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Technical Article

Intervening factors in the costs of fluoridation in water supply systems: a case study in seven population sizes

Fatores intervenientes nos custos da fluoretação em sistemas de abastecimento de água: estudo de caso em sete portes populacionais

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ABSTRACT

The aim of this study was to analyze the costs of fluoridation in water supply systems of different population sizes. A case study was carried out comprising cities in the state of Espírito Santo, Brazil. The costs of initial installation, the chemical product, the operation of the system, and the control of fluoride levels between the years 2012 and 2017 were considered. The annual *per capita* cost of the treatment was calculated to estimate the fluoridation weight concerning the total expenses. The fluoridation annual *per capita* cost ranged from R$ 20.14 (US$ 7.23) in towns with less than two thousand inhabitants to R$ 0.39 (US$ 0.14) in cities with a population of approximately 520 thousand inhabitants. In systems that supply up to 30 thousand inhabitants, the running cost was responsible for most of the expenses, ranging from 98.2 to 84%. For cities with 520 thousand inhabitants, the costs with the chemical product corresponded to 74.7% of the expenses. Compared with the total treatment cost, the water fluoridation cost ranged from 0.2 to 0.6% for population sizes of 30 thousand inhabitants or more and varied from 1.3 to 7.3% for towns with less than 10 thousand inhabitants. Considering that the decision-making process is complex in the field of public policies, and decision-makers suffer multiple influences as for different policy alternatives, knowing the implications of population size for costs is essential for informed decision-making.

Keywords: fluoridation; cost analysis; water supply.

RESUMO

O objetivo foi analisar os custos da fluoretação em sistemas de abastecimento de água de diferentes portes populacionais. Realizou-se estudo de caso em municípios do estado do Espírito Santo, Brasil. Foram considerados dados referentes aos custos de instalação inicial, do produto químico, da operacionalização do sistema e do controle dos teores de flúor nos anos de 2012 a 2017. Foi calculado o custo *per capita* anual do tratamento da água a fim de estimar o peso do custo da fluoretação na totalidade das despesas. O custo *per capita* anual da fluoretação variou de R$ 20,14 (US$ 7,32) para o porte com menos de 2 mil habitantes a R$ 0,39 (US$ 0,14) para o porte com cerca de 520 mil habitantes. Nos sistemas que servem até 30 mil habitantes, o custo de operacionalização foi responsável por maior parte dos gastos, variando de 98,2 a 84%. No porte de 520 mil habitantes, os custos com o produto químico corresponderam a 74,7% dos gastos. O custo da fluoretação da água em relação ao custo total variou de 0,2 a 0,6% nos portes populacionais de 30 mil habitantes ou mais e de 1,3 a 7,3% nos portes abaixo de 10 mil habitantes. Como o processo de tomada de decisão no campo das políticas públicas é complexo e os tomadores de decisão sofrem múltiplas influências em torno de diferentes alternativas de políticas, conhecer a implicação do porte populacional nos custos é essencial para uma tomada de decisão informada.

Palavras-chave: fluoretação da água; análise de custos; abastecimento de água.

INTRODUCTION

The Community Water Fluoridation (CWF) is a public health intervention technology defined by adjusting the fluoride concentration in drinking water, acknowledged as safe (BEAL; LENNON, 2017) and effective to reduce dental caries in the population (MCDONAGH *et al*., 2000; WHELTON *et al*., 2019). Its effectiveness occurs even in populations that use fluoride toothpaste. Depending on the extent of the water supply system, it can reduce social inequality in access to fluoride and benefit the entire population, especially the most vulnerable ones (KUMAR, 2008; NARVAI *et al*., 2014; SANDERS *et al*., 2019). The availability of CWF 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 related to its implementation (FRAZÃO; NARVAI, 2017).

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One reason claimed by sanitation companies to prevent the expansion of fluoridation coverage is related to the installation cost of the concentration adjustment system and the costs of the chemical product and professional updating and training (FRIAS *et al.*, 2006; RAMOS; VALENTIM, 2012). Although studies in different countries have demonstrated that fluoridation costs are low compared with the savings resulting from averted treatment (GRIFFIN; JONES; TOMAR, 2001; KROON; VAN WYK, 2012; MARIÑO, 2013), few studies have described the intervening factors in the cost of implementing this public policy.

The average cost per inhabitant/year for 2003 was R$ 0.08 (US$ 0.03) in the city of São Paulo, Brazil. The accumulated cost for 18 years of implementation and maintenance of the fluoridation system was R$ 1.44 (US$ 0.97) *per capita* (FRIAS *et al.*, 2006). In the city of Sorocaba (state of São Paulo), the *per capita* cost was R$ 1.43 (US$ 0.72) in 2009, and from 1989 to 2008 the estimated *per capita* cost ranged from R$ 1.19 to R$ 1.43 (US$ 0.59 to 0.72) (MARTINEZ *et al.*, 2013). However, both Brazilian studies refer to large cities, with more than 500 thousand (Sorocaba) and 10 million (São Paulo) inhabitants, and have no detailed information about the intervening factors in the costs.

The feasible factors that influence the cost composition in the different population sizes may be related to the types of equipment that vary according to the system flow, employed technology, monitoring devices, and the need for metering pumps and storage tanks. It is estimated that the cost of chemical product is the second-largest expense in the operation of water treatment plants, representing 26% of the total cost. The first expense is related to human resources, materials, and services (FRANCISCO; ARICA, 2018). Operational and management aspects of water treatment plants located in small communities, occasionally distant from large urban centers, must also be taken into account.

Furthermore, health researches on costs have achieved an important role as a decision and analysis instrument to determine programs and public policies. This is because the integration among different areas of knowledge, such as economics, administration, and health, provides a better comprehension of the efficiency, efficacy, and effectiveness of health services, actions, and policies. Therefore, considering that scientific information on fluoridation cost can provide subsidies for incorporating this technology and supporting its maintenance in areas that have this benefit, the objective was to analyze the cost of fluoridation of water supply systems in seven population sizes.

METHOD

A case study was carried out on the costs of fluoridation in Water Treatment Plants (WTP), considering seven population sizes during 68 months in the period from January 2012 to December 2017. The WTP were managed by Espírito Santo Sanitation Company responsible for supplying 67% of the municipalities in the state of Espírito Santo (ES) and also for approximately 88 WTP in the territory, which has produced on average seven thousand liters per second of treated water. It is a mixed-capital corporation, in which the State Government is the majority shareholder. In 2010, according to Brazilian Demographic Census, 83.1% of the ES population was covered by water supply systems and 16.4% by wells or springs inside or outside their property. For each population size analyzed, a WTP was selected. The size of the population and the availability of complete data were considered for the selection of cases.

Costs of water treatment

The average annual cost of water treatment was calculated considering the availability of complete data for the period from January 2014 to December 2018. The cost of the m^3 produced in the municipality where the WTP was located and the volume of water produced in the respective year were estimated. Then, the cost for the period was multiplied by the volume produced in each year and divided by the population supplied by WTP in the period. The items considered for calculating water treatment costs are listed in Chart 1.

Costs of fluoridation

The average annual cost of water fluoridation was calculated from January 2012 to December 2017, considering the availability of complete data. Information was collected from the supply company regarding costs of initial installation, the chemical product, the operation of the system, and the control of fluoride levels, as described by Frias *et al.* (2006). Costs for the construction of new plants were not included, as this capital already exists and would not have been an additional cost, regardless of the fluoridation status. Therefore, the costs were estimated as follows:

Chart 1 – Composition of the costs of the complete treatment of public water supply.

Human Resources	- Normal and overtime wages - Layoff, 13th salary, Brazilian Government Severance Indemnity Fund for Employees, leave of absence (premium/maternity/paternity) - Transport and food benefits - Medical and social insurance
Materials	- Expedient material, use and consumption - System operation and maintenance material - Treatment material - Laboratory material - Safety and protection material - Cleaning and hygiene material - Fuels and lubricants
Outsourced services	- System operation services - Professional technical services - Maintenance and cleaning services - Surveillance services - Real estate, machinery and car rentals - Electricity - Communication services (publicity and advertising) - Material handling, loading and unloading services - Printing, copying and binding services
Depreciation and amortization	- Depreciation and amortization of property, plant and equipment
Financial, tax and fiscal-related costs	- Interest, fines and monetary updates - Bank expenses - Compensation of own capital - Union contribution - Urban real estate tax, Social Security Financing Contribution, Social Integration Program, Tax on financial transactions, Tax on vehicles, and Contribution for Intervention in the Economic Domain - Provisions for tax, civil, labor, and environmental proceedings
Other costs	- Driving, travel and accommodation - Donations - Exhibitions, congresses and commemorative events - Labor indemnities - Loss of receipt of tariffs - Expenses on incorporations

Source: prepared by the authors.

- Costs of initial installation (CII) – the following items were considered: equipment costs (metering pump, storage tank, and fluoride dosage control equipment); installation costs, which represent about 85% of the equipment cost (CDC, 1991); and technical consultancy costs, corresponding to 15% of total costs related to installation capital. The lifetime of the equipment was considered; therefore, the installation capital was stratified for 20 years. This calculation included the initial capital plus technical consultancy, divided over 20 years;
- Costs of the chemical product (CCP) – the annual consumption of fluorosilicic acid in kilograms in each WTP was considered and then multiplied by its cost in the respective year;
- Costs of the system operation (CSO) and of fluoride level control (CFC) – to estimate the system operation costs, depreciation and maintenance of equipment costs were considered, which represent approximately 10% of the initial capital distributed over its lifetime, and human resource costs of one employee per WTP, calculated considering the average annual cost of wages plus labor charges. Furthermore, in this section, fixed costs for measuring and controlling fluoride levels by the SPADNS (2-(parasulfophenylazo)-1,8-dihydroxy-3,6-naphthalene-disulfonate) colorimetric method were estimated.

Therefore, to calculate the *per capita* costs of fluoridation, Equation 1 was applied:

$$\text{Costs of fluoridation} = \frac{\text{CCII} + \text{CCP} + \text{CSO} + \text{CFC}}{\text{covered population by year}} \quad (1)$$

The fluoride consumption was calculated according to the Fluoridated Water for Human Consumption Manual (BRASIL, 2012). Considering that flow rate data of water from WTP (QWTP) were informed by the company, the flow rate of acid dosage (Qacid) was calculated, as reported by Equation 2:

$$\text{Qacid} = \frac{Q_{WTP} \text{ x ion content to be applied x proportionality factor}}{\text{Concentration of fluorosilicic acid}} \quad (2)$$

The concentration of fluorosilicic acid is 291.3 g.L-1 (24%) and the proportionality factor (relationship between its molecular weight and the amount of fluoride ions released by its molecule) represents 1.263. Subsequently, the expected consumption was determined considering the density of 1.2136 kg.L-1 at a concentration of 24% (BRASIL, 2012) according to Equation 3:

$$\text{Expected consumption}_{acid} = Q_{acid} \text{ x acid density} \quad (3)$$

The ion content to be applied used in Equation 1 was 0.7 $mg.L^{-1}$ and variations of up to 14% in the expected consumption were accepted, as the optimal concentration ranged between 0.6 and 0.8 $mg. L^{-1}$.

The results were presented in reais, the Brazilian monetary unit (BRL), and also in United States Dollars (USD) to allow comparison with international studies (NIESSEN; DOUGLASS, 1984). The average variations of the real-dollar for the period from 2012 to 2017 (USD 1 = BRL 2.75 [1.95 – 3.19]) and for the period from 2014 to 2018 (USD 1 = BRL 3.20 [2.35 – 3.66]), released by the Central Bank of Brazil, were considered.

Finally, the percentage represented by the cost of fluoridation in the total cost (cost of fluoridation plus cost of water treatment) was determined to estimate its weight concerning the total expenses.

RESULTS

The chemical product applied to all WTP was the fluorosilicic acid (H2SiF6), in a concentration of 24%. The range of the acid costs is shown in Table 1. Values varied from R$ 0.39/kg in 2012 to 1.23/kg in 2017, increasing 315%. In the WTP that supplied less than two thousand inhabitants, the total cost ranged from R$ 194.22 (2012) to R$ 339.48 (2017), and in the one that supplied 520 thousand inhabitants, it ranged from R$ 96,984.03 to R$ 236,473.08. This expense included the product transport cost from the supplier to the WTP (Table 1).

Data on WTP that supplied different population sizes in the state of Espírito Santo were used. In addition to differences in the population size and active

Table 1 – Cost of fluorosilicic acid, according to the year and population size.

Year	Fluorosilicic acid	Population size (in thousand inhabitants)						
		< 2	6	9	30	70	160	520
2012	Cost (R$/Kg)	0.39	0.39	0.39	0.39	0.39	0.39	0.39
	Total cost (R$)	194.22	398.93	877.97	2,831.40	11,673.09	33,545.15	96,984.03
2013	Cost (R$/Kg)	0.48	0.48	0.48	0.48	0.48	0.48	0.48
	Total cost (R$)	174.24	528.14	1,253.95	3,518.59	14,457.60	39,673.44	111,951.84
2014	Cost (R$/Kg)	0.67	0.67	0.67	0.67	0.67	0.67	0.67
	Total cost (R$)	286.22	864.41	1,916.74	5,589.02	21,141.85	55,420.39	154,530.32
2015	Cost (R$/Kg)	0.83	0.83	0.83	0.83	0.83	0.83	0.83
	Total cost (R$)	310.75	1,000.06	2,085.46	5,812.66	27,121.08	53,953.32	169,683.62
2016	Cost (R$/Kg)	1.10	1.10	1.10	1.10	1.10	1.10	1.10
	Total cost (R$)	302.28	1,199.62	2,412.96	8,118.73	34,946.25	64,714.44	223,124.74
2017	Cost (R$/Kg)	1.23	1.23	1.23	1.23	1.23	1.23	1.23
	Total cost (R$)	339.48	1,190.64	3,337.76	8,484.28	38,979.84	63,990.75	236,473.08

Source: prepared by the authors.

connections of water, WTP also differed in volume of produced water and its flow rate, varying respectively from 9,302.76 to 4,709,286.39 (m^3 per month), and from 25.19 to 6,480.45 (m^3.h-1).

The initial capital cost for each WTP included the common metering pump (by impulse), the storage tank, and the fluoride dosage control equipment (SPANDS), plus the installation (85% of the total equipment costs) and technical consultancy cost (15% of the installation costs). For WTP with a population size less than or equal to 30 thousand inhabitants, the total costs were R$ 5,896.24; when stratified for 20 years, such costs were R$ 294.91 per year. According to the sanitation company, for WTP larger than 50 thousand inhabitants, two metering pumps, a high-volume storage tank, and one fluoride control equipment (SPANDS) are used. Installation and technical consultancy costs, therefore, amounted to R$ 9,196.24; when stratified for 20 years, such costs were R$ 459.81 per year.

In terms of system operation, to estimate human resources costs, the earnings of one operational technical employee per WTP were considered. The average monthly wage of operators working in WTP located in the countryside of the state (≤ 30 thousand inhabitants), from 2012 to 2017, was R$ 2,059.44. For WTP located in urban centers, the average monthly wage was R$ 3,620.19. The 13th salary, labor charges, and 1/3 vacation per year were also considered. From these values, the average for the period was calculated, totaling R$ 31,647.03/year and R$ 55,630.68/year of human resources costs per WTP, located in rural areas and urban centers, respectively.

Depreciation and maintenance costs of the equipment were also considered into system operation, which represent 10% of the initial capital costs of installation, therefore R$ 29.48 for WTP with less than 10 thousand inhabitants and R$ 45.98 for larger WTP. The costs of the fluoride concentration control method (laboratory glassware and reagents), used in all WTP, were included in the initial capital.

The annual *per capita* cost varied according to the population size; therefore, the cost was: R$ 20.14 (US$ 7.32) for the population size of less than two thousand inhabitants; R$ 5.60 (US$ 2.04) for six thousand inhabitants; R$ 3.96 (US$ 1.44) for nine thousand inhabitants; R$ 1.20 (US$ 0.44) for 30 thousand inhabitants; R$ 1.16 (US$ 0.42) for 70 thousand inhabitants; and R$ 0.70 (US$ 0.26) and R$ 0.39 (US$ 0.14) for 160 and 520 thousand inhabitants, respectively (Table 2).

The percentage composition of expenses was also different according to the size of the population. In systems that supplied up to 30 thousand inhabitants, the cost of operation had high participation in the composition of expenses, varying from 98.2% in the area with less than two thousand inhabitants to 84.03% in the area with 30 thousand inhabitants. These costs decreased about 15% in the size of 70 thousand inhabitants compared with the 30 thousand inhabitants. There was a balance in the participation of the items in the total cost in the population size of 160 thousand inhabitants. For 520 thousand inhabitants, the chemical product was the largest expense corresponding to 74.7% of the costs (Table 2).

In areas with two and six thousand inhabitants, the consumption of fluorosilicic acid was less than expected, with a variation of -96.0% and -19.4%, respectively. In other sizes, the percentage of variation was within the expected values: ± 14% (Table 2).

The annual costs of water treatment ranged from approximately R$ 418 thousand, for the smallest population size, to R$ 90 million for the largest area. In systems that supplied up to 30 thousand inhabitants, costs on human resources were responsible for the highest percentage in the composition of total costs, varying from 58.4% in the area with less than two thousand inhabitants to 41.8% in the area with 30 thousand inhabitants. The costs of outsourced services were responsible for over 30% of the total composition of costs in sizes larger than

Table 2 – Annual estimates of performance indicators of Water Treatment Plants, composition of costs and consumption of fluorosilicic acid, for the period from 2012 to 2017, according to population sizes.

Performance indicators of Water Treatment Plants	Population size (in thousand inhabitants)						
	< 2	6	9	30	70	160	520
Active connections (mean)	595.90	2,031.90	3,106.99	10,886.65	22,841.13	30,006.63	121,135.64
Produced volume (m^3 per month)	9,302.76	30,204.49	58,352.69	192,073.32	749,235.46	1,487,214.98	4,709,286.39
Produced flow rate ($m^3.h^{-1}$)	25.19	42.72	82.49	267.12	1,029.90	2,048.91	6,480.45
Operating time (hours/-month)	402.57	708.51	707.55	719.34	727.69	725.97	726.82
Composition of costs							
Cost of initial capital for installation* (R$)	294.81	294.81	294.81	294.81	459.81	459.81	459.81
% of costs	0.91	0.90	0.87	0.78	0.57	0.43	0.21
Cost of chemical (R$)	297.87	863.63	1,980.81	5,725.78	24,719.95	51,882.91	165,457.94
% of costs	0.9	2.6	5.8	15.19	30.57	48.0	74.7
Costs of the system operation (R$)	31,676.52	31,676.52	31,676.52	31,676.52	55,676.66	55,676.66	55,676.66
% of costs	98.2	96.5	93.3	84.03	68.86	51.5	25.1
Per capita cost (R$)	20.14	5.60	3.96	1.20	1.16	0.70	0.39
Per capita cost (US$)	7.32	2.04	1.44	0.44	0.42	0.26	0.14
Consumption of fluorosilicic acid							
Registered (kg)	368.90	1,112.80	2,524.04	7,368.98	31,290.38	71,207.25	218,680.93
Expected (kg)	723.03	1,328.10	2,564.42	8,304.28	32,018.25	63,697.68	201,467.92
% variation	-96.0	-19.4	-1.6	-12.69	-2.33	+10.55	+7.87

*Fractional cost over 20 years considering the life span of the equipment. Source: prepared by the authors.

70 thousand inhabitants. The cost of m³ produced decreased as the population size increased, ranging from R$ 4.08 to R$ 1.98 (Table 3).

The cost of water fluoridation compared with the total cost varied from 0.7 to 0.2% in the population sizes of 30 thousand inhabitants or more, and from 1.3 to 7.3% in the three smallest population sizes (Table 4).

DISCUSSION

The CWF cost changed in line with the size of treatment plant coverage, i.e., the smaller the population size covered, the higher the cost per person. Operationalization and chemical costs were the factors mainly responsible for the total cost composition, in both small and large population sizes, respectively. In the smallest size, the fluoridation cost nearly corresponded to 7% of the total water treatment, whereas in the size of 520 thousand inhabitants this fraction represented only 0.2% of the total cost.

This is the first Brazilian study comparing intervening factors in the costs of CWF and the water treatment in seven different population sizes. Francisco and Arica (2018) presented an analysis model considering only chemical costs of water treatment in Campos dos Goytacazes city, in the state of Rio de Janeiro. Other studies have estimated the annual *per capita* cost of water fluoridation in large municipalities without providing detailed information on the intervening factors (FRIAS *et al.*, 2006; MARTINEZ *et al.*, 2013).

In the present study, the annual *per capita* cost was R$ 20.14 (US$ 7.32) for less than two thousand inhabitants and R$ 0.39 (US$ 0.14) for the size of 520 thousand inhabitants. Differences in fluoridation costs according to population size have also been observed in Australia. In communities with less than

Table 3 – Composition of the annual costs of water treatment (in thousands of reais), for the period from 2014 to 2018.

	Population size (in thousand inhabitants)						
	< 2	6	9	30	70*	160*	520
Human Resources	248.40	768.13	1,407.93	2,863.01	24,588.96	24,588.96	22,440.71
% of costs	59.4	62.1	52.7	41.8	28.3	28.3	24.7
Materials	10.82	28.43	73.29	259.88	3,618.44	3,618.44	2,393.43
% of costs	2.6	2.3	2.7	3.8	4.2	4.2	2.6
Outsourced services	92.41	216.73	602.54	2,032.93	31,490.70	31,490.70	29,888.50
% of costs	22.1	17.5	22.5	29.7	36.3	36.3	32.9
Depreciation and amortization	15.22	49.96	200.08	762.66	6,426.46	6,426.46	6,059.21
% of costs	3.6	4.0	7.5	11.1	7.4	7.4	6.7
Financial, tax and fiscal-related costs	35.09	124.38	297.47	730.61	11,930.21	11,930.21	14,014.07
% of costs	8.4	10.1	11.1	10.7	13.8	13.8	15.4
Other costs	16.12	49.43	91.04	194.24	8,698.18	8,698.18	16,047.34
% of costs	3.9	4.0	3.4	2.8	10.0	10.0	17.7
Total	418.06	1,237.07	2,672.35	6,843.32	86,752.96	86,752.96	90,843.26
Costs of m³ (in reais)	4.08	3.43	4.00	2.97	1.98	1.98	2.15

*Water Treatment Plants located in the same municipality. Source: prepared by the authors.

Table 4 – Comparison of the annual *per capita* costs of water treatment with the costs of fluoridation. Mean value and standard deviation.

	Population size (in thousand inhabitants)						
	< 2	6	9	30	70	160	520
Average cost of water treatment (R$)	254.63	240.70	304.69	214.45	239.24	231.07	203.03
Standard deviation	33.28	24.36	38.92	23.14	14.68	37.49	5.72
Average cost of water treatment (US$)	79.57	75.22	95.22	67.02	74.76	72.21	63.45
Standard deviation	10.40	7.61	12.16	7.23	4.59	11.71	1.79
Average cost of Community Water Fluoridation (R$)	20.14	5.61	3.96	1.20	1.16	0.70	0.39
Standard deviation	2.52	0.79	0.55	0.19	0.19	0.24	0.10
Average cost of Community Water Fluoridation (US$)	7.32	2.04	1.44	0.44	0.42	0.25	0.14
Standard deviation	0.92	0.29	0.20	0.07	0.07	0.09	0.04
Percentage of fluoridation cost in the total cost (in reais)	7.3	2.3	1.3	0.6	0.5	0.3	0.2
Percentage of fluoridation cost in the total cost (in dollar)	8.3	2.6	1.5	0.7	0.6	0.3	0.2

Source: prepared by the authors.

five thousand inhabitants, the *per capita* cost was A$ 4.38, whereas in those with more than 50 thousand inhabitants, it was A$ 0.53 (FYFE *et al*., 2015).

In the state of Florida, United States of America, a study carried out on 44 communities with different population sizes, between 1981 and 1989, showed that the cost of fluoridated public water supply is highly dependent on the organizational structure of the supply system and population size. Thus, the annual *per capita* cost was US$ 2.12 for communities with less than 10 thousand inhabitants, US$ 0.68 for population sizes between 10 and 50 thousand inhabitants, and US$ 0.31 for 50 thousand inhabitants or more (RINGELBERG; ALLEN; BROWN, 1992).

Costs for installing fluoridation varied from five to nine thousandreais, depending on the studied population size. These costs were lower than those estimated for the municipality of São Paulo (FRIAS *et al*., 2006) due to the greater number of WTP and equipment required in that municipality.

In addition, there are differences related to the technology employed among supply companies. The company reported in this study used the colorimetric method to analyze fluoride concentration in all population sizes. This method, although more prone to reading errors due to the presence of interfering ions in the water (SILVA *et al*., 2007), is cheaper compared with the electrometric method (MOTTER *et al*., 2011), a fact that can influence the decision-making for using the colorimetric technique by supply companies.

For WTP with the largest population size (and also the highest water flow rate), chemical costs accounted for about 74% of the total cost. Moreover, it was observed that the cost of fluorosilicic acid per kilogram significantly increased over the analyzed years: approximately 315%. This increase may be related to market interests in the product, as fluorosilicic acid is a secondary product of the fertilizer industry and, according to the authors' experience in this field of study, for many years it was distributed to sanitation companies at no cost.

Personnel costs linked to the operationalization of the system increased in smaller population sizes. In six of the seven population sizes, this portion represented, from the total fluoridation costs, half of it or more, whereas for treatment, three of the seven population sizes analyzed had higher expense on human resources in the total composition of costs. These costs are part of the operating costs that are proportional to the amount of treated water (BHOJWANI *et al*., 2019). In contrast to the expense on chemicals, which increases according to the quantity of produced water, personnel expenses are fixed and their weight in the total operating cost tends to decrease as the amount of produced water increases.

Another important aspect of the study concerns the chemical consumption used to adjust the fluoride concentration. The results showed higher variation of expected consumption in smaller population sizes. A previous study on 40 municipalities in the state of São Paulo described a higher percentage of samples within the standard regarding the concentration of fluoride in larger systems, where the frequency of monitoring water quality is generally greater (DARÉ; DALL'AGLIO SOBRINHO; LIBÂNIO, 2009).

This study compared the fluoridation cost with the total cost involving the treatment and the fluoridation of water. In population sizes of 30 thousand inhabitants or more, this weight was the smallest regarding all the involved costs. Conversely, in population sizes smaller than 10 thousand inhabitants, this value represents between 1.3 and 7.3% of the total cost. Those in management, regulation, and operation of sanitation services must be responsible for creating alternatives related to public policies that ensure suitable conditions for the rational use of natural resources, the economic and financial balance, and the universal access to treated and fluoridated water in the WTP serving small population sizes.

A limitation of the present study was the difficulty in generalizing the obtained results, considering that it is a case study involving seven population sizes. However, this type of study design allowed the investigation and in-depth analysis of factors involved in the fluoridation costs. It is worth mentioning that about 70% of Brazilian municipalities have a population size up to 20 thousand inhabitants (IBGE, 2011), in such a way that the information produced in this study may assist managers of public and private companies and other decision-makers serving different population contexts in the sanitation sector. In addition, it is necessary to consider that there are myriads of options and methods for managing water supply and treatment systems due to the wide variety of water sources, treatment methods, and recycling options (BHOJWANI *et al*., 2019). With the advancement of remote communication and monitoring resources, the operating costs estimated in this study for population sizes smaller than 10 thousand inhabitants could be significantly reduced.

CONCLUSIONS

Regarding the findings, the authors conclude that the cost of fluoridation over the total cost of the operation (treatment and fluoridation) varied from 0.2 to 0.6% in the population sizes of 30 thousand inhabitants or more, and from 1.3 to 7.3% of the total cost in population sizes smaller than 10 thousand inhabitants.

AUTHORS' CONTRIBUTIONS

Belotti, L.: Conceptualization, Data Curation, Formal Analysis, Methodology, Writing – original draft. Frazão, P.: Conceptualization, Data Curation, Methodology, Supervision, Writing – original draft.

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