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Association between water for human consumption and health of the population of the state of Rio de Janeiro: the case of hepatitis A between 2007 and 2018

Associação entre água para consumo humano e saúde da população do estado do Rio de Janeiro: o caso da hepatite viral do tipo A entre 2007 e 2018

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ABSTRACT

This article analyzes the relationship between incidences of hepatitis A — a water-borne disease that can also be transmitted by lack of hygiene — and quality indicators in the provision of water supply services, through secondary data extracted from the National Information Systems for Notifiable Diseases and on Sanitation, in the period between 2007 and 2018, for the municipalities of the State of Rio de Janeiro, Brazil. The indicators were initially submitted to Principal Component Analysis (PCA) to reduce numerous variables that showed autocorrelation with each other. Subsequently, the principal components were submitted to Pearson's correlation analysis with the incidence of hepatitis A. A correlation coefficient of -0.32 was observed, at the level of significance ($p < 0.05$) between the cumulative incidences of hepatitis A and the principal component (PC3) formed by a set of quality indicators for the provision of water supply services. The indicators that best described PC3, with factor loadings ranging from -0.88 to 0.70, were those related to: hydrometer, water and revenue losses, water revenue, the participation of residential water savings, micro-measurement related to water consumption, water consumption and average water consumption per economy, average duration of outages, and the incidence of non-standard total coliform analyses. Thus, the observed results point to an association between the quality of water supply services and the incidence of hepatitis A, which may indicate both failures in treatment efficiency and lack of hygiene.

Keywords: hepatitis A; water supply; principal components; Rio de Janeiro; quality of public services.

RESUMO

Este artigo analisa a relação entre incidências de hepatite A — doença transmitida pela água ou falta de higiene — e indicadores de qualidade da prestação dos serviços de abastecimento de água por meio de dados secundários extraídos dos Sistemas Nacionais de Informação de Agravos de Notificação e sobre Saneamento, no período entre 2007 e 2018, para os municípios do estado do Rio de Janeiro. Os indicadores foram submetidos, inicialmente, à análise de componentes principais (PCA) para redução de variáveis numerosas que apresentaram autocorrelação entre si. Posteriormente, as componentes principais foram submetidas à análise de correlação de Pearson com a incidência de hepatite A. Foi observado coeficiente de correlação de -0,32, ao nível de significância $p < 0,05$, entre as incidências acumuladas de hepatite A e a componente principal (PC3) formada por um conjunto de indicadores de qualidade da prestação dos serviços de abastecimento de água. Os indicadores que melhor descreveram a PC3, com cargas fatoriais variando de -0,88 a 0,70, foram aqueles relacionados: à hidrometração, a perdas de água e de faturamento, ao faturamento de água, à participação das economias residenciais de água, à micromedição relativa ao consumo, ao consumo de água e ao consumo médio de água por economia, à duração média das paralisações e à incidência das análises de coliformes totais fora do padrão. Desse modo, os resultados alcançados apontam para uma associação entre a qualidade da prestação dos serviços de abastecimento de água e a incidência de hepatite A, podendo indicar tanto falhas na eficiência do tratamento como na higienização.

Palavras-chave: hepatite A; abastecimento de água; componentes principais; Rio de Janeiro; qualidade dos serviços públicos.

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Introduction

Water is essential for human and non-human life on this planet. For humans, adequate water quality and sufficient quantity are required to meet their needs, protect their health, and enable their economic activities (Plessis, 2017; Gurung et al., 2019; Singh et al., 2019), and access to water was established as a human right by the General Assembly of the United Nations on July 28, 2010 (United Nations, 2010; Palmer et al., 2018). However, it is possible to observe intense water degradation, both in quality and quantity, over the years. The worsening of climate change, disorderly urban growth, inadequate disposal of solid waste, deforestation of forests and riparian forests of rivers, the release of domestic and industrial effluents *in natura*, the diffuse pollution that causes pollutants, disorderly exploitation of water reserves, and the commodification of a common good are among the factors responsible for the pressures on water bodies, as demonstrated over two decades, by Machado and Klein (2003), Shiva (2016), Escher et al. (2019), Fonseca et al. (2020) and the Intergovernmental Panel on Climate Change (IPCC, 2021).

This reality directly impacts the access to safe water of quality and quantity for the population, especially in developing countries in Latin America and Africa facing severe health and environmental crises, intensified by the new coronavirus pandemic since 2020 (Britto et al., 2019; Ekumah et al., 2020; Gaber et al., 2021; Gwenzi, 2021; Purnama and Susanna, 2020). In this sense, the *Progress on drinking water, sanitation and hygiene report: 2000-2017: Special focus on inequalities* (UNICEF and WHO, 2019) points out that, since 2000, 1.8 billion people have been guaranteed access to basic drinking water services. Nevertheless, one in ten people (785 million) remains without access to basic water services, including 144 million who access untreated water sources. The report also shows that there is an inequality between the richest and the poorest countries, as the former have at least twice as much coverage of basic services than the later (UNICEF and WHO, 2019). According to Santos et al. (2015, p. 11), half of the urban population in Africa, Asia, Latin America and the Caribbean suffers from one or more diseases associated with inadequate water supply and lack of sanitation.

Within the Brazilian scenario, the results of the 2019 Continuous National Household Sample Survey (Continuous PNAD) demonstrate that 86% of the 72.4 million households had access to water supply through the general water network as the main source of supply, and 68.3% had a general network of sanitary sewer. However, there is regional inequality between North (58.8%), Northeast (80%), Midwest (87.2%), South (87.9%), and Southeast (92.3%) (IBGE, 2020). According to these data, regarding the availability and frequency of the water supply service provided by the general water network, 88.5% of households had daily availability, whereas the remaining 11.5% had frequency variations that could range between once and three times a week. Concerning the regions, the Northeast presented lower coverage of daily water supply (69.0%), followed by the North (89%), Midwest (94.9%) and Southeast (94.8%), and the best condition was observed in the South (97.0%) (IBGE, 2020). With regard to sanitary sewer, according to PNAD, there is regional inequality in access to the general network, as follows: North (27.4%) and Northeast (47.2%) had lower coverage; the South and Midwest reached 68.7%; and the Southeast had the best performance, with 88.9% (IBGE, 2020).

Among the water-borne diseases, hepatitis A stands out, a transmission disease associated with the quality of water for human consumption, hygiene habits, or water scarcity (Ensink and Cairncross, 2012; Singh and Mondal, 2019), which is the focus of the present study. In addition, Brazil recorded 1,189 deaths associated with hepatitis A between 2000 and 2018, of which 70.9% (843) had the disease as de underlying cause and 29.1% (346) as the associated cause, according to the "Epidemiological Bulletin on Viral Hepatitis" (*Boletim Epidemiológico Especial sobre Hepatites Virais*) published by the Brazilian Ministry of Health (Brasil, 2020). Also according to the Bulletin, the highest percentage of deaths from hepatitis A as the underlying cause occurred in the Northeast region (35.1%), followed by the Southeast (27.6%). It is noteworthy that the mortality rate due to hepatitis A as the underlying cause has shown a downward trend in all Brazilian regions in the last ten years (Brasil, 2020). Nevertheless, two recent outbreaks in the two largest Brazilian cities reversed the downward trend in the incidence of this disease.

In 2017, in the city of São Paulo alone, there were 694 cases of this infection (one third of that recorded in the entire country in 2015). Conversely, in the municipality of Rio de Janeiro (MRJ) there was a sudden increase in the disease at the end of that year, with most cases occurring in the neighborhood of Vidigal. This neighborhood ranked as the 121st in the social development index and, in 2010, as the 123th in percentage of households with water supply among the 163 neighborhoods of the MRJ, according to the Census of the Brazilian Institute of Geography and Statistics (IBGE), totaling 119 cases (Data Rio, 2010; Brasil, 2020); conversely, in 2016, there were only ten records. Although in São Paulo the main suspicion of the Municipal Health Department (*Secretaria Municipal de Saúde* – SMS) for the advancement of the disease was unprotected sexual intercourse, in Rio de Janeiro managers of the healthcare sector related its cause to the use of water contaminated with the virus. The high vulnerability of areas with lack of basic sanitation was highlighted, as observed in Vidigal, a slum with more than 2 million residents that gave rise to the neighborhood in the South region of the MRJ (Guimarães, 2018).

Considering the public health issue in question, it is worth questioning whether water supply services of the general network have been provided in sufficient quantity and quality to guarantee the human right to water for the served population. Hence, the State of Rio de Janeiro (SRJ) was prioritized as an object of identification and analysis of the relationships between the incidence of hepatitis A and the quality indicators of water supply services in its 92 municipalities, based on a quantitative database methodology, with systematization, treatment, interpretation, and representation of data extracted from Government agencies. The SRJ proved to be an important territorial selection due to the history of water supply systems, dating back to the 19th century, and the strong dependence on few centralized water supply systems — such as the Paraíba do Sul basin, which supplies water to 17.6 million people, and the Guandu River basin, which receives water from the Paraíba do Sul River through transposition, supplying about 80% of the Metropolitan Region of Rio de Janeiro (MRRJ).

This article is organized into five sections, starting with this Introduction, followed by the presentation of the study area and the methods of data collection and analysis. Subsequently, the obtained results are presented, followed by the discussions and, finally, the conclusions of this article.

Study Area and Methods

Territorial selection of the study: the state of Rio de Janeiro

The study area covers the territorial extension of 43,750,427 km^2, with an estimated population, according to IBGE, of 17,366,189 million inhabitants (IBGE, 2021). Historically, the SRJ has water supply systems centralized in large pipelines and water treatment plants; in addition, these systems are dependent on water sources transported over long distances through transposition systems, especially for the MRRJ (Britto and Quintslr, 2017). According to Britto and Quintslr (2017), there are three periods of the development of urban water systems, between the years 1870 and 1980. The first consists of water transfers over long distances to overcome the absence of water treatment techniques. The second, in turn, is marked by the advent of new water treatment techniques based on the scientific technical development of sanitary engineering. Finally, the third period includes sustainable management, which seeks sustainable water use, demand management and supply control as well as water reuse (Britto and Quintslr, 2017).

Taking this into consideration, the choice for the SRJ is justified by three factors. The first is the centralized and infrastructural characteristic of the water supply systems of the state, especially the Water and Sewage Company of the State of Rio de Janeiro (*Companhia Estadual de Águas e Esgotos do Rio de Janeiro* – Cedae). Under public administration, this mixed-economy company fully or partially provides 64 municipalities with water supply, with an estimated population of 6,747,815 inhabitants in 2020, of which 97.41% were supplied with water services (Brasil, 2021c), and was recently taken to auction with a view to privatization (Silva et al., 2021). In addition, there are seven municipalities served by autarkies of the Autonomous Water and Sewage Services (*Serviços Autônomos de Água e Esgoto*); five by municipal governments operating as direct public administration and, finally, 16 private companies, according to the National Sanitation Information System (*Sistema Nacional de Informações sobre Saneamento* – SNIS) (Brasil, 2021c).

The second factor is related to the possibility of using secondary data on the quality of water supply services, based on the SNIS, with higher percentages of information due to the link between the filling of these data by the operators of water supply systems and the release of resources from investment programs of the Brazilian Ministry of Regional Development, including the Growth Acceleration Program (*Programa de Aceleração do Crescimento* – PAC). Finally, the third factor is the strong dependence on water supply sources, especially the Paraíba do Sul River and the Guandu River, the former being fundamental to maintain the quality of the water of the later through transposition – dated in the 1950s – between the Santa Cecília reservoir, in Piraí (RJ), which, integrated with other reservoirs, such as Ribeirão das Lajes, will supply the Guandu System.

Study design

In this article, the authors chose to use the data available in the Information Systems of institutional databases, namely: The Notifiable Diseases Information System (SINAN-Net), which is part of the system catalog of the Unified Health System Informatics Department (DATASUS) of the Brazilian Ministry of Health; the National Sanitation Information System (SNIS), of the Brazilian Ministry of Regional Development; and the 2010 Demographic Census, of IBGE (2011). Data collection was carried out through access to the database available in the aforementioned information systems, and several visits were made to the information systems until the year 2021. Then, the data were stored, organized, and processed using the *R Project*, version 4.0.2, and *Excel* software. Initially, descriptive statistics analysis techniques were used to perform exploratory analysis, as well as data pre-processing for later use in inferential statistics analysis.

A percentage of zeros and failures of 45% was observed in the samples of the historical series of the municipalities of the SRJ, both for the SINAN-Net and for the SNIS, making it necessary to exclude 35 municipalities. This enabled to identify that the period between 2007 and 2018 had greater data filling. In the case of SNIS, this fact can be justified by the requirement to regularly send data to the System as a criterion for selecting, ranking, and releasing financial resources. Therefore, the analysis was limited to municipalities with more complete data records (lower percentage of failures and zeros), reaching 57 of them (Angra dos Reis, Araruama, Arraial do Cabo, Barra do Pirai, Belford Roxo, Bom Jardim, Bom Jesus do Itabapoana, Cabo Frio, Cachoeiras de Macacu, Campos dos Goytacazes, Cantagalo, Duque de Caxias, Guapimirim, Itaboraí, Itaguaí, Italva, Itaperuna, Itatiaia, Japeri, Macaé, Macuco, Magé, Mangaratiba, Maricá, Mesquita, Miguel Pereira, Natividade, Nilópolis, Niterói, Nova Friburgo, Nova Iguaçu, Paracambi, Paraty, Paty do Alferes, Petrópolis, Pinheiral, Porciúncula, Queimados, Quissamã, Resende, Rio Bonito, Rio Claro, Rio das Flores, Rio das Ostras, Rio de Janeiro, São Fidelis, São Francisco de Itabapoana, São Gonçalo, São Joao da Barra, São Joao de Meriti, São Jose do Vale do Rio Preto, Sapucaia, Saquarema, Seropédica, Tanguá, Teresópolis, Trajano de Morais, Três Rios, and Volta Redonda). The same criterion was followed for data on hepatitis A.

Thus, the annual database referring to 57 of the 92 municipalities in Rio de Janeiro was used for this time frame regarding:

- indicators of the quality of water supply services, via SNIS, consolidated by municipalities (Brasil, 2019, 2021c) in the operational, economic-financial, and water quality categories, based on which the arithmetic means of these indicators were calculated per municipalities, in the period from 2007 to 2018. Components with excess zeros or lack of data were excluded, and 32 indicators were selected from the operational, economic-financial, and water quality categories (Brasil, 2019);
- cumulative incidence of hepatitis A (cases of hepatitis A per 100,000 inhabitants distributed per municipality), reported in the Brazilian Unified Health System (SUS), via SINAN-Net/DATASUS (Brasil, 2021b), with calculation of the cumulative frequency of the total reported cases of hepatitis A in the period from 2007 to 2018, divided by the respective population of each municipality x 100,000, as demonstrated by Rafael et al. (2020);
- census data, via the 2010 IBGE Demographic Census (2011), of the 57 studied municipalities of the SRJ and that were used for the calculations of the incidence of hepatitis A as previously mentioned.

Data analysis

To analyze the relationship between hepatitis A and the quality indicators of water supply services, the cumulative incidence of hepatitis A and the means of the indicators selected in the time frame of this study were calculated. Subsequently, both sets of variables were submitted to normality tests and validation of the principal component analysis. The Shapiro-Wilk normality test was chosen, with a significance level of $p < 0.05$. Regarding the data of the indicators of the quality of the provision of water supply services, the correlation matrix between the variables was first analyzed, and then the Bartlett's test of sphericity and the Kaiser-Meyer-Olkin (KMO) test, which consists in a measure of the adequacy of the Principal Component Analysis (PCA).

With regard to the normality test, the two data sets – cumulative incidence of hepatitis A and mean of the indicators of quality of the provision of water supply services – indicated a non-normal distribution according to the Shapiro-Wilk test, with a significance level of $p < 0.0001$. Thus, the authors opted for logarithmization of the variable "cumulative incidence of hepatitis A," which met the normality, as demonstrated by the Shapiro-Wilk test ($p > 0.05$). For data on the quality indicators of the provision of water supply services, normalization took place in the development of the statistical analyses in the *R Project* program, using the *vegan* package, *rda* function (Legendre and Legendre, 2012; Oksanen et al., 2020). Normality was also tested after PCA using the Shapiro-Wilk test, and the authors identified that the principal components presented normal distribution (PC1, PC2, PC3, PC4 — $p > 0.05$).

In the present study, it was observed that the quality indicators of water supply services are strongly associated with each other, a characteristic that may limit the type of statistical analysis to be used or produce spurious results – for example, the independence of the variables is a requirement for Pearson's correlation analysis (Taylor and Bates, 2013). Thus, PCA – a technique frequently applied by several authors to the most different areas, especially those related to the topic of the present article – proved to be interesting for the development of studies with these indicators as it allowed to reduce a set of correlated variables to a smaller number of principal components, independent of each other (Hernández-Flores et al., 2017; Zeinalzadeh and Rezaei, 2017; Corrêa et al., 2019; Tripathi and Singal, 2019). The results obtained from this statistical technique consist of eigenvalues of a sample covariance matrix (Legendre and Legendre, 2012; Santo, 2012). In this matrix, the principal components and the resulting eigenvalues are independent of each other and can therefore be used in subsequent statistical analyses (Logan, 2015).

Subsequently, the Pearson's correlation analysis was performed between the principal components and the incidence of hepatitis A. According to Callegari-Jaques (2003 *apud* Feil et al., 2015), the Pearson's correlation can be qualitatively evaluated regarding its intensity as follows: null, when the correlation is 0; weak, when it is between 0 and 0.3; regular, when it is between 0.31 and 0.6; strong, when it is between 0.61 and 0.9; very strong, when it is between 0.91 and 99; and full, when it is equal to 1. The sign of the coefficient indicates the direction of the association (Moore, 2007). To perform the analyses with the PCA and correlation techniques, the free *R Project* software, version 4.0.2, was used, as well as its *vegan, FactorMiner,* and *xlsx* packages.

Results

Table 1 presents the descriptive statistics for the variables used in the analyses developed in this article: cumulative incidence of hepatitis A and indicators of the quality of water supply services, between 2007 and 2018. Mean, median, standard deviation, and confidence intervals are presented, with their respective lower and upper limits for all variables.

Hepatitis A scenario in the state of Rio de Janeiro

The distribution of cumulative incidences of hepatitis A for the 2007-2018 period was determined, according to the territorial location of the highest rates, as well as the mean (20.2 cases per 100,000 inhabitants) for the SRJ (dashed line), as shown in Graph 1.

Among the analyzed municipalities, 13 had values of cumulative incidence of hepatitis A above the estimated state average for Rio de Janeiro. Among them, Mangaratiba, Paraty, and Sapucaia presented 86.56, 72.72, and 84.27% of average water supply coverage, respectively, in the period between 2007 and 2018. Still among these 13 municipalities, Três Rios (99.13%), Rio de Janeiro (97.41%), Petrópolis (96.93%), Angra dos Reis (90.44%), Macuco (86.94%), Duque de Caxias (84.50%), Macaé (75.05%), Porciúncula (74.95%), Magé (72.86%), and Tanguá (51.68%) stand out for their percentage of water supply. Graph 2 shows the percentages of coverage for water supply, based on SNIS data, for the 57 municipalities observed in the present study.

Table 1 — Descriptive statistics of hepatitis A incidences and quality indicators of water supply services.

Variables	Description of variables	Mean	Median	Standard Deviation	Confidence Interval (95%)	
					Lower Limit	Upper Limit
IHepA	Cumulative incidence of hepatitis A	20.70	10.97	43.55	9.40	32.01
IN001	Density of water economy per connection	16.28	15.66	3.74	15.30	17.25
IN005	Average water rate	37.86	37.06	12.26	34.68	41.05
IN009	Hydrometer index	807.46	892.23	343.77	718.21	896.71
IN010	Micro-measurement index related to the available volume	474.45	472.12	227.13	415.49	533.42
IN013	Revenue loss index	498.82	552.97	217.41	442.38	555.26
IN014	Micro-measurement of water consumption per economy	180.61	190.90	39.21	170.43	190.79
IN017	Water consumption billed per economy	169.64	173.80	41.57	158.85	180.43
IN020	Extension of the water network per connection	143.96	137.80	81.92	122.70	165.23
IN022	Average *per capita* water consumption	2,173.62	2,208.20	569.69	2,025.73	2,321.52
IN023	Urban water service index	983.62	1,025.60	185.87	935.37	1,031.88
IN025	Volume of water provided per economy	357.84	330.60	147.81	319.47	396.22
IN028	Water revenue index	653.81	622.36	211.05	599.02	708.60
IN043	Participation of residential water economies in the total water economies	1,060.38	1,094.74	109.03	1,032.08	1,088.69
IN044	Micro-measurement index related to consumption	782.20	803.90	333.97	695.50	868.90
IN049	Distribution loss index	430.09	407.69	149.32	391.33	468.86
IN050	Gross linear loss index	637.06	531.56	489.78	509.91	764.21
IN051	Loss index per connection	6,830.62	5,570.45	4,596.5	5,637.33	8,023.91
IN052	Water consumption index	722.54	742.93	143.90	685.18	759.90
IN053	Average water consumption per economy	195.04	202.10	50.31	181.98	208.10
IN055	Total water service index	935.65	980.37	198.62	884.08	987.21
IN057	Water fluoridation index	420.17	104.10	472.51	297.50	542.83
IN058	Electric energy consumption index in water supply systems	7.14	4.90	7.61	5.17	9.12
IN071	Economies affected by outages	29,210.16	7,759.00	51,791.53	15,764.65	42,655.67
IN072	Average duration of outages	62.61	52.70	43.41	51.34	73.89
IN073	Economies affected by intermittences	7,685.46	0.00	3,4031.93	-1,149.52	16,520.43
IN074	Average duration of intermittences	10.88	0.00	28.24	3.55	18.21
IN075	Incidence of non-standard residual chlorine analyses	13.84	4.60	21.69	8.21	19.47
IN076	Incidence of non-standard turbidity analyses	54.65	14.78	76.65	34.75	74.54
IN079	Sample quantity compliance index (free residual chlorine)	1,350.15	1,264.04	710.13	1,165.79	1,534.51
IN080	Sample quantity compliance index (turbidity)	1,378.55	1,291.36	705.73	1,195.33	1,561.76
IN083	Average duration of provided services	947.05	825.58	875.85	719.67	1,174.43
IN084	Incidence of non-standard total coliform analyses	25.98	6.81	37.45	16.25	35.70
IN085	Sample quantity compliance index (total coliform)	1,497.51	1,268.90	955.93	1,249.34	1,745.68

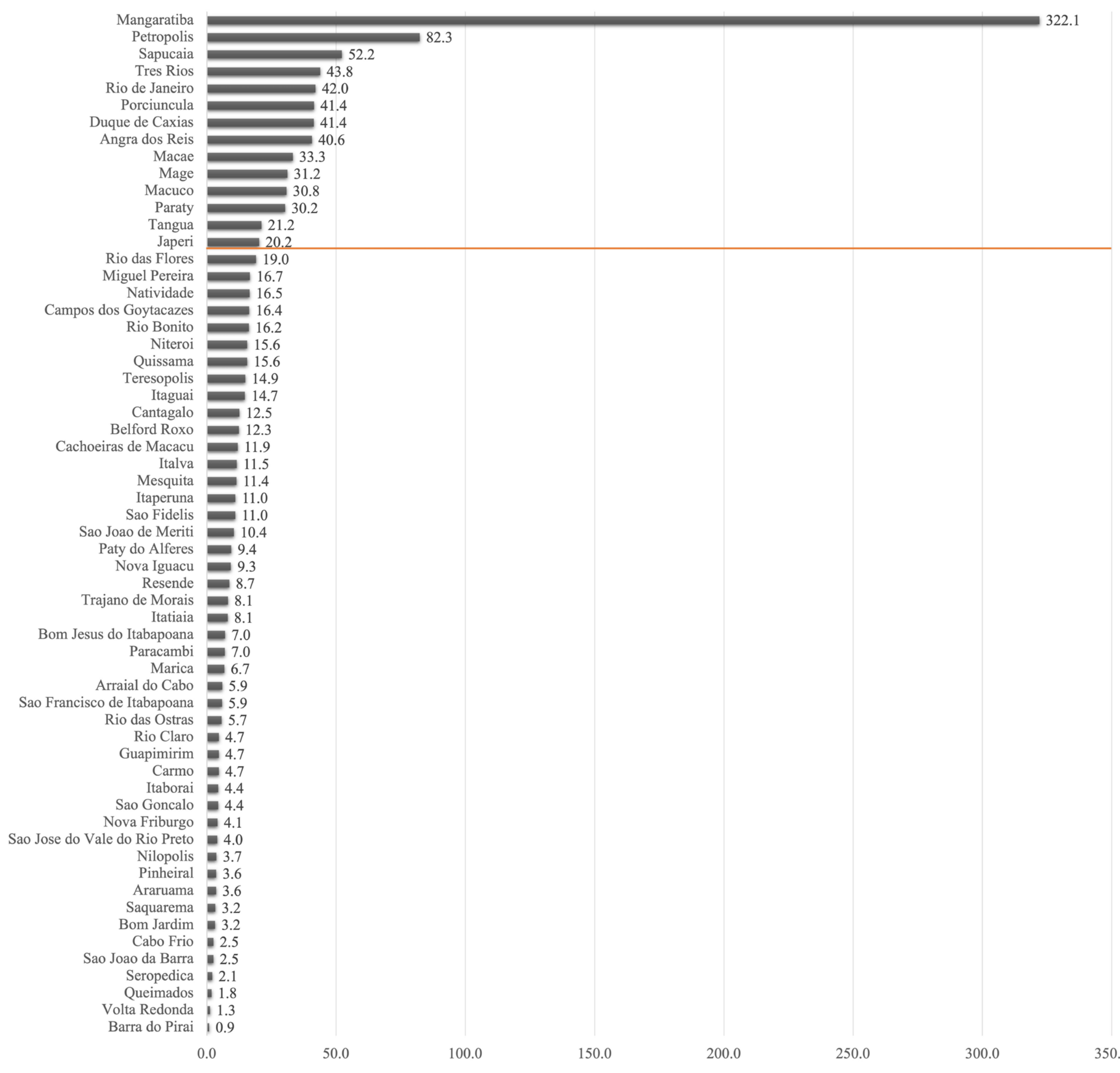
Source: Prepared by the authors based on data from SINAN-Net and SNIS, based on the cumulative incidence of hepatitis A and the average quality of water supply indicators, using the *R Project* software, version 4.0.2.

Analysis of principal components of the indicators of the National Sanitation Information System

As for the set of quality indicators of water supply services, the KMO suitability test obtained a value of 0.52, higher than the acceptable critical limit of 0.5 (Hair et al., 2009). Furthermore, Bartlett's test of sphericity was statistically significant ($p > 0.0001$). In both cases, the tests suggest that the data are suitable for statistical treatment.

Thus, the PCA of the quality indicators of the provision of water supply services evidenced those that significantly contributed to the variance of the main axes of the set of analyzed variables. Hence, the authors could identify four principal components (PC1 to PC4), which explain 54.5% of the variance of the set of analyzed variables. PC1 explains 21.4% of the total variance of the data and presents high positive factor loadings for the indicators concerning: micro-measurement related to the available volume (IN010), micro-measurement related to water consumption (IN044), hydrometer (IN009), and water revenue (IN028); and moderate-to-strong negative factor loading for the indicators concerning revenue losses (IN013) and the volume of water provided per economy (IN025), with correlation coefficients ranging from 0.92 to -0.72, at a significance level of $p < 0.001$.

PC2, in turn, explains 15.8% of the total variance of the data and presents high positive factor loadings for the indicators concerning average *per capita* water consumption (IN022), micro-measurement related to water consumption per economy (IN014), water consump-



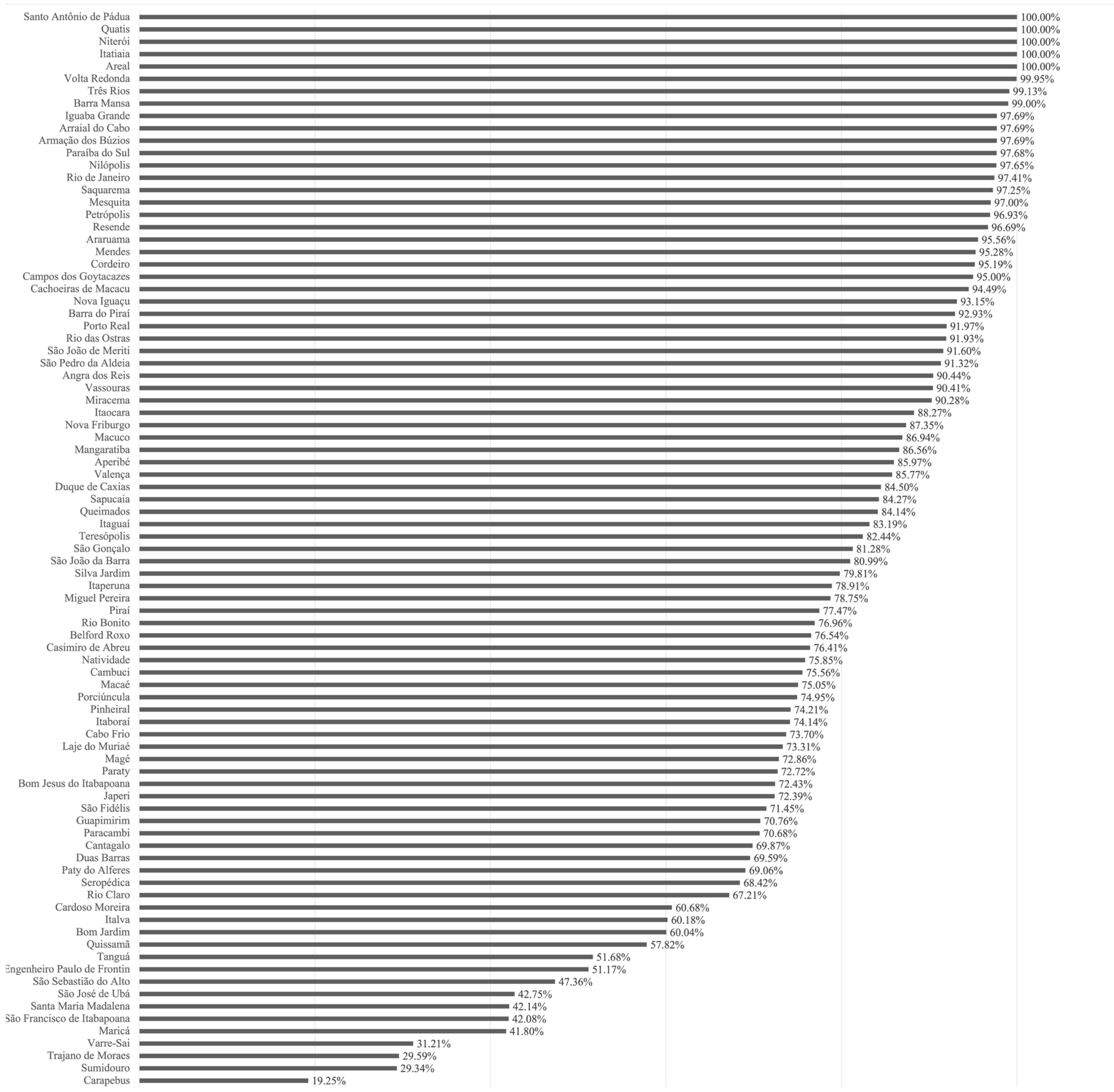
Graph 1 — Hepatitis A incidence per 100,000 inhabitants and per municipalities in the state of Rio de Janeiro and state average (orange line) for the period between 2007 and 2018.

Source: Prepared by the authors based on SINAN-Net data (Brasil, 2021b).

tion billed per economy (IN017), and average water consumption per economy (IN053), with correlation coefficients ranging from 0.80 to -0.43, at a significance level of $p < 0.001$.

Conversely, PC3 corresponds to 9.3% of the total variance of the data and presents a weak-to-moderate positive factor loading for indicators concerning water consumption (IN052) and the incidence of non-standard total coliform analyses (IN084) and strong negative factor loading for the indicator related to distribution losses (IN049), with correlation coefficients ranging from 0.71 to -0.88, at a significance level of $p < 0.001$.

Lastly, PC4 explains 7.9% of the total variance of the data and presents a weak-to-moderate positive factor loading for the indicators concerning economy achieved by outages (IN071), duration of outages (IN072) and water fluoridation (IN057) and presented a weak negative



Graph 2 — Water supply coverage of the municipalities of the state of Rio de Janeiro for the 2007-2018 period.
Source: prepared by the authors based on SNIS data (Brasil, 2021c).

factor loading for the indicator regarding extension of water network (IN020), with correlation coefficients ranging from 0.61 to -0.45, at a significance level of $p < 0.001$.

Association between hepatitis A and the principal components of the water supply

Based on the results achieved with the PCA technique in the study of water supply indicators, it was possible to solve multicollinearity and reduce the set of variables in the main axes for the analysis of the association with the incidence of hepatitis A. It is worth emphasizing that the choice for the PCA technique was made to meet the fundamental assumptions of many data analyses, including the Pearson's correlation — according to which the data are independent and the errors are independent and identically distributed (Taylor and Bates, 2013) — as well as to reduce the number of variables.

Therefore, Pearson's correlation analyses showed an association between the incidence of hepatitis A and the PC3 axis, with a correlation coefficient of -0.32, at a significance level of $p < 0.05$, as shown in Table 2.

As aforementioned, the most explanatory variables of PC3 are indicators related to water consumption (IN052), incidence of non-standard total coliform analyses (IN084), and distribution losses (IN049), as previously mentioned. Thus, observing the positive factor loadings of the IN052 and IN084 indicators, it is possible to infer that there is an inversely proportional relationship between them and the cumulative incidence of hepatitis A. In the case of IN052, this may indicate that greater water consumption means greater access to treated and distributed water, which contributes to the maintenance of hygiene habits, subsequently reducing the incidence of hepatitis A cases due to water scarcity.

Conversely, the IN084 initially indicates a strange relationship, as it was expected that the higher incidence of total coliform analyses with non-standard samples could increase the risk of contamination by the hepatitis A virus, whether due to failures in water treatment, or due to poor water quality in water supply sources or recontamination in the distribution networks. It was observed that 23 of the 57 municipalities present less than 85% of the required samples. However, it can be assumed that municipalities with the highest IN084 values are those that periodically monitor water supply systems, following the protocols defined by Ordinance No. 888 of May 4, 2021 (Brasil, 2021a), among other regulations and guidelines for the control and surveillance of water quality for human consumption. Therefore, the prior diagnosis of risk situations in monitoring the quality of water supply systems may contribute to reducing the incidence of hepatitis A.

Finally, the negative factor loading of IN049, related to distribution losses, demonstrates that the high rate of these losses can cause several problems in the access to water, compromising the health of the population due to increased risk of hepatitis A contamination, among other diseases that were not addressed in this study.

Table 2 — Pearson's correlation coefficients between cumulative incidence of hepatitis A and the principal components of the means of the indicators of the quality of the provision of water supply services. Significant results ($p < 0.05$) in bold.

Dimensions	Pearson's correlation coefficient	p-value	Confidence intervals	
			Lower limit	Upper limit
PC1	-0.06	0.69	-0.21	0.31
PC2	0.21	0.13	-0.06	0.44
PC3	**-0.32**	**0.02**	-0.53	-0.06
PC4	-0.14	0.30	-0.39	0.13

Source: Prepared by the authors based on data from SINAN-Net (Brasil, 2021b) and SNIS (Brasil, 2021c).

Discussion

The obtained results point to an association between the incidence of hepatitis A and indicators of the quality of water supply services — of the principal component (PC3), which explains 9.3% of the total variance of the data — in addition to what has already been found in other studies concerning the relationship between health and sanitation (Siqueira et al., 2017; Paiva and Souza, 2018; Dall'agnol et al., 2019). Some authors highlighted the presence of hepatitis A virus in urban sanitation networks (Holanda and Vasconcellos, 2015), especially in the MRJ (Prado et al., 2012), demonstrating high viral activity in summer and spring, under the presence of coliforms (Prado et al., 2012).

This association indicates a relationship between the cumulative incidence of hepatitis A and PC3, in which the quality indicators of the provision of water supply services IN052, IN084, and IN049 stand out, with higher factor loadings. In this sense, it is suggested that this relationship may be due to several factors, such as: poor quality of water from water supply sources, inefficiency in water treatment in ensuring its potability for human consumption, absence or precariousness in the monitoring and control of the surveillance of water quality in the supply systems, interruptions and outages in supply, which compromise water and food security, and the hygiene habits of the population.

With regard to the loss of water quality in water sources, the presence of viruses in sewage becomes more severe when there is low coverage of sanitary sewer, as was evidenced in the SRJ, especially in the state capital and in the metropolitan region, according to data on average sanitation coverage of sanitary sewer presented in this article, which corroborate the discussions of Britto et al. (2019). Moreover, the release of untreated effluents contributes to the degradation of water quality of water sources in the SRJ, as highlighted by Nunes (2021), in line with the historical framework of the abandonment of water sources to degradation, rectification, and channeling presented by Britto and Quintslr (2018).

Furthermore, this scenario of degradation of water quality of the water supply sources compromises, *a posteriori*, the water that will be used in water catchment, treatment, and distribution to supply the population (SOS Mata Atlântica, 2019). This is because the water from water sources may not meet the quality standards required by Resolution No.

357/2005 of the National Environment Council of Brazil (Conselho Nacional do Meio Ambiente – CONAMA) for human supply, influencing the efficiency of water treatment. In turn, compromising this efficiency may lead to non-compliance with potability standards, as established by Ordinance No. 888 of the Brazilian Ministry of Health of May 4, 2021, which amends Annex XX of the GM/MS Consolidation Ordinance No. 5, of September 28, 2017, to provide information on the control and surveillance procedures for the quality of drinking water and its potability standard. For illustrating this type of situation, what the MRRJ has been facing can be mentioned, in which the presence of geosmin has been associated with poor water quality in water bodies and the inefficiency of water treatment in achieving the potability standard required by Ordinance No. 888 of the Brazilian Ministry of Health (Brasil, 2021a).

This corroborates what some authors have demonstrated regarding the association of hepatitis A and other fecal-oral diseases, transmitted by water or due to lack of hygiene habits or water scarcity, with the quality of consumed water and access to water services (Holanda and Vasconcellos, 2015; Santos, 2019; Jesus, 2020). With regard to access, the water consumption indicator (IN052) – which showed a strong correlation (0.71) with PC3 – may indicate that, when access to water is guaranteed, higher consumption rates imply lower incidence of hepatitis A. Furthermore, higher consumption rates may be related to socioeconomic factors, as demonstrated by Fan et al. (2017). In other words, according to the authors of the aforementioned study conducted in China, the socioeconomic situation was one of the main factors that contributed to high water consumption and, in cities with low water consumption, this consumption was lower than the minimum amount required to sustain life, being "restricted by water supply capacity and household economic status" (Fan et al., 2017, p. 131).

As for the indicator related to the incidence of analyses of total coliforms with non-standard samples (IN084), it is suggested that efficient monitoring of water supply systems may lead to the recording of incidents, which in turn contributes to the monitoring of water quality for human consumption. In this sense, studies have shown that the monitoring performed by the quality control of the water supply was relevant in reducing diarrhea and hepatitis A, including during periods with records of intermittent supply (Castro et al., 2019).

With regard to the indicator related to distribution losses (IN049), Orellana et al. (2018) stress that the ageing of water supply systems is inevitable because they are among the first infrastructures installed and also because they accompany the development of cities. The authors emphasize that, as systems age, the trend is the increase in the number of leaks, ruptures, and interruptions in supply, as well as incrustation in the pipes. Such impacts can compromise water quality, increase internal roughness, reduce the hydraulic diameter and consequently the pressures that, in turn, cause intermittences and outages (Orellana et al., 2018).

Concerning distribution losses – which can aggravate intermittences and outages –, the impermanence of water supply through the general network interferes with access to water in quantity and quality due to problems of under pressure and recontamination in the network, as well as induces the search for alternative sources of supply, enabling the spread of water-borne diseases or those transmitted due to lack of hygiene habits resulting from water scarcity, such as hepatitis A — as discussed in the manuals prepared by the Secretariat of Health Surveillance of the Brazilian Ministry of Health (Brasil, 2006a, 2006b). Another factor related to intermittences is the operation of the general network, which guides the performance of systematic discharges to clean the pipes, preventing contamination of the water inside them (Brasil, 2006a, 2006b). This procedure is essential for monitoring and controlling the quality of water for human consumption. However, more detailed studies are needed in order to expand the knowledge of this relationship, using, for this purpose, other water-borne diseases or those transmitted due to lack of hygiene resulting from water scarcity, under multiple methods of analysis, and even considering the increase in historical series on specific regions and intra-urban studies.

Although the correlation between the incidence of hepatitis A and the principal component is not strong, it is still significant, with a significance level of $p < 0.05$, which encourages further investigation of this relationship. Hepatitis A is an oligosymptomatic disease, that is, it is presented by several factors that interact with each other and influence its manifestation. As previously discussed, among these factors are: lack of hygiene and access to water; consumption of water contaminated by animal feces, for example, through inadequate disposal of sewage into water bodies; and the risk associated with water contamination in the general network, which may occur due to losses, intermittences and supply outages, which produce a negative pressure in the pipes and, consequently, end up absorbing whatever is on the ground.

Furthermore, diseases such as hepatitis A, persistent in developing countries, are characterized as "diseases of poverty" because they are more prevalent among vulnerable social groups, or neglected diseases triggered by the absence or precariousness of sanitation and water supply services and housing conditions (Machado et al., 2017). Accordingly, Sotero-Martins et al. (2020) developed a study that evaluated the spatial distribution of municipalities and subnormal clusters of the SRJ according to the regional concession blocks for the privatization of Cedae, relating it to data on the incidence of diseases associated with inadequate environmental sanitation (*Doenças Relacionadas ao Saneamento Ambiental Inadequado* – DRSAI). The results achieved by the authors show that there is a spatial association between the municipalities of the SRJ and the incidence rate of DRSAI in 31 municipalities covered by Cedae. Also according to this study, 45.6% of the municipalities in the SRJ have subnormal clusters, especially the capital, Rio de Janeiro, which has the highest percentage of subnormal clusters in the entire state, 57.3% (Sotero-Martins et al., 2020).

In addition, it is worth deepening the investigation into the knowledge and formulation of these indicators of the quality of the provision of water supply services, enabling a better understanding of the information contained by them. Given the importance for the quality of life and health of the population served by the general water supply network, such research may contribute to the improvement of the information system and the quality of the provided service.

Nonetheless, the association of these indicators of the quality of the provision of water services with the analyzed disease points to the existence of deficiencies or inadequacies in the water supply systems for human consumption. In addition to the technical aspects of water supply systems, it is worth highlighting the structural nature of the decision-making processes regarding the choices of political-institutional actors. Hence, Britto and Quintslr (2018, p. 9, free translation) state that the review of the historical and structural process in the development of water supply macrosystems – such as in the case of the MRRJ – enabled to observe that the decisions were centralized "by political actors and engineers from the civil engineering sector, acting as builders of these urban service networks," which led to the concentration of supply in a single system for this region to the present day. According to the authors, Cedae has been operating since 1975 as a "developer of this macrotechnical system," although the development and expansion of the macrosystem over the years has not guaranteed the universalization of water services for the entire population, in terms of quality and quantity.

Conversely, the privatization process of Cedae demonstrates that social groups lacking the access to quality and quantity water services, residing in more vulnerable regions, may end up remaining outside the urgent universalization of access to safe water for human consumption (Nunes, 2021). Furthermore, centralization in a single system can also increase the risk of collapse in the face of the worsening of successive water crises and the worsening of the water quality conditions of the water sources. This was evidenced in the consecutive geosmin crises in the city of Rio de Janeiro (Formiga-Johnsson and Britto 2020; Nunes, 2021), but it had already been observed in a study for almost two decades (Machado, 2004). During the water crisis, the transposition flows of the Paraíba do Sul River, the main water supply source of the SRJ, were reduced; together with the degraded waters of the Guandu River, they supplied the MRRJ (Castro et al., 2019), which could justify the poor quality of the water and the worsening of interruptions in their supply networks.

Finally, no studies were found in the literature that explored the relationship between hepatitis A and SNIS variables based on the PCA technique, specifically in the SRJ, although some authors have analyzed this relationship to a lesser extent, using other methodologies.

Conclusions

The results achieved in this study contribute to a deeper understanding of the indicators contained in official databases and data systems regarding water supply and their relationship with the health of the population served, regarding the cumulative incidence of hepatitis A. They also contribute to a proposal for a differentiated analysis, such as the one performed with the application of the PCA technique, which allowed the identification of the principal components and their respective sets of variables with higher factor loadings, aiming to later analyze the correlation between the components and the *cumulative* incidence of hepatitis A. The use of this technique may allow further analyses with other types of dependent variables other than hepatitis A.

In addition, the association between hepatitis A and indicators of the quality of the provision of water supply services also proves to be important, as it indicates a certain vulnerability in the supply system, especially due to failures in water distribution, evidenced by the increase in the disease when related to indicators concerning distribution losses (IN049). The results also demonstrate the importance of monitoring and controlling water quality from treatment, undergoing distribution, and up to consumption, as a way of guaranteeing safe water for the population, in the face of environmental degradation and the negligence of the Government in solving a public health issue.

Finally, we emphasize the need – already pointed out by Machado and Klein (2004) for almost two decades – to rethink and promote actions in an integrated manner with policies on public health, environment, water resources, and sanitation, seeking to meet the fundamental needs of the population in a safe, equitable, and fair manner. The universalization of good quality water supply services for human consumption is an existential imperative of present and future generations and which integrates the right to health, as determined by Article 225 of the 1988 Federal Constitution of Brazil. In democratic state ruled by law, the Constitution is above everyone else.

Contribution of authors:

Nunes, D.G.: Conceptualization, Methodology, Analysis, Research, Writing – Original Draft. Machado, C.J.S.: Conceptualization, Methodology, Writing – Review & Editing. Pistón, N.: Analysis, Writing – Review & Editing.

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