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Water quality inequalities in Brazilian municipalities: surveillance challenges for the 21st century

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Lorrayne Belotti[1*]; Anna Laura Santos Doalto[2]; Paulo Frazão[2]

[1]Centro de Estudos, Pesquisa e Prática em APS e redes. Einstein Hospital Israelita, Avenida Albert Einstein, n° 627, CEP: 05652-000, São Paulo, SP, Brazil.
[2]Faculdade de Saúde Pública. Departamento de Política, Gestão e Saúde. Universidade de São Paulo (USP), Avenida Dr Arnaldo, n° 715, CEP: 01246-904, São Paulo, SP, Brazil.
E-mail: alsdoalto@gmail.com, pafrazao@usp.br
[*]Corresponding author. E-mail: lorraynebelotti@gmail.com

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ABSTRACT

Surveillance is the main strategy to ensure water quality. This study aimed to analyze the basic water quality parameters in Brazilian municipalities in 2018 according to their demographic, socioeconomic and geographic characteristics in order to explore the challenges of surveillance for the 21st century. We conducted a cross-sectional ecological study using official data from the Information System for Water Quality Surveillance for Human Consumption. More than 420K records from water supply systems across all 5,570 municipalities were submitted to a data cleaning and validation protocol processed with RStudio software. Variables included turbidity, free residual chlorine, pH, fluoride concentration, and the absence of *Escherichia coli*. Municipalities were categorized by population size, Human Development Index, and macro-region. The percentage of municipalities with valid information and compliance with expected standards was calculated based on institutional and scientific criteria. The results showed that E. coli and turbidity yielded the best performance (more than 75% of the municipalities had valid information) while pH and fluoride, the worst (less than 50% of the municipalities). In relation to the conformity, among municipalities with validated information, 80% or more were compliant with expected patterns for turbidity, free residual chlorine and pH and about half for E. coli and fluoride. In conclusion, the water quality surveillance was well implemented in one at each five Brazilian municipalities with significant differences according to demographic, socioeconomic and geographic characteristics of the municipalities.

Keywords: public health surveillance, public policy, water quality standards, water supply.

Desigualdades na qualidade da água nos municípios brasileiros: desafios da vigilância para o século XXI

RESUMO

A vigilância é a principal estratégia para garantir a qualidade da água. O objetivo foi analisar os parâmetros básicos da qualidade da água em municípios brasileiros em 2018, de acordo com suas características demográficas, socioeconômicas e geográficas, a fim de explorar os desafios da vigilância para o século XXI. Realizamos um estudo ecológico transversal utilizando dados oficiais do Sistema de Informação de Vigilância da Qualidade da Água para Consumo Humano. Mais de 420 mil registros de sistemas de abastecimento de água em todos os 5.570 municípios foram submetidos a um protocolo de limpeza e validação de dados processados com o software RStudio. As variáveis incluíram turbidez, cloro residual livre, pH, concentração de flúor e ausência de Escherichia coli. Os municípios foram categorizados por tamanho populacional, Índice de Desenvolvimento Humano e macrorregião. A porcentagem de municípios com informações válidas e conformidade com os padrões esperados foi calculada com base em critérios institucionais e científicos. Os resultados mostraram que E. coli e turbidez apresentaram o melhor desempenho (mais de 75% dos municípios tinham informações válidas), enquanto pH e flúor, o pior (menos de 50% dos municípios). Em relação à conformidade, entre os municípios com informações validadas, 80% ou mais estavam em conformidade com os padrões esperados para turbidez, cloro residual livre e pH, e cerca de metade para E. coli e flúor. Conclui-se que a vigilância da qualidade da água foi bem implementada em um em cada cinco municípios brasileiros, com diferenças significativas de acordo com as características demográficas, socioeconômicas e geográficas dos municípios.

Palavras-chave: abastecimento de água, padrões de qualidade da água, políticas públicas, vigilância em saúde pública.

1. INTRODUCTION

Water is essential for human life, as well as for the social and economic development of any world's region. In 2022, 27% of the world's population (2.2 billion people) did not have safely managed drinking water (WHO, 2023). Achieving universal and equitable access to safe and affordable drinking water, as well as adequate and equitable sanitation by 2030, is one of the targets of Goal 6 in the Sustainable Development Goals (United Nations, 2022). Since 1958, the WHO has recognized independent monitoring by external bodies as the primary strategy to ensure water quality, as it is crucial for preventing waterborne diseases that cause significant mortality in less developed areas (WHO, 2017).

Access to water services and its quality varies between countries due to factors such as territorial availability, financial resources and technical capabilities. Consequently, low- and middle-income countries often experience lower water quality. Furthermore, the lack of information on water quality also poses a health risk by preventing the assessment of conditions of its potability and the identification of system failures needed for improvements (Thacker *et al.*, 2012).

Potable water regulation is governed by national and international legislation through standards and guidelines based on local characteristics and needs (Thacker *et al.*, 2012). In the United States, the Safe Drinking Water Act authorizes the Environmental Protection Agency (EPA) to set national health-based standards for drinking water to protect against both naturally-occurring and man-made contaminants that may be found in drinking water. Several European countries follow the European Union Council Directive 98/83/EC. South Africa has guidelines for regulating drinking water quality. As the availability of safe water for human health is of strategic interest to public health, legislation that defines water quality parameters can be considered a public policy due to the multiplicity of associated interests, the complexity of the decisions involved and the administrative and management requirements to ensure its fulfillment. The determination of quality parameters depends on the use or purpose for which the resource is intended. Water quality for the purposes of preserving aquatic ecosystems requires parameters of pH, temperature, phosphorus and nitrogen concentration. In relation to water for human consumption, parameters that represent a health risk such as the presence/absence of Escherichia coli (E. coli) and chlorine concentration are very important for water quality. Analysis of the results of public policies ensuring water quality for human consumption in different contexts and countries contributes to an understanding of the global context of this public policy.

Since 1977 in Brazil, the Ministry of Health has had jurisdiction to define water quality parameters. In 1986, under the Federal Executive Order of the National Program of Surveillance of Water Quality for Human Consumption, conditions were created for bringing closer different stakeholders (state health departments, basic sanitation corporations, organs of environmental control, universities, reference laboratories, sanitation corporations, associations etc.). Two years later, the country has created a three-level federal system, approved by the Brazilian Constitution of 1988, that assures power and relative autonomy for the central government (first level), the 26 states and one Federal District (second level), and 5,570 cities (third level) (Frazão *et al.*, 2018).

In countries with a federative structure, there is great concern regarding the mechanisms for coordinating public policies, so that these are actually implemented and do not remain just "on paper" (Hochman and Faria, 2013). Studies suggest that the process of implementing Brazilian federalism is in a transition phase, as it presents a low governance capacity, as a result of general changes that have occurred in the various sectors of public policies, including sanitation and health. In addition to addressing local inequalities and the different bureaucratic capacities of the levels of government, it is necessary to develop mechanisms to understand what happens at the frontline, that is, at the local level, in order to examine the effects produced by the implementation process and learn lessons for redesigning the policy, adapting it to the different local realities and seeking new institutional arrangements focused on coordination and governance (Oliveira *et al.*, 2019; Sanchez *et al.*, 2021).

The surveillance of water used for human consumption may be performed by auditing data produced by water supply companies, or by means of direct observation, examining water samples from the distribution system. Since 2000 in Brazil, monitoring the quality of water supplied to the population has been the responsibility of municipal health authorities, who carry out surveillance and implement proper sampling plans guided by directives that define basic parameters for water samples (Freitas and Freitas, 2005; Frazão *et al.*, 2018).

Data is made available electronically through the Information System for Surveillance of Drinking Water Quality (SISAGUA), which aids in the management and quality control of water (Oliveira-Júnior *et al.*, 2019). The surveillance strategy consists of an institutional arrangement that monitors compliance with potability standards. This responsibility is part of the activities carried out by local and regional authorities in partnership with the Ministry of Health (Oliveira-Júnior *et al.*, 2019). As federal republics with autonomous and interdependent governmental levels face more difficulties than countries with unitary governments in accomplishing public policy goals (Howlett *et al.*, 2009), examining the effects of policies for ensuring potable water quality may be useful to the understanding of embedded challenges.

There are few studies on water quality surveillance in Brazil mostly restricted to determined places (Bárta *et al.*, 2021). Analyzing the data input and compliance values for basic parameters in each Brazilian municipality can provide an idea of the extent of public policy implementation in the country. Identifying distribution patterns according to local demographic and socioeconomic characteristics can help policymakers identify the challenges for water monitoring in the 21st century. Analyzing the implementation of water quality monitoring policies in different contexts and countries contributes to understanding the global framework of this public policy.

The objective of the study was to analyze the basic water quality parameters in Brazilian municipalities according to their demographic, socioeconomic and geographic characteristics in order to explore 21st century challenges for water quality surveillance.

2. MATERIAL AND METHODS

A cross-sectional ecological study based on 2018 official data was carried out covering all municipalities in Brazil. The year 2018 was selected because it corresponded to the fifth year after the new version of the information system came into operation (Oliveira-Júnior *et al.*, 2019) and intergovernmental mechanisms of agreement and understanding around indicators and goals were implemented two years earlier (Brasil, 2017). It is worth noting that, in September 2017, the Potability Ordinance approved in 2011 became Annex XX of Consolidation Ordinance No. 5/2017, with no change in the content of the standard (Brasil, 2017).

2.1. Study area

In 2018, Brazil, with a population of approximately 208 million, comprised 5,570 municipalities across 27 federative units, including 26 states and the Federal District. These units are grouped into five macro-regions: North, Northeast, Southeast, South, and Central-West. The majority of the urban population is concentrated in the Southeast, Northeast, and South, while the Central-West is the least populated. The vast differences and inequalities across Brazilian territory reflect the diverse ways in which these regions have been integrated into the country's socio-spatial development processes (Arretche, 2015).

2.2. Data source

We used official data from the Information System for Water Quality Surveillance for Human Consumption (SISAGUA in Portuguese), managed by the National Program for Environmental Health Surveillance related to Water Quality for Human Consumption (VIGIAGUA in Portuguese) (Brasil, 2005; Oliveira-Júnior *et al.*, 2019). The data for municipal characterization, sourced from the Department of Informatics of the Unified Health System, originate from demographic census data and projections developed by the Brazilian Institute of Geography and Statistics (IBGE in Portuguese).

2.3. Variables and Data Processing

The parameters of turbidity, free residual chlorine, *Escherichia coli*, pH, and fluoride were selected taking into consideration the consolidated knowledge in the specialized literature and for normative reasons (WHO, 2017; Brasil, 2016). The Guidelines for Drinking-water Quality are one of the longest-standing normative publications from WHO (2017). It establishes that the quality of water for human consumption should be assessed through the measurement of variables such as chlorine residual, pH, and turbidity. Among other recommendations from the WHO, there is also the need for chemical corrections in water, such as fluoride, which is essential for the prevention of dental caries, and the evaluation of microbial quality through indicator microorganisms, with Escherichia coli being the chosen indicator for monitoring in order to prevent the transmission of waterborne diseases (WHO, 2017). In addition, these parameters were also required by Brazilian normative dispositions (Brasil, 2016).

2.3.1. Turbidity

Turbidity levels were evaluated against a maximum allowable limit of 5.0 μT across the distribution system. Although levels above this threshold do not pose a direct health risk, they can be aesthetically displeasing and may lead to public rejection. Additionally, suspended particles can harbor pathogenic microorganisms and reduce the effectiveness of disinfection treatments (Dassoler *et al.*, 2015). Municipalities with 90% of samples showing turbidity values up to 5.0 μT were classified as compliant, based on the institutional indicators established by the National Water Quality Surveillance Program for Human Consumption for 2018 (Brasil, 2016).

2.3.2. Free Residual Chlorine

The analysis of free residual chlorine focused on compliance with concentrations between 0.2 mg/L and 2.0 mg/L. Levels below 0.2 mg/L indicated potential failures in the disinfection process, while concentrations between 2.1 mg/L and 5.0 mg/L were considered above compliance due to the potential for taste and odor issues, leading to the use of unsafe alternative water sources. Concentrations exceeding 5.0 mg/L were deemed non-compliant, representing health risks (Brasil, 2016). Municipalities with 75% of samples within the 0.2 mg/L to 2.0 mg/L range were classified as compliant.

2.3.3. Escherichia coli

The presence of *Escherichia coli* was analyzed as an indicator of potential contamination by other pathogenic microorganisms (Brasil, 2016). The adopted criterion was the absence of total coliforms and *E. coli* in 100 mL of sample, following prior research (Queiroz *et al.*, 2009; WHO, 2017). Null values were retained since a zero value is desirable for this parameter. Municipalities where 90% of samples were free of total coliforms and *E. coli* were deemed compliant.

2.3.4. pH

Drinking water typically has pH values between 5 and 10 (Deborde and Von Gunten, 2008). In this study, pH values ranging from 6.0 to 9.5 were considered compliant according to the Brazilian guidelines (Brasil, 2016). The proportion of samples within this range was calculated for each municipality, and the criteria were compared with scientific literature to determine a minimum acceptable value. Municipalities with 75% of samples falling within the 6.0 to 9.5 range were classified as compliant.

2.3.5. Fluoride

For fluoride, the analysis was guided by the Technical Consensus Document on the classification of public water supplies based on fluoride content. Concentrations between 0.000 to 0.444 mg F/L were categorized as low, with negligible benefits and risks to health. Values between 0.445 to 0.944 mg F/L were classified as optimal, while concentrations from 0.945 to 1.544 mg F/L were considered to offer questionable benefits with a moderate to high risk of dental fluorosis. Concentrations above 1.544 mg F/L were deemed to pose a very high risk to dental health (CECOL/USP, 2011). Municipalities with 80% of samples within the optimal concentration range were classified as compliant (Belotti *et al.*, 2022).

Data on the municipality included population size, Municipal Human Development Index (MHDI) and the geographical region to which it belongs. Population size was included due to its influence on water supply infrastructure and the challenges related to quality monitoring. Municipalities with different population sizes face distinct contexts in terms of monitoring capacity, resource distribution, and adequacy of supply systems (Bain *et al.*, 2014). The variable was categorized into three groups more than 50,000, between 10,000 and 50,000 and up to 10,000 to allow comparison with other studies (Frazão *et al.*, 2013; Paulino *et al.*, 2022).

The MHDI is a composite measure that evaluates municipalities based on three dimensions: education, income, and life expectancy, offering a comprehensive overview of human development at the local level. It was included in the analysis because it reflects key social and economic factors that are closely linked to the quality of public services, including water supply systems (Libânio *et al.*, 2005). It was divided in three categories: very high and high, middle and low and very low.

Brazil is divided into five geographic macro-regions: North, Northeast, Southeast, South and Middle-West. These regions vary significantly in terms of climate, economy, and infrastructure, which could directly influence the quality of water supply systems (Silva *et al.*, 2020). Moreover, their socioeconomic development trajectories have been uneven (Arretche, 2015). Therefore, it is important to verify if this pattern manifests itself in the feeding and compliance of water quality parameters.

Data processing used the municipality code provided by IBGE for identification, with municipalities categorized by Brazilian states and macro-regions to analyze the distribution of absolute and relative frequencies of the concentration values for the investigated parameters. The data validation protocol proposed by Prado and Frazão (2019) was used for data validating related to parameters of turbidity, free residual chlorine, pH and fluoride. Three exclusion filters were applied: (1) municipalities with less than four months of recorded data; (2) records with null values; and (3) outlier values for each municipality. For consistency with previous studies, the administrative regions of the Federal District were excluded, except for Brasília. The first filter was used to validate the registers of *Escherichia coli*.

2.4. Data Analysis

The database for descriptive analysis was created using the free software RStudio. In this environment, available parameters were read, and data on E. coli, turbidity, free residual chlorine, pH and fluoride were selected utilizing R's language to tailor packages and functions for the proper processing of data from SISAGUA (Paulino *et al.*, 2022).

After applying the data cleaning protocol and following the processing in R, the data were exported to Excel®, where variables such as macro-region, state or federal unit, and municipal population size were assigned. The percentage values related to compliance rates were calculated using the number of municipalities with valid information as the denominator. Next, the basic water quality parameters were combined in descending order to highlight the influence of each parameter on the percentage of municipalities with validated information and on the percentage of those with conformity according to expected values. The analysis of policy implementation was undertaken according to macro-regions to which the municipality belongs, its level of human development and population size. Scientific publications on water quality surveillance at country level implemented by government agencies added to health policy literature were used to interpret the findings.

3. RESULTS AND DISCUSSION

Out of 5,570 municipalities, 4,659 had water supply systems (WSS). Table 1 shows municipalities and registers included after filters according to basic parameters related to turbidity, free residual chlorine, E. coli, pH and fluoride. The parameter E. coli had the largest volume of records (420,621) and the highest number of municipalities with data registered (4,582) and also the lowest percentage of non-included municipalities (11.2%). The parameters with highest rates of non-included municipalities were pH (67.3%) and fluoride (73.5%). For turbidity and free residual chlorine, 24.9% and 37.5% of the municipalities were not included after the filtering process.

Table 1. Municipalities and registers included after filters according to basic parameters related to turbidity, free residual chlorine, E. coli, pH and fluoride (Brasil, 2018).

	Municipalities			**Registers**		
	N	**%***	Cum	**N**	**%***	Cum
Total of municipalities	5,570					
Municipalities with WSS	4,659					
E. coli						
Total data registered	4,582	1.7		420,621		
Municipalities with four or more months of records	4,170	9.0	10.7	414,907	1.4	1.4
Turbidity						
Total data registered	3,989	14.4		410,336		
Municipalities with four or more months of records	3,592	10.0	24.4	403,678	1.6	
Valid records without null values	3,574	0.5	24.9	380,267	5.8	7.4
Valid records without aberrant values	3,574	0.0	24.9	350,556	7.8	15.2
Free residual chlorine						
Total data registered	3,410	26.8		381,092		
Municipalities with four or more months of records	3,071	9.9	36.7	375,425	1.5	
Valid records without null values	3,047	0.8	37.5	355,105	5.4	6.9
Valid records without aberrant values	3,046	0.0	37.5	337,295	5.0	11.9
pH						
Total data registered	2,327	50.1		227,695		
Municipalities with four or more months of records	1,939	16.7	66.8	221,351	2.8	
Valid records without null values	1,927	0.6	67.4	220,069	0.6	3.4
Valid records without aberrant values	1,927	0.0	67.4	208,980	5.0	8.4
Fluoride						
Total data registered	2,150	53.9		110,485		
Municipalities with four or more months of records	1,774	17.5	71.4	104,736	5.2	
Valid records without null values	1,736	2.1	73.5	96,937	7.4	12.6
Valid records without aberrant values	1,735	0.1	73.5	91,252	5.9	18.5

Note: WSS = water supply system; Cum = Cumulative.
*Correspond to the percentage of municipalities and records removed.

Table 2 shows municipalities with validated information and compliant values according to basic water quality parameters and each Brazilian macro-region. The heterogeneity was high. Out of municipalities with WSS, 89.5% had validated information for Escherichia coli, 76.7% for turbidity, 65.4% for free residual chlorine, 41.4% for pH, and 37.2% for fluoride. In general, the values were higher for the Southeast macro-region and lower for the North macro-region. The South macro-region presented the highest percentage of municipalities with validated information for turbidity (94.8%) and fluoride (80.1%).

Although E. coli had the highest percentage of municipalities with validated information (89.5%) in the country, it had the lowest compliance rate among the analyzed parameters (50.8%) followed by fluoride at 52.8%. More than 80% of municipalities were compliant for the remaining parameters. It is worth highlighting that the absolute number of municipalities decreased in the following order: turbidity, free residual chlorine, E. coli, pH and fluoride.

Regarding compliance rates, the turbidity parameter stood out in all macro-regions of the country, with percentage values of municipalities above 85.5%. In contrast, fluoride shows the lowest compliance rates, ranging from 0.0% in the North to 78.3% in the Southeast, with other regions below 50.0%. E. coli had better rates in the Southeast (62.8%) and South (60.0%), while the Northeast had the lowest rate at 24.3%. Free residual chlorine and pH showed compliance rates above 59.9% in all macro-regions (Table 2).

Table 2. Municipalities with validated information and compliant values according to basic parameters of water quality in supply systems and Brazilian macro-regions (Brasil, 2018).

	Municipalities			
	Information		Conformity	
Brazil (4,659)	**N**	**%**	**N**	**%**
Escherichia coli	4,170	89.5	2,120	50.8
Turbidity	3,574	76.7	3,348	93.7
Free residual chlorine	3,046	65.4	2,475	81.3
pH	1,927	41.4	1,598	82.9
Fluoride	1,735	37.2	916	52.8
North (300)				
Escherichia coli	234	78.0	88	37.6
Turbidity	232	77.3	213	91.8
Free residual chlorine	103	34.3	72	69.9
pH	65	21.7	39	60.0
Fluoride	3	1.0	0	0.0
Northeast (1,247)				
Escherichia coli	1,019	81.7	248	24.3
Turbidity	986	79.1	843	85.5
Free residual chlorine	789	63.3	507	64.3
pH	693	55.6	529	76.3
Fluoride	166	13.3	14	8.4
Southeast (1,634)				
Escherichia coli	1,590	97.3	999	62.8
Turbidity	1,109	67.9	1081	97.5
Free residual chlorine	911	55.8	813	89.2
pH	760	46.5	679	89.3
Fluoride	683	41.8	535	78.3
South (1,051)				
Escherichia coli	934	88.9	560	60.0
Turbidity	996	94.8	979	98.3
Free residual chlorine	934	88.9	842	90.1
pH	200	19.0	186	93.0
Fluoride	842	80.1	350	41.6
Central-West (427)				
Escherichia coli	393	92.0	225	57.3
Turbidity	251	58.8	232	92.4
Free residual chlorine	309	72.4	241	78.0
pH	209	48.9	165	78.9
Fluoride	41	9.6	17	41.5

The data were grouped by levels of Human Development Index (HDI) and by population size in Table 3. In relation to validated information, 80% or more of the municipalities had credible data for E. coli independently of the HDI and population size. The values decreased in the following order: turbidity, free residual chlorine, pH and fluoride. For turbidity, the values were higher than 80% only in those with very high and high human development, and population size greater than 50 thousand inhabitants, and above 70% in the remaining categories. For free residual chlorine, the value was above 80% only in the category with very high and high human development and between 50 to 79% in the remaining categories. The percentage of municipalities with validated information for pH and fluoride parameters was lower than 50% in all categories except for fluoride in the municipalities with very high and high human development and pH in those with population size higher than 50 thousand inhabitants.

Table 3. Number and percentage of municipalities with validated information and the conformity according to basic parameters of water quality in supply systems, human development level and population size (Brasil, 2018).

	Municipalities			
	Information		**Conformity**	
	N	**%**	**N**	**%**
Level of Human Development				
Very High and High (1818)				
Escherichia coli	1,700	93.5	1,120	65.9
Turbidity	1,557	85.6	1,531	98.3
Free residual chlorine	1,465	80.6	1,307	89.2
pH	863	47.5	760	88.1
Fluoride	1,185	65.2	718	60.6
Medium (1908)				
Escherichia coli	1,745	91.5	804	46.1
Turbidity	1,352	70.9	1,257	93.0
Free residual chlorine	1,093	57.3	826	75.6
pH	601	31.5	494	82.2
Fluoride	497	26.0	192	38.6
Very Low and Low (928)				
Escherichia coli	772	83.2	193	26.7
Turbidity	662	71.3	557	84.1
Free residual chlorine	48	52.3	340	70.1
pH	461	49.7	342	74.2
Fluoride	50	5.4	5	10.0
Population Size				
More than 50,000 (605)				
Escherichia coli	560	92.6	303	54.1
Turbidity	503	83.1	476	94.6
Free residual chlorine	476	78.7	373	78.4
pH	303	50.1	260	85.8
Fluoride	292	48.3	172	58.9
Between 10,000 and 50,000 (2,018)				
Escherichia coli	1,797	89.0	862	48.0
Turbidity	1,551	76.9	1,424	91.8
Free residual chlorine	1,328	65.8	1,031	77.6
pH	895	44.4	710	79.3
Fluoride	673	33.3	338	50.2
Up to 10,000 (2,036)				
Escherichia coli	1,813	89.0	955	52.7
Turbidity	1,520	74.7	1,448	95.3
Free residual chlorine	1,242	61.0	1,071	86.2
pH	729	35.8	628	86.1
Fluoride	770	37.8	406	52.7

Note: The sample size is reduced due to the unavailability of Human Development Index (HDI) data for four municipalities.

Regarding conformity rates, turbidity stood out among the results. In all categories, the percentage of municipalities with values ≤5.0 µT was higher than 80%. Furthermore, 80% or more of the municipalities with very high and high human development and population size up to 10 thousand inhabitants had compliant values for turbidity, free residual chlorine and pH parameters. The percentage of municipalities with expected values for E. coli and fluoride was lower than 66% in all categories (Table 3).

Table 4 presents the parameters' data combined into four groups regarding validated information. Group A included E. coli and turbidity. Only 39.9 of Brazilian municipalities presented adequate feeding and credible data. Macro-regions Northeast, Southeast and Central-West, municipalities with more than 10 thousand inhabitants, and in the categories with very low and low and with very high and high human development had percentages above value observed for the country as a whole. As expected, the percentage of municipalities decreased according to inclusion of other parameters. Only 17.9% of the municipalities presented validated information for all basic water quality parameters. The value was higher in the categories of very high and high human development, more than 50 thousand inhabitants and in the macro-region Southeast (Table 4).

Table 4. Number and percentage of municipalities with validated information of combined basic water quality parameters in supply systems according to Brazilian macro-regions, human development level and population size. Brazil. 2018.

	Municipalities								
		A		B		C		D	
	N	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Brazil	4659	1860	39.9	1648	35.4	838	18.0	834	17.9
Macro-region									
North	300	62	20,7	36	12,0	1	0,3	1	0,3
Northeast	1247	662	53,1	526	42,2	55	4,4	54	4,3
Southeast	1634	739	45,2	699	42,8	593	36,3	591	36,2
South	1051	200	19,0	197	18,7	165	15,7	165	15,7
Central-West	427	197	46,1	190	44,5	24	5,6	23	5,4
Population Size									
More than 50 thou	605	292	48,3	277	45,8	172	28,4	170	28,1
10 to 50 thou	2018	864	42,8	743	36,8	316	15,7	315	15,6
Up to 10 thou	2036	704	34,6	628	30,8	350	17,2	349	17,1
Human Development Index									
Very High and High	1818	848	46,6	819	45,0	663	36,5	661	36,4
Medium	1908	571	29,9	498	26,1	156	8,2	155	8,1
Very Low and Low	928	439	47,3	329	35,5	17	1,8	16	1,7

Note: The sample size (N) is reduced due to the unavailability of Human Development Index (HDI) data for four municipalities. A: E. coli+Turbidity; B: E. coli+Turbidity+Free residual chlorine; C: E. coli+Turbidity+Free residual chlorine+pH; D: C+Fluoride.

Table 5 shows the parameters' data combined into four groups regarding conformity according to the absolute frequency of municipalities. Group A included turbidity and free residual chlorine. Of municipalities with WSS, 62.2% were compliant with expected patterns for these parameters. Macro-region South, municipalities with more than 50 thousand inhabitants and very high and high human development presented percentages above value observed for the country as a whole. As expected, the percentage of municipalities decreased according to inclusion of other parameters. Only 17.9% of the municipalities were compliant with the expected pattern for all basic water quality parameters. The value was higher in the categories of very high and high human development, more than 50 thousand inhabitants and in the macro-region Southeast (Table 5).

Table 5. Number and percentage of municipalities with conformity of combined water quality basic parameters in supply systems according to Brazilian macro-regions, human development level and population size (Brasil, 2018).

	Municipalities								
		A		B		C		D	
	N	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Brazil	4659	2897	62,2	2799	60,1	1622	34,8	834	17.9
Macro-region									
North	300	99	33,0	96	32,0	36	12,0	1	0,3
Northeast	1,247	749	60,1	734	58,9	513	41,1	54	4,3
Southeast	1,634	879	53,8	872	53,4	693	42,4	591	36,2
South	1,051	926	88,1	864	82,2	195	18,6	165	15,7
Central-West	427	244	57,1	233	54,6	185	43,3	23	5,4
Population Size									
More than 50 thou	605	453	74,9	446	73,7	275	45,5	170	28,1
10 to 50 thou	2,018	1248	61,8	1204	59,7	732	36,3	315	15,6
Up to 10 thou	2,036	1196	58,7	1149	56,4	615	30,2	349	17,1
Human Development Index									
Very High and High	1818	1421	78,2	1372	75,5	815	44,8	661	36,4
Medium	1908	1017	53,3	986	51,7	488	25,6	155	8,1
Very Low and Low	928	456	49,1	438	47,2	317	34,2	16	1,7

Note: The sample size (N) is reduced due to the unavailability of Human Development Index (HDI) data for four municipalities. A: Turbidity+Free residual chlorine; B: Turbidity+Free residual chlorine+E. coli; C: Turbidity+Free residual chlorine+E. coli+pH; D: C+Fluoride .

This study analyzed the basic water quality parameters in Brazilian municipalities in 2018 according to their demographic, socioeconomic and geographic characteristics. The data were provided by the Brazilian program of water quality surveillance. The data feeding coverage and the conformity values found are of great relevance because they may be considered the result of the undertaken efforts to date for policy implementation. In relation to data input, E. coli and turbidity yielded the better performance (more than 75% of the municipalities had valid information), while pH and fluoride, the worst (less than 50% of the municipalities). Regarding conformity, among municipalities with validated information, 80% or more were compliant with expected patterns for turbidity, free residual chlorine and pH, and about half for E. coli and fluoride. Major differences were observed according to the macro-regions to which the municipality belongs, its level of human development and population size. Only 17.9% of the municipalities presented validated information and compliant values for all basic water quality parameters. Under both conditions, the percentage of municipalities was higher in the categories of very high and high human development, more than 50 thousand inhabitants and in the macro-region Southeast. The findings suggest that the water surveillance undertaken by health authorities reached one in five municipalities. Therefore, great room for expansion and improvement of public policy remains.

The data of the current study were generated from surveillance actions maintained by the Brazilian State. There are few country-level studies on water quality monitoring and even fewer on water quality surveillance. A systematic review on fluoride concentration in worldwide water supply systems based on articles published between 2008 and 2012 showed that less than half of the studies related to surveillance as an action of the State in which most of them were undertaken in Brazil (Venturini *et al.*, 2016).

Lopes *et al.* (2022) identified and mapped worldwide surveillance actions and initiatives of drinking water quality implemented by government agencies and public health services. Out of 2,658 registers selected for reading of titles and abstracts, 71 were selected for full-text reading and only 49 were included because they involved a surveillance action of water quality. The majority of publications (31/49) were developed in the USA and Brazil. Only six studies examined water quality at country level as the current study did. Two of them analyzed potential effects from implementation of water safety plans. In Iceland it was observed that noncompliance of microbiologic parameters significantly reduced (Gunnarsdottir *et al.*, 2012). In France and Spain, compliance improved at most locations (Setty *et al.*, 2017). Two studies described contaminant levels in community water systems (CWS) for 24 and 26 states respectively within the USA. The first investigated data surveillance from 2010 to 2015. Of the total, 7% of CWSs reported at least one annual mean concentration greater than the maximum contaminant level (MCL) for 10 contaminants combined (arsenic, atrazine, di(2-ethylhexyl) phthalate (DEHP), haloacetic acids (HAA5), nitrate, perchloroethene (PCE), radium, trichloroethene (TCE), total trihalomethanes (TTHM), and uranium). The percentage increased from 5.4% in large central metropolitan counties to 10% in noncore counties, a significant difference adjusted for U.S. region, CWS size, water source, and potential spatial correlation (Strosnider *et al.*, 2017). The second examined data surveillance from 2000 to 2010 and also showed excessive concentrations (above the MCL) of disinfection byproducts, TTHM) and HAA5; arsenic; nitrate; radium and uranium. High proportions occurred mostly in very small and small CWS, which serve a year-round population of 3,300 or less (Monti *et al.*, 2019).

In Latin American, two studies were identified at country level. In Costa Rica, out of 81 territories 22.4% were served by no chlorinated water (Mora-Alvarado and Araya-García, 2008). In Colombia, the water's potability level did not meet current standards for a high percentage of municipalities being more acute in rural areas. Between 2008 and 2012, pH and turbidity presented compliant values for more than 90% of samples. However, the presence of E. coli varied from 28 to 23% of samples and the absence of free residual chlorine was observed in nearly 30% of samples. The water quality risk indices calculated for 1,067 Colombian municipalities showed that only 18.3% had water quality at level of no risk (Guzmán *et al.*, 2015).

In the current study, while more than 80% of municipalities were compliant for pH, free residual chlorine and turbidity, nearly half of them presented an absence of E. coli and fluoride level according to the expected patterns. Only 17.9% of the municipalities showed compliance for all basic water quality parameters. In Brazil, the health authorities may require those responsible for WSS to prepare and implement a WSP, in accordance with the methodology and content recommended by the WHO and defined in guidelines from the Ministry of Health; however its use as a preventive instrument for planning and monitoring water resources and controlling health risks is recent in the country, and the few existing experiences are in the implementation phase and seeking methodological consolidation (Ventura *et al.*, 2019).

One of limitations related to water quality surveillance actions has been due to an insufficient number of samples (Lopes *et al.*, 2022). The results of the current study showed that the parameters were not monitored with the same frequency. The parameter with the highest percentage of municipalities with validated information was E. coli followed by turbidity, free residual chlorine, pH, and fluoride. Only 17.9% of the municipalities presented validated information for all basic water quality parameters. Higher rates were observed in those pertaining to the Southeast macro-region, with more than 50 thousand inhabitants and with very high and high human development. It is worth noting that the inclusion criterion required only four or more months of registers for each parameter. These findings are an important indication of the implementation stage of the country's water quality surveillance policy, a branch of the Brazilian health policy.

The approval of the 1988 Constitution and the institutionalization of the Unified Health System (SUS, in Portuguese) created conditions to ensure an important share of power and autonomy to sub-national governments, favoring political-administrative decentralization of health actions, including environmental and epidemiological surveillance actions. As it was mentioned the country became decentralized by means of a three-level federal system that assures power and relative autonomy for the central government, regional entities at second level, and local authorities at third level. Therefore, giving Brazilian federalism a more cooperative rather than competitive character has been a major challenge for expanding and qualifying health policies without this resulting in unequal policy implementation. One way to address the decentralization of public policy in a highly unequal federation like Brazil was to create intergovernmental cooperation arrangements that steadily moved toward organization around national policy systems. Health policy was a pioneer in organizing this type of intergovernmental cooperation committee (Grin *et al.*, 2023). Since 2016, government entities at central, regional and local levels have established indicators and targets by common agreement regarding the percentage of water samples to be analyzed for turbidity, total coliform and free residual chlorine parameters (Brasil, 2017). Despite these efforts, there remains great room for expansion and improvement of public policy aimed at guaranteeing water quality. A study on the structure and degree of implementation of water quality monitoring activities for public water supplies in relation to the fluoride parameter among Brazilian states, including the Federal District, found that coordination mechanisms and the governance process of water quality monitoring policy were insufficient to ensure a more homogeneous development of activities in this institutional subsector of the health sector (Sanchez *et al.*, 2021).

This picture confirms the notion that Brazilian federalism is in a transition phase. Its low governance capacity leaves an open path for frontline organizations' discretion that may vary in scope, contingent upon the degree of policy structure/detail and the comprehensiveness and ambiguity of rules upheld within the organizations (Carneiro *et al.*, 2023). Water surveillance actions are managed by local governments with distinctive health policy-related compromises. Such governments operate as frontline organizations that may utilize their discretion to form arrangements blending different dimensions aimed at attaining politically and socially desired outcomes within a legitimately defined direction. These arrangements could elucidate disparities in the frontline implementation of public policy. Such arrangements are not solely born from management of local governments but can result from the interplay of a network comprising diverse local governments and frontline organizations operating either in isolation or collaboratively (Loyens, 2019).

Although high heterogeneity and unfinished implementation are present, the results were promising. One in each five municipalities reached high water quality. These municipalities were distributed in all geographic macro-regions and could operate as reference for the remaining ones.

Among the challenges for the 21st century, three points are highlighted: the need to qualify the coordination mechanisms as governance and planning arrangements with the capacity to ensure the continued commitment of political and administrative actors to achieve results and goals; the importance of facilitating the exercise of social control by collegiate bodies over the execution of policy implementation; the relevance of using data and communication technologies to disseminate information in an accessible way and expand its use at various levels of society that may trigger the action of judicial and political institutions with authority to require compliance with the standards.

As limitations of the study, it is worth noting that the percentage values related to compliance rates were calculated using the number of municipalities with valid information as the denominator, after applying the data cleaning protocol. Therefore, it should be noted that these values would be lower if all municipalities were considered, regardless of data validity. In spite of this trait, the use of water quality measures is a strong point of the current study due to their relevance for ensuring an enhanced surveillance strategy (Bain *et al.*, 2014).

4. CONCLUSION

In conclusion, the water quality surveillance was well implemented in one at each five Brazilian municipalities with significant differences according to demographic, socioeconomic and geographic characteristics of the municipalities.

5. DATA AVAILABILITY STATEMENT

The survey data is only available upon request.

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