residual compounds (if the disinfectant used is not chlorine) must be carried out on all samples collected for microbiological analysis. The quality of the water during storage and before reaching the final user is defined by Federal Law number 5/2017 (PRC no. 5, annex XX), in terms of mg/L of FRC. The maintenance of the minimum FRC is 0.2 mg/L in the distribution system, which includes reservoir and network. In this way, it is necessary to apply the disinfectant at intermediate points of the distribution network in order to guarantee the free residual at the network ends. The standard also recommends that the concentration of FRC in the entire distribution network not exceeds 2 mg/L. Also according to the standard, for the turbidity parameter, the maximum allowed a value at the output of the rapid filtration is 0.5 uT, which must be maintained throughout the system, including reservation and distribution. During database analysis, we verified that the numbers of samples collected for FRC and turbidity measurements should be equal to or greater than the number of samples collected for microbiological analysis. Based on this assumption, only 25% of municipalities, Cachoeiras de Macacu, Niterói, Queimados, Rio Bonito and Seropédica, complied with the Law (Table 3).

Of the 5,322 tests performed for total coliforms, 1,814 (34.1%) were positive, and of the 2,303 tests performed for

Table 3 | Number of samples collected for the surveillance of drinking water quality in 2013 by municipalities of the metropolitan region of Rio de Janeiro

	Number of tests performed per parameters				Number of samples	
Municipalities	**FRC**	**Turbidity**	**Total coliforms**	***E. coli***	**Collected samples[a]**	**Required samples[b]**
Belford Roxo	0	0	221	8	230	2,482
Cachoeiras de Macacu	437	437	369	235	437	1,486
Duque de Caxias	0	0	344	142	344	3,408
Guapimirim	52	0	120	24	122	1,480
Itaboraí	2	0	93	60	94	1,879
Itaguaí	84	218	311	40	311	1,618
Japeri	0	0	308	74	308	1,585
Magé	0	0	286	208	286	1,902
Maricá	24	24	72	24	72	1,662
Mesquita	0	0	329	142	331	1,760
Nilópolis	78	78	185	65	195	1,734
Niterói	321	320	319	0	321	2,526
Nova Iguaçu	400	0	343	239	404	3,267
Paracambi	39	47	46	0	47	1,469
Queimados	146	147	145	35	147	1,687
Rio Bonito	244	245	232	98	245	1,489
Rio de Janeiro	1,009	666	957	319	1,020	13,356
São Gonçalo	0	0	373	104	376	3,755
São João de Meriti	–	170	7	417	492	2,457
Seropédica	262	262	262	69	262	1,544
Total	3,098	2,614	5,322	2,303	6,044	52,546

[a]The number of tap water samples were collected from surveillance agencies in each municipality to carry out the tests of the water quality parameters.
[b]The total number of samples to be collected per parameter, according to Federal Law 5/2017 (PRC no. 5, annex XX), were performed.

E. coli, 343 (14.9%) were positive. The municipalities of Belford Roxo, Magé, Cachoeiras de Macacu and Japeri presented the highest frequencies for *E. coli*, with 87.5, 40.9, 27.2 and 25.7%, respectively. Seropédica was the only municipality that complied with the Law for analysis of *E. coli* (Table 4).

The most analyzed parameters in 2013 were the microbiological ones, despite two municipalities, Niterói and Paracambi, have not performed tests for *E. coli* (Table 4). The least analyzed parameters were FRC and turbidity, of which six (Belford Roxo, Duque de Caxias, Japeri, Magé, Mesquita and São Gonçalo) and nine municipalities (Belford Roxo, Duque de Caxias, Guapimirim, Itaboraí, Japeri, Magé, Mesquita, Nova Iguaçu and São Gonçalo), respectively, did not carry out these tests.

The results show that the participating municipalities in the metropolitan region of Rio de Janeiro did not comply with the Federal Law, which advocates the absence of fecal coliform (in 100 mL) in 95% of samples collected monthly, throughout the water supply system, which includes the output area of water treatment plants, the network and reservoirs (Table 4).

Moreover, it was observed that in Belford Roxo and São João de Meriti municipalities, the number of positive samples for *E. coli* is higher than for total coliforms (Table 4). Probably, this result is due to errors made during the filling of the worksheet or during the analytical execution, since it is expected that the number of positive samples for *E. coli* is less than or equal to the total positive samples for total coliforms.

Table 4 | Number of positive samples performed with the absence or presence of total coliforms and *E. coli*

	Number of positive samples	
Municipalities	**Total coliforms (%)**	***E. coli* (%)**
Belford Roxo	0 (0)	7 (87.5)
Cachoeiras de Macacu	218 (59.1)	64 (27.2)
Duque de Caxias	143(41.6)	24 (16.9)
Guapimirim	24 (20)	2 (8.3)
Itaboraí	60 (64.5)	9 (15)
Itaguaí	40 (12.9)	4 (10)
Japeri	74 (24)	19 (25.7)
Magé	208 (72.7)	85 (40.9)
Maricá	24 (33.3)	2 (8.3)
Mesquita	142 (43.2)	27 (19)
Nilópolis	65 (35.1)	8 (12.3)
Niterói	0 (0)	n.a.
Nova Iguaçu	201 (58.6)	22 (9.2)
Paracambi	0 (0)	n.a.
Queimados	35 (24.1)	2 (5.7)
Rio Bonito	85 (36.6)	16 (16.3)
Rio de Janeiro	319 (33.3)	23 (7.2)
São Gonçalo	104 (27.9)	16 (15.4)
São João de Meriti	3 (42.9)	13 (3.1)
Seropédica	69 (26.3)	0 (0)
Total	1,814 (34.1)	343 (14.9)

n.a., not available.

Table 5 | Number of collected water samples according to the relevance of the sampling points by municipalities of the metropolitan region of Rio de Janeiro

Municipalities	Strategic points (%)	Nonstrategic points (%)	Missing[a] (%)	Total
Belford Roxo	64 (82.1)	9 (11.5)	5 (6.4)	78
Cachoeira de Macacu	23 (42.6)	31 (57.4)	0 (0)	54
Duque de Caxias	105 (84.7)	16 (12.9)	3 (2.4)	124
Guapimirim	21 (95.5)	1 (4.5)	0 (0)	22
Itaboraí	31 (93.9)	2 (6.1)	0 (0)	33
Itaguaí	29 (40.3)	41 (56.9)	2 (2.8)	72
Japeri	33 (75)	3 (6.8)	8 (18.2)	44
Magé	48 (80)	11 (18.3)	1 (1.7)	60
Maricá	14 (93.3)	1 (6.7)	0 (0)	15
Mesquita	59 (52.7)	47 (42)	6 (5.4)	112
Nilópolis	12 (26.7)	31 (68.9)	2 (4.4)	45
Niterói	73 (38)	111 (57.8)	8 (4.2)	192
Nova Iguaçu	62 (44)	74 (52.5)	5 (3.5)	141
Paracambi	6 (42.9)	8 (57.1)	0 (0)	14
Queimados	45 (50.6)	40 (44.9)	4 (4.5)	89
Rio Bonito	32 (97)	0 (0)	1 (3.0)	33
Rio de Janeiro	103 (92.8)	8 (7.2)	0 (0)	111
São Gonçalo	32 (39)	45 (54.9)	5 (6.1)	82
São João de Meriti	2 (0.7)	287 (96.3)	9 (3)	298
Seropédica	13 (37.1)	21 (60)	1 (2.9)	35
Total	807 (48.8)	787 (47.6)	60 (3.6)	1,654

[a]Absence of information: the addresses of the collected samples could not be characterized or defined, neither as a strategic nor as a nonstrategic place.

Representativeness of the monitoring stations

The number and location of monitoring stations inform how these samplings were distributed in the territories. It was possible to identify through the location of the monitoring stations that 807 points were considered to be located at a strategic place and 787 are nonstrategic points (represented by private households).

In this sense, Rio Bonito, Guapimirim, Itaboraí, Maricá and Rio Janeiro municipalities presented the best representativeness of the monitoring stations (97, 95.5, 93.9, 93.3 and 92.8%, respectively) (Table 5). On the other hand, Niterói, Seropédica, Nilópolis and São João de Meriti municipalities presented the worst rates of representativeness (38, 37.1, 26.7 and 0.7%, respectively) (Table 5). São João de Meriti municipality is the most critical, since practically no point selected for the sampling plan follows what the Federal Law advocates.

Transmission routes of IPIs

The present work tried to understand the high prevalence of IPIs among individuals from the metropolitan region of Rio de Janeiro state, previously found in a study published by our group, overlapping the results obtained from the SISAGUA database and the geographical distribution of participants positive for protozoan infections (Faria *et al.* 2017). The distribution of parasite species varied among the municipalities (Table 6). In Rio de Janeiro, it was possible to detect 104 enteric parasites (60.1%), and Duque de Caxias was the second municipality with 19 (11%), followed by Nova Iguaçu (18; 10.4%), Belford Roxo (8; 4.6%), São João de

Table 6 | Distribution of intestinal parasites species by the metropolitan region of Rio de Janeiro state in 2013

Municipality	Number (%) of intestinal parasites species	Number (%) of protozoa species	Number (%) of helminths species
Belford Roxo	8 (4.6)	7 (4.5)	1 (4.8)
Cachoeira de Macacu	2 (1.2)	2 (1.3)	0
Duque de Caxias	19 (11)	18 (11.5)	1 (4.8)
Itaboraí	2 (1.2)	1(0.6)	1 (4.8)
Itaguaí	1 (0.6)	0 (0)	1 (4.8)
Mesquita	1 (0.6)	1 (0.6)	0
Nilópolis	5 (2.9)	5 (3.2)	0
Niterói	1 (0.6)	1 (0.6)	0
Nova Iguaçu	18 (10.4)	17 (10.8)	2 (9.5)
Rio de Janeiro	104 (60.1)	93 (59.2)	15 (71.4)
São Gonçalo	5 (2.9)	5 (3.2)	0
São João de Meriti	7 (4.0)	7 (4.5)	0
Guapimirim, Japeri, Magé, Maricá, Paracambi, Queimados, Rio Bonito and Seropédica	0 (0)	0 (0)	0
Total	173	157	21

Meriti (7; 4.0%), Nilópolis (5; 2.9%), São Gonçalo (5; 2.9%), Cachoeira de Macacu (2; 1.2%), Itaboraí (2; 1.2%), Itaguaí (1; 0.6%), Mesquita (1; 0.6%) and Niterói (1; 0.6%). We did not have positive samples from participants of Guapimirim, Japeri, Magé, Maricá, Paracambi, Queimados, Rio Bonito and Seropédica.

It was not possible to obtain satisfactory results after the overlap of SISAGUA with the database obtained from the study carried out in the metropolitan region of Rio de Janeiro state. The comparison between distinct databases is not an easy task, since the objectives of each vary according to the purposes/needs, together with the inaccuracy verified in the SISAGUA database. It was observed that the water sampling points were not the same or close to where the participants lived.

In spite of these discrepancies, comparing the municipalities that participated in both databases in the year 2013, we verified that Niterói municipality was the only one that presented a low frequency of protozoan infections (0.6%) and was negative for total coliform count. This result is compatible with data provided by the Brazilian Institute of Statistics and Geography (IBGE) (Table 1), in which Niterói is the only municipality in the metropolitan region of Rio de Janeiro that has 100% drinking water coverage. While the municipalities of Duque de Caxias (11.5%), Belford Roxo (4.5%), São Gonçalo (3.2%) and Nilópolis (3.2%) presented a high prevalence for protozoa and also presented the highest frequencies for *E. coli*, with 16.9, 87.5, 15.4 and 12.3%, respectively.

DISCUSSION

The current study analyzed the SISAGUA database in the metropolitan area of Rio de Janeiro, covering a population of 11,812,482 inhabitants, the second largest in Brazil. Therefore, a significant geographical extension, representing 6% of the Brazilian population according to the last census conducted in 2010 (IBGE 2010). As reported by the National Information System on Water, Sanitation and Solid Waste (SNIS), the percentage of the population supplied by the water network in 2013 (the reference year of the present study) was 89%, reaching 93% in 2016 (Brasil 2016). This proportion of the population served shows a significant advance in drinking water supply, which reinforces the need for an effective and permanent water monitoring program for human consumption, covering the water service providers responsible for municipality.

Based on a study developed by CGVAM, up to 2010, 4,036 Brazilian municipalities had information registered in SISAGUA, corresponding to 73% of Brazilian municipalities (Bevilacqua *et al.* 2014); while in 2011, this percentage increased to 90% of Brazilian municipalities, distributed in all States and the Federal District (Brasil 2012). However, despite the increase in this percentage, the distribution is heterogeneous among the Brazilian regions, with North and Northeast regions having the lowest percentage of municipalities with registered information (Brasil 2012).

The results of this study indicate that during the analyzed period, there was an increase in the participation of the municipalities that compose the metropolitan region of Rio de Janeiro in VIGIAGUA. This is a consequence of a massive investment of the Ministry of Health, from 1999, through resources from the Project for Modernization of the Health Surveillance System (VIGISUS), in the agreement of the goals aimed at health surveillance actions having the objective of structuring the program at the national level, through municipal capacity-building strategies, as well as the transfer of resources to the municipal level for the acquisition of equipment and laboratory supplies (Brasil 2004).

The information generated at the local level feeds the SISAGUA; therefore, it is necessary that the program can execute the surveillance actions according to what is recommended by the Federal Law number 5/2017 (PRC no. 5, annex XX). In this way, it was possible to verify that the total number of samples collected in the year 2013 was only 10%. Considering the entire population of the metropolitan region of Rio de Janeiro, these values constitute a very low coverage of the program in the immense urban area. In the same year, only 2,303 tests were performed for the detection of *E. coli*, i.e. only 4% of the total recommended value. It should be noted that this is the most used indicator to attest the impropriety of water for human consumption; it should be absent in the water supply network. However, it was present in about 13% of the tests performed for the detection of *E. coli*, demonstrating the vulnerability of the system.

Regarding the uniformity of the collected water samples and the representativeness of sampling points in the distribution system, we observed that these parameters were not adequately performed in any municipality. The most critical cases were observed in 11 municipalities, where this representativeness was between 0.7 and 52.7%. These results indicate that the selection of sampling points used family households as a priority, leading to a greater exposure of the population not covered by the water surveillance program. As mentioned above, sampling points should have been selected in places where there is great circulation of people, buildings that serve risk groups and vulnerable parts of the drinking water supply systems.

Better compliance rates need to be achieved, such as those seen in EU Member States, where chemical and microbiological parameters, analyzed in large water supply systems at 96,000 water sources, increased from an average of 95% in 1998 (based on 15 Member States that year) to around 97% in 2005 and, more recently, to a level of compliance greater than 99% in all 27 Member States, according to the 2016 evaluation committee report (EC 2016).

Water distribution system deficiencies are associated with significant increases in waterborne diseases, and even with well-operated drinking water systems, drinking water can still become contaminated. Drinking water contamination is more common in low-income countries, but the safety of drinking water is also affected in high-income countries (Baldursson & Karanis 2011; Yan g *et al.* 2012; Bylund *et al.* 2017). For example, in 2013, three community waterborne outbreaks caused by *Cryptosporidium* spp. have been reported in Ireland, with contamination of drinking water being the most likely cause (Health Protection Surveillance Centre Ireland 2014). Obviously, the transmission of waterborne diseases is not only due to water supply failures (independent of its mode of transmission: untreated water supplies, contaminated water sources, failures in treatment processing, contamination of reservoirs or post-treatment contamination) but also due to lack of basic sanitation and inadequate hygiene behaviors (Prüss-Ustün *et al.* 2019).

Corrective response actions must be related by parameters and to each type of case. According to the European Commission's evaluation report (EC 2016), for contamination by coliform, most corrective actions (67%) were related to problems in the distribution network or issues related to the operational aspects of water treatment (e.g. disinfection and filtration).

In the USA, between 2001 and 2002, 5 of the 25 (20%) waterborne outbreaks were associated with deficiencies in the municipal drinking water distribution systems. As well as the seven reported outbreaks involving community water systems, four (57.1%) were also related to problems in the distribution system (Blackburn *et al.* 2004).

IPIs are transmitted by the fecal–oral route and through drinking contaminated water; thus, infections are more present where access to clean water and sanitation is inadequate (Bethony *et al.* 2006; Pullan & Brooker 2012; Speich *et al.* 2016). Both conditions have long been associated with diarrhea (Cairncross *et al.* 2010), which is among the main contributors to global child mortality (Liu *et al.* 2012). A systematic review and meta-analysis showed that sanitation facilities and water treatment are associated with lower risks of infection with intestinal protozoa and could also prevent diarrheal diseases (Speich *et al.* 2016). The same relationships were observed for soil-transmitted helminths (Strunz *et al.* 2014).

A study conducted by Faria and colleagues (2017) looked at socioeconomic indicators (social vulnerability indicator) for intestinal infections, in particular family income, education and sanitation (access to safe drinking water). The construction of a material deprivation index showed that intestinal parasites are strongly associated with the socioeconomic status of the population, thus making it possible to identify socially vulnerable areas.

It is worth mentioning that pathogenic protozoa account for most of the waterborne outbreaks. Recently, Rosado-García *et al.* (2017) noticed that information on the prevalence and detection of waterborne parasitic protozoa are limited or not available in Latin America. Despite the high prevalence of parasitic protozoa in Brazil, few studies have been conducted in recent years. So far, only two studies were performed in Rio de Janeiro (Bahia-Oliveira *et al.* 2003; Vieira *et al.* 2015), and consequently, little is known about the transmission routes of waterborne parasitic diseases.

The high frequency of protozoan infections (89.6%) observed in the metropolitan area of Rio de Janeiro led our group to overlap the available databases (SISAGUA and published by Faria *et al.* 2017) in order to unravel possible transmission routes. In 2013, a total of 1,059 individuals had the parasitological tests done, with 173 (16.3%) positive samples for one or more enteric parasites and 886 (83.7%) individuals with negative results (Faria *et al.* 2017). Of the nine species of protozoa detected, four were pathogenic (complex *E. histolytica*/*E. dispar*, *Cryptosporidiu*m spp., *C. belli* and *G. lamblia*), and five were nonpathogenic (*B. hominis*, *Endolimax nana*, *Entamoeba coli*, *Entamoeba hartmani* and *Iodamoeba butschilii*). The pathogenic species comprise 26.6% of the studied participants, while the nonpathogenic reached 73.4%. Since most of these protozoa are typically transmitted through the fecal–oral route, they can infect humans through various means of contamination of water sources and recreational water venues by animal or human feces (Karanis *et al.* 2007; Plutzer & Karanis 2016; Efstratiou *et al.* 2017). So, the main hypothesis to explain our high prevalence of protozoa is their potential transmission through water.

The potential for transmission through drinking water is high, since infective (oo)cysts are widely distributed in the environment; due to their size, they can overpass physical barriers in conventional water treatment processes and are disinfectant resistant. Deficiencies in the drinking water treatment process are among the most frequent reasons for cryptosporidiosis and giardiasis outbreaks, for example (reviewed in Smith *et al.* 2007).

Such studies are imperative and improvements in water quality, basic sanitation and hygiene conditions of the population could reduce disease cases, especially in the most vulnerable age groups, such as children and the elderly.

Despite the massive public investment in the expansion and implementation of the program throughout the national territory, SISAGUA presented an insufficient stored information flow for an analysis since its implementation in 2007. This suggests the occurrence of problems related to program management both in the generation of information by the municipalities and states as in the capacity to manage this flow of information by the Ministry of Health.

It is essential that there is a resumption of the investment of this public health service in order to adapt the actions to what is recommended in Federal Law 5/2017 (PRC no. 5, annex XX). The rigor in the preparation and fulfillment of the sampling plans, as well as the established criteria for the minimum number of samples per parameter, uniformity of sampling distribution and representativeness of the monitoring stations, must be respected. Permanent technical training, expansion of regional public health laboratories, and investment in field analysis and georeferencing equipment are imperative. Accordingly, it is essential for the effectiveness of environmental health surveillance, represented as a set of actions that allow the knowledge and detection of any changes in the determinants and conditioning factors of the environment that may interfere in human health, in order to identify the measures prevention and control of environmental risk factors related to water for human consumption.

CONCLUSION

According to our results, the uniformity of the collected water samples, the minimum number of samples collected during the year and the representativeness of sampling points in the distribution system were not adequately performed in any municipality. So, these inaccuracies in the SISAGUA database made it difficult to compare the presence of coliforms and intestinal parasites in the study region. Certainly, local conditions that affect water safety can vary greatly, making direct comparisons between studies difficult.

Despite these obstacles, we observed that the municipalities with a high prevalence for protozoa were also the ones that had the highest counts for coliforms (Belford Roxo, Duque de Caxias, São Gonçalo and Nilópolis). The reverse can also be observed; the Niterói municipality had a lower frequency of protozoa and low coliform count. This study may indicate a transmission through contaminated drinking water. The surveillance of the drinking water quality consists of continuous actions that ensure that the water for human consumption complies the current drinking standards in order to assess and prevent possible health risks associated with the consumption of nonpotable water. Therefore, it is necessary for the public surveillance system to present the continuity and technical–operational quality of monitoring in order to ascertain the quality of the water supplied by the supply companies.

We conclude, according to the presented results, that the system, in fact, has flaws, and most of them located, likely, at the local level, where the data are generated. Under the country's health legislation, municipalities are responsible for implementing, executing and maintaining the water quality surveillance program. This involves the need for permanent training of the technicians responsible for preparing the monitoring plan, strictly following the guidelines recommended by Brazilian Federal Law 5/2017 (PRC no. 5, annex XX). Since water quality surveillance is one of the goals of the Brazilian Unified Health System, subject to the contingency of financial resources, for the entire system to function fully, in a more efficient and effective manner, it is essential that resources are transferred continuously in order to guarantee the achievement of the proposed goals, and this involves constant technical training, the acquisition and maintenance of analytical equipment, expanding the capacity of reference laboratories and increasing investments in risk information and communication systems. And this flow must be understood and respected as a policy of the state and not of transitional governments, which, if not, tends to weaken the entire system.

To make the system more reliable, effective and efficient, investment in strategic and basic actions is essential. The first concerns: (i) general coordination of the water quality surveillance program, which results in the fulfillment of established goals and priorities, enabling the detection, prediction and prevention of water contamination, with a focus on reducing the incidence of diseases transmitted by water; (ii) continuous training in human resources, through refresher and improvement courses; (iii) structuring, accreditation and decentralization of the laboratory network that allows expanding the number of parameters analyzed, which could include pesticides, heavy metals, cyanotoxins and other toxic substances; (iv) research development, through cooperation agreements between universities and health services, through the provision of scientific and technological subsidies for surveillance practices, allowing the development of new analysis and monitoring technologies; (v) standardization and uniform procedures between Federal Law and local laws, the latter of state and municipal scope, avoiding the occurrence of different monitoring and analysis procedures and methodologies; (vi) articulation between the different institutions of the public and private sectors that make up the UHS in the areas of sanitation, environment and water resources in the country, which contributes to the development of a unique system that gathers information on both the quality of raw water and treated water (Bevilacqua *et al.* 2014). Currently, there are information systems for each sector mentioned above; however, they are not integrated.

As for the basic level, we agree with Bevilacqua *et al.* (2014) who propose the following actions: (i) permanent knowledge of the forms of supply existing in the municipalities for adequate surveillance planning and this involves the identification, registration and inspection of the different forms of supply. This should be done based on the concept of water security and checklist-type techniques, in order to categorize the contamination threats to these sources. (ii) Monitoring of water quality, either through tests carried out on the spot, with the use of kits, for example, or through the collection of samples to be sent to the laboratory for more complex analyses, such as intestinal parasites, pesticides and metals. (iii) Integrated, spatial and epidemiological assessment and analysis between the different information systems existing in the country, for example, SISAGUA and DATASUS, the latter is the country's official information system and gathers data on the notification of diseases and conditions. Currently, these two systems are not integrated and make environmental epidemiological analysis a huge challenge for technicians working in health departments, for example, in correlating outbreaks of waterborne diseases to possible problems in supply. (iv) Systematic analysis of health and environment indicators involving a joint action of epidemiological, health and environmental surveillance. (v) Identification and assessment of risk factors associated with different forms of water supply, which are present in the hydrographic basin, in the treatment plant and in the distribution and reserve of water. (vi) Acting with the person(s) responsible for the operation of the system or alternative supply solution in order to correct risk situations previously identified by the technicians. (vii) Conducting epidemiological inquiries and investigations in order to identify risk factors related to the quality, treatment and distribution of water and sanitary habits. (viii) Permanent and continuous dissemination of information on water quality to the population. (ix) Education and communication and social actions aimed at the sustainability and water security of the water sources used to supply the population.

Finally, as we have already highlighted, the results obtained in this study refer only to a 'portrait' of the system at that time, the spreadsheets obtained from the Ministry of Health allowed us to proceed with this past analysis. To go deeper with a more up-to-date and detailed analysis of the functioning of the system, in addition to the spreadsheets obtained, a second round of investigation is necessary, through surveys with the system managers and the technicians who generate the data at the local level. We believe that this way we will be able to obtain more detailed explanations about the flaws found in the spreadsheets.

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DATA AVAILABILITY STATEMENT

All relevant data are available from an online repository or repositories (http://sisagua.saude.gov.br/sisagua/login.jsf).

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