Per capita cost of fluoridating the public water supply in a large municipality

Custo per capita da fluoretação da água de abastecimento público em um município de grande porte

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ABSTRACT

Objective
To estimate the per capita cost of fluoridating the municipal water supply of Sorocaba in 2009 and describe the costs from 1989 to 2008.

Methods
Sorocaba's Autonomous Water and Wastewater Service disclosed the initial capital required for implementing the water fluoridation system and the costs associated with the purchase of chemicals, system operation, and control of fluoride concentration. These numbers were added and divided by the municipal population with piped water.

Results
In 2009 the per capita cost was R$ 1.43 (US$ 0.72), 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).

Conclusion
The per capita cost of water fluoridation is low, and when the fluoride concentration is kept at the recommended levels, it is an efficient, simple, and safe public policy for preventing dental caries. Knowing its cost allows comparisons and encourages its implementation.

Indexing terms: *Dental caries. Fluoridation. Water supply.*

RESUMO

Objetivo
Estimar o custo per capita da fluoretação das águas de abastecimento público para o município de Sorocaba, em 2009 e descrever seus custos financeiros de 1989 a 2008.

Métodos
Foi realizada uma pesquisa junto ao Serviço Autônomo de Água e Esgoto de Sorocaba e os dados sobre custos do capital inicial de instalação, do produto químico, da operacionalização do sistema e do controle dos teores de fluoreto foram obtidos, calculados e divididos pelo número de habitantes abastecidos por água no município.

Resultados
a) O custo per capita foi de R$ 1, 43 (US$ 0,72) em 2009 e b) no período de 1989 a 2008, a estimativa do custo per capita variou de R$ 1,19 a R$ 1,43 (US$ 0,59 a 0,72).

Conclusão
O custo per capita da fluoretação da água é baixo, comprovando que, quando praticada com os níveis de fluoreto recomendados, torna-se uma medida de saúde pública eficiente, simples e segura para a prevenção da cárie dentária. Estimar seu custo é importante para efeito de comparação e incentivo a sua implementação para outros municípios.

Termos de indexação: Cárie dentária. Fluoretação. Abastecimento de água.

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INTRODUCTION

Fluoridation of the public water supply is considered one of the top ten public health measures of the 20th century[1], but its efficacy, effectiveness, toxicity, and cost are still questioned[2]. Its temporary or permanent discontinuation, or fluoride levels below the recommended levels prevents dental caries less effectively[3].

According to the National Survey of Basic Sanitation[4], 45% of the Brazilian municipalities fluoridated their water supply by the year 2000, and by 2008, this percentage had increased to 60.6%[5]. Despite this increase, water fluoridation does not yet benefit all Brazilians: those in rural and city outskirt areas are possibly left out. These are the areas that most require fluoridation because of the low socioeconomic level of their inhabitants, increasing inequalities[6].

Given that dental caries is still the main oral health problem of the Brazilian population, water fluoridation is one of the most effective means of maintaining low levels of fluoride in the oral cavity. The anticariogenic action of fluoride is widely recognized. In terms of public health, the effects are greater when water is used as vehicle because of its widespread use and lower cost[7].

According to water treatment plants, the factors that prevent water fluoridation include the high cost of installing the necessary equipment and the cost of the chemicals[8]. In 1974, water fluoridation became compulsory in all Brazilian municipalities with water treatment plants[9]. Therefore, analyzing the cost of implementing and maintaining water fluoridation may technically subsidize the municipalities that wish to implement and maintain it because it is an efficient, simple, inexpensive, and safe public health measure when the fluoride levels are correct[10-12]. The objectives of this case study were: a) to estimate the cost of water fluoridation per capita in 2009; b) to describe its costs from 1989 to 2008; and c) to analyze the dental caries indices since the implementation of water fluoridation in 1973.

METHODS

In 2009 Sorocaba had an estimated population of 584,313 inhabitants[13], and by 2008, 99% of this population had piped water at home[14].

In Sorocaba, water fluoridation is performed by the Autonomous Water and Wastewater Service (SAAE) of Sorocaba, an autonomous municipal water and wastewater treatment plant. There are two plants: ETA 1 (Cerrado) supplies water to 90% of the city, has been fluoridating water since October 1973, and treats 2000 liters of water per second15; and ETA 2 (Éden) has been fluoridating water since 1982 and treats as much as 200 liters of water per second[15].

The two plants were studied. The data provided by SAAE were: cost reports for the equipment, chemicals, system operation, and control of fluoride concentration in the water supply. The companies that provided the equipment were also consulted. Calculation of the costs included[10]:

Initial capital (IC)

a) equipment: metering pump; storage tanks; fluoride concentration control and testing equipment; b) installation: represents 85% of equipment cost[16-17]; c) technical consultancy: represents 15% of the initial capital[17-18].

The initial capital was stratified by twenty years, the equipment lifetime. This calculation included the initial capital plus technical consulting divided by twenty (number of years).

Cost of the chemicals (CC)

The fluoride added to reach the recommended concentration of 0.7 ppm took the fluoride present naturally in the water into account. The cost is given by ton of product.

System operating cost (SOC)

a) equipment depreciation and maintenance: these represent roughly 10% of the initial capital distributed according to equipment lifetime; b) electricity: percentage of the costs with electricity for the two ETA plants divided by the proportion of electricity cost for running the fluoridation pumps; c) human resources: mean annual cost of the salaries and labor costs of the water treatment plant operators (one operator per plant).

Cost of controlling fluoride concentration (CCFC)

a) metering and control equipment (fluorometer): fixed amount already added to the initial capital required for implementing water fluoridation; b) chemical products: reagents; c) ion-selective electrodes: lifetime of one year[17].

The cost of water fluoridation per capita per year was given by the following formula[10]:

Fluoridation cost indicator: (IC + CC + SOC + CCFC) / city population

This estimate included the cost divided by the number of inhabitants of Sorocaba who received fluoridated water, estimating the cost of the system/year and the cost of the system/person/year in 2009.

The cost of operating the system from 1989 to 2008 included the operating costs and costs with chemicals. The initial capital was stratified for twenty years. However, SAAE only provided the cost of controlling the fluoride concentration for the year of 2009, so the estimated cost of controlling the fluoride concentration from 1989 to 2008 was given by multiplying it to the percentage of this cost in 2009 in relation to the total cost of the same year, that is, 1.47%. Therefore, the cost of controlling the fluoride concentration from 1989 to 2008 was given by multiplying the total cost of that period by 1.47%.

RESULTS

The chemical used today is fluosilicic acid (FSA), which is added at the end of the water treatment process.

In ETA Cerrado the water has a natural fluoride concentration of roughly 0.11 mg/L and fluoridation is done by a gravimetric rotameter. In ETA Éden the water has a natural fluoride concentration of 0.3 mg/L and fluoridation is done by a metering pump.

All costs provided by SAAE were expressed in reais, the current Brazilian currency.

Initial capital (IC)

Table 1 shows how the initial capital (IC) was calculated. The equipment cost was added to the installation cost (85% of the equipment cost) and to the technical consultancy cost (15% of the initial capital). The total cost was R$ 295,423.05, which divided by 20 years gives R$ 16,697.82.

Table 1. Initial capital required to implement water fluoridation in reais, Sorocaba (SP), 2009.

Initial capital (IC)	Amount (R$)
Equipment	138 859,25
Installation	118 030,36
Subtotal	256 889, 61
Consultancy	38 533,44
Total	295 423,05

Cost of the chemicals (CC)

Table 2 shows the total amount of fluosilicic acid (H2SiF6) used per year in tons, mean monthly and annual costs of purchasing the chemicals in reais, number of Sorocaba, , and volume of treated water in liters from 1989 to 2009 in Sorocaba (SP).

Table 2. Estimated fluosilicic acid cost, population, and volume of treated water from 1989 to 2009, Sorocaba (SP).

Year	H_2SiF_6			Population (inhab.)	Treated water volume (m^3)
	Tons/ year	Mean monthly cost (R$)	Annual cost (R$)		
1989	162	34 020	408 240	358 952	45 062 307
1990	162	34 020	408.240	365 529	47 434 008
1991	164	35 916	430 992	379 006	48 901 039
1992	165	36 135	433 620	388 539	48 949 989
1993	168	36 792	441 504	397 553	49 195 969
1994	170	37 570	450 840	403 695	50 199 968
1995	169	37 180	446 160	409 689	50 707 039
1996	172	40 420	485 040	431 561	52 275 297
1997	175	41 475	497 700	444 664	53 342 140
1998	173	41 347	496 164	455 706	53 610 191
1999	175	42 175	506 100	466 825	55 843 949
2000	207	49 887	598 644	493 468	58 783 105
2001	198	48 114	577 368	508 848	57 630 495
2002	202	49 086	589 032	517 553	58 212 621
2003	209	50 787	609 444	528 727	61 928 320
2004	205	52 070	624 840	552 194	66 589 592
2005	208	52 832	633 984	565 182	71 369 698
2006	210	53 340	640 080	567 459	73 780 636
2007	211	58 869	706 428	570 845	69 919 495
2008	213	62 622	751 464	580 078	72 017 079
2009	214	62 916	754 992	584 313	73 737 250

Source: Costs and planning sector/SAAE- Sorocaba (SP), 2010.

System operating cost (SOC)

a) equipment depreciation and maintenance (10% of the IC); b) electricity: amount consumed by the pumps of the two plants, which corresponded to 0.025% of the total electricity used by ETA Cerrado and to 0.053% of the total electricity used by ETA Éden (SAAE); c) human resources.

Table 3 shows the cost of operating the system from 1989 to 2009 in reais.

Table 3. Estimated cost of operating the water fluoridation system (SOC) from 1989 to 2009 in reais, Sorocaba (SP).

Year	Depreciation and maintenance	Mean annual salary and labor costs	Electricity	SOC
1989	1669.78	1 502.73	1 136.10	4 308.61
1990	1669.78	2 002.06	1 148.02	4 819.86
1991	1669.78	2 602.29	1 146.47	5 418.54
1992	1669.78	3 379.75	1 158.87	6 208.40
1993	1669.78	5 461.95	1 163.97	8 295.70
1994	1669.78	8 819.80	1 171.92	11 661.50
1995	1669.78	14 265.24	1 169.85	17 104.87
1996	1669.78	19 748.29	1 179.63	22 597.70
1997	1669.78	23 387.46	1 374.30	26 431.54
1998	1669.78	25 047.92	1 200.78	27 918.48
1999	1669.78	26 300.43	1 209.14	29 179.35
2000	1669.78	28 141.27	1 310.85	31 121.90
2001	1669.78	29 267.18	1 336.27	32 273.23
2002	1669.78	31 432.98	1 347.57	34 450.33
2003	1669.78	32 690.10	1 355.42	35 715.30
2004	1669.78	35 795.68	1 366.66	38 832.12
2005	1669.78	38 615.35	1 374.34	41 659.47
2006	1669.78	41 637.00	1 377.44	44 684.22
2007	1669.78	43 094.34	1 385.59	46 149.71
2008	1669.78	45 032.30	1 403.68	48 105.76
2009	1669.78	47 806.11	1 418.61	50 894.50

Cost of controlling fluoride concentration (CCFC)

The fluoride concentration at ETA Cerrado is controlled by an ion-selective electrode, with ten analyses being performed per day, and three electrodes being bought per year, and by the SPADNS method (twelve analyses per day). ETA Éden uses only the SPADNS method. The costs include laboratory glassware and the reagents required for both methods (TISAB II, standard fluoride solution, SPADNS reagent). The costs of the necessary equipment, namely spectrophotometers and potentiometers, have already been included in the initial capital.

The cost of controlling fluoride concentration from 1989 to 2008 was given by multiplying the percentage of this cost by the total cost of the initial capital and of operating the system and purchasing reagents in 2009, that is, by 1.47%.

Dividing the cost indicator formula (represented by adding the costs of the initial capital, chemicals, system operation, and fluoride concentration control) by the estimated population of Sorocaba (SP) in 2009 we get:

$$\text{CIF} = \frac{834\,656.32}{584\,313^*} = \text{R\$ 1.43 per person per year}$$

Source: IBGE[13].

Hence, the cost of fluoridating water in Sorocaba (SP) in 2009 was R$ 1.43 reais/person/year (0.72 USD/person/year). Reais was converted into dollars by multiplying the amount in reais by the average selling rate practiced by banks in 2009, which was of R$ 1.99 per dollar.

Table 4 shows the final composition of the estimated cost in reais/person/year of fluoridating the public water supply of Sorocaba, SP, from 1989 to 2009. The total cost includes the initial capital for implementing the system, the chemicals, and the cost of operating the system, which were provided by SAAE, and the cost of controlling the fluoride concentration in the water (given by multiplying the total cost of the system from 1989 to 2008 by 1.47%, as described previously).

Studies done in 1974, twelve months after the implementation of water fluoridation in the municipality of Sorocaba[16], and in 1985[19] investigated the prevalence of caries in schoolchildren aged 7 to 12 years using the same indices.

Other epidemiological oral health studies done in 1999, 2002, and 2006 included schoolchildren aged 7 to 12 years attending public schools. Table 5 shows their decayed-missing-filled (DMF) index. The listed studies used different study designs and sampling methods[20].

Table 4. Composition of the estimated costs in reais of fluoridating the public water supply of Sorocaba from 1989 to 2009, Sorocaba (SP).

Year	IC	CC	SOC	CCFC 1.47%	Total	Population	Cost/capita/year
1989	16 697.82	408 240.00	4 308.61	6 309.92	435 556.35	358 952	1.21
1990	16 697.82	408 240.00	4 819.86	6 317.43	436 075.11	365 529	1.19
1991	16 697.82	430 992.00	5 418.54	6 660.69	459 769.05	379 006	1.21
1992	16 697.82	433 620.00	6 208.40	6 710.93	463 237.15	388 539	1.19
1993	16 697.82	441 504.00	8 295.70	6 857.51	473 355.03	397 553	1.19
1994	16 697.82	450 840.00	11 661.50	7 044.23	486 243.55	403 695	1.20
1995	16 697.82	446 160.00	17 104.87	7 055.45	487 018.14	409 689	1.19
1996	16 697.82	485 040.00	22 597.70	7 707.73	532 043.25	431 561	1.23
1997	16 697.82	497 700.00	26 431.54	7 950.19	548 779.55	444 664	1.23
1998	16 697.82	496 164.00	27 918.48	7 949.47	548 729.77	455 706	1.20
1999	16 697.82	506 100.00	29 179.35	8 114.06	560 091.23	466 825	1.20
2000	16 697.82	598 644.00	31 121.90	9 503.01	655 966.73	493 468	1.33
2001	16 697.82	577 368.00	32 273.23	9 207.18	635 546.23	508 848	1.25
2002	16 697.82	589 032.00	34 450.33	9 410.64	649 590.79	517 553	1.25
2003	16 697.82	609 444.00	35 715.30	9 729.29	671 586.41	528 727	1.27
2004	16 697.82	624 840.00	38 832.12	10 001.43	690 371.37	552 194	1.25
2005	16 697.82	633 984.00	41 659.47	10 177.41	702 518.70	565 182	1.24
2006	16 697.82	640 080.00	44 684.22	10 311.49	711 773.53	567 459	1.25
2007	16 697.82	706 428.00	46 149.71	11 308.35	780 583.88	570 845	1.37
2008	16 697.82	751 464.00	48 105.76	11 999.13	828 266.71	580 078	1.43
2009	16 697.82	754 992.00	50 849.50	12 072.00	834 656.32	584 313	1.43

Note: IC: initial capital required for implementing the system; CC: cost of the chemicals; SOC: system operating cost; CCFC: cost of controlling the fluoride concentration.

Table 5. Mean decayed-missing-filled (DMF) indices found by studies using different methods of schoolchildren aged 7 to 12 years from Sorocaba (SP), 2009.

Age (years)	DMF-I				
	1974	1985	1999	2002	2006
7	2.77	1.85	0.48	-	0.24
8	3.62	2.88	0.74	-	0.43
9	4.87	4.26	1.05	-	0.45
10	6.11	5.65	0.99	-	0.77
11	8.06	7.68	1.70	-	0.80
12	9.78	9.35	2.30	1.38	1.04

Source: Sorocaba's City Hall[20].

DISCUSSION

Manau et al.[21] compared the costs of water fluoridation with semimonthly gargling with a 0.02% sodium fluoride (NaF) solution at school and supervised tooth brushing with fluoride toothpaste, also at school. The estimated cost of water fluoridation (installation, equipment, chemicals, maintenance) was US$ 0.39, and those of semimonthly gargling and supervised tooth brushing were US$ 2.24 and US$ 8.80, respectively. Water fluoridation is not only cheaper, but also more widespread, benefitting the entire population and making the measure highly efficient.

O'Connell et al.[22] estimated that water fluoridation in Colorado, United States of America (USA), resulted in savings of 148.9 million dollars in 2003, or approximately US$ 60.78 per person.

For the American Dental Association (ADA)[23], water fluoridation is profitable. In most American communities, each dollar spent on water fluoridation saves 38 dollars of dental treatment.

According to the Center for Studies in Public Health (NESP)[24], the cost of water fluoridation in Brazil, considering initial capital, chemicals, and system operation, is estimated to be R$ 0.13 per person per year.

According to the Guide to community-preventive services[25], the estimated mean water fluoridation cost of 2002 varied from US$ 2.70 per person in towns with up to 5,000 inhabitants to US$ 0.40 per person in towns with more than 20,000 inhabitants.

Frias et al.[10] estimated the mean annual cost of water fluoridation in São Paulo, SP, from 1985 to 2003 to be R$ 0.08 (US$ 0.03) per person; this estimate included the initial capital required for implementing the system, chemicals, cost of operating the system, and cost of controlling fluoride concentration. The accumulated cost in 18 years was R$ 1.44 (US$ 0.97) per person. According to the author, the results should be interpreted with caution because of the economic characteristics of each country, state, and city, population, and the data collection criteria and methods.

In Sorocaba, water fluoridation in 2009 cost R$ 1.43 (US$ 0.72) per person and the estimated cost for the period from 1989 to 2009 varied from R$ 1.19 to R$ 1.43. These costs are much higher than those estimated by Frias et al.[10], probably because of the municipal demographic profile.

The present study found that the most expensive item associated with water fluoridation is the cost of the chemicals, representing more than 90% of the total cost, which varied insignificantly over the 20-year study period.

An epidemiological study conducted in 1974[18] in Sorocaba, 12 months after the implementation of water fluoridation, found DMF indices of 2.77; 3.62; 4.87; 6.11; 8.06, and 9.78 for children aged 7, 8, 9, 10, 11, and 12 years, respectively.

A study conducted by the Pontifical Catholic University of Campinas in 1985 covering the period from 1973 to 1985[19] found DMF indices of 1.85, 2.88, 4.26, 5.65, 7.68, and 9.35 for children aged 7, 8, 9, 10, 11, and 12 years, respectively. The caries prevalences in children aged 7, 8, 9, 10, 11, and 12 years decreased by 33.22%, 20.45%, 12.53%, 7.53%, 4.72%, and 4.40%, respectively. The study concluded that the reduction in the prevalence of dental caries between 1974 and 1985 did not reach the mean found by similar studies conducted in other municipalities that fluoridated their waters during the same period, such as Campinas. In Campinas, ten years after the implementation of water fluoridation, the prevalences of dental caries in children aged 7, 8, 9, 10, 11, and 12 decreased by 70.76%, 55.84%, 50.92%, 55.21%, 45.20%, and 50.68%, respectively. The low reduction in the prevalence of caries observed during the period may be due to irregular water fluoridation. The SAAE may not have maintained the appropriate fluoride concentrations in the first 12 months of water fluoridation because of interruptions or inadequate fluoride addition to the water, and only maintained the appropriate fluoride concentrations during 3 or 4 years. Effective control of water fluoridation began in 1995, when the Paulista Association of Dental Surgeons - Sorocaba Division (APCD) and University of Campinas' (Unicamp) biochemistry laboratory began to test the water fluoride concentration quarterly, and found optimal fluoride concentrations for caries prevention, a procedure that continues to this day (APCD, 1990 - 0.76 ppm; 1995 - 0.76 ppm; 1996 - 0.74 ppm; 1997 - 0.72 ppm; 1998 - 0.72 ppm; 2005 - 0.70 ppm; 2006 - 0.73 ppm; 2007- 0.67 ppm; 2008 - 0.69 ppm;

0.69 ppm; 2009 - 0.66 ppm)[26]. This shows the need of maintaining the optimal fluoride concentration effectively to obtain the desired results.

Comparison of the DMFTs of 1985 to 1999 shows that the caries prevalence in children aged 12 years dropped 75.4%; the prevalence of 1985 is classified as very high by the World Health Organization (WHO), but that of 1999 is classified as low. In 2002, the DMFT was 40% lower than the previous finding. Subsequent studies have shown that caries prevalence continues to decrease, proving that water fluoridation and its monitoring, greater availability of fluoride toothpastes, and other health care measures are effective. As a matter of fact, the DMFT of 12-year-olds was 1.04 in 2006, 24.65% lower than the previous finding and classified as very low by the WHO[20].

The Oral Health Conditions in the State of São Paulo in 2002[27] found a DMFT of 2.5 for children aged 12 years, 6.4 for children aged 15 to 19 years, 20.3 for adults, and 28.2 for the elderly. A national study conducted in 1986 found a DMFT of 6.0 for children aged 12 years from the Brazilian Southeast. This number decreased significantly in the state of São Paulo, reaching 3.7 in 1998 and 2.5 in 2002. The DMFT of 12-year-olds from municipalities that fluoridate their water is 2.3, while for those from municipalities that do not, it is 3.5. Thus, dental caries is 34.3% more prevalent in locations without water fluoridation. Although not as expressive, the same is observed in 5-year-olds: the mean dmft in municipalities with and without fluoridated water is 2.2 and 3.1, respectively, a difference of 29%.

In 2003 Cypriano et al.[28] reported the prevalence and severity of caries in preschoolers aged 5 to 6 years and schoolers aged 7 to 12 years from seven municipalities representative of the region of Sorocaba, SP, exposed or not to fluoridated water. The 5-year-olds had a dmft of 3.1, and 37.6% were caries-free (dfmt=0). The 12-year-olds had a DMFT of 2.6, and 32.3% were caries free. The caries prevalence in the region is considered low. Children of all ages presented better oral health conditions in municipalities with fluoridated water; the proportion of caries-free 12-year-olds was higher (p=0.019), and the dmft was lower (p=0.001). The oral health goal of the WHO/International Dental Foundation (IDF) for 2000 for 12-year-olds was achieved, but 30.1% of the children had a DMFT higher than 3.0. The goal for 5-year-olds was not achieved given that only 37.3% of the children were caries free. These groups require special care to meet their needs.

Today the population in greatest need of dental care is that with the highest DMFT. Thus, this is one more argument in favor of water fluoridation. Frazão et al.[29] confirm this statement in a study about early tooth loss in adults aged 35 to 44 years, reporting that, in a context of high caries prevalence, water fluoridation, age, and socioeconomic status help to prevent tooth loss in this age group.

The study results show that water fluoridation continues to benefit oral health considerably, which is essential in communities with high proportions of low-income children or people in general. Moreover, water fluoridation has a very good benefit-cost ratio for preventing dental caries, even in locations where the incidence of dental caries has decreased in the last years. In Brazil, water fluoridation is very beneficial and should be always maintained at the optimal fluoride concentration[30].

CONCLUSION

In Sorocaba the per capita cost of water fluoridation was low during the study period. The present study corroborates others showing that when the recommended fluoride concentrations are observed, water fluoridation is an effective, simple, and safe public health measure for preventing dental caries. Estimating its cost allows comparisons between studies and encourages its implementation by municipalities that have not yet adhered to the practice.

Although the epidemiological studies of dental caries mentioned herein use different methods, secondary data analysis showed a significant decrease in the prevalence of dental caries. A DMFT of 1.04 is considered very low by the WHO.

Collaborators

ÉHS MARTINEZ designed the study, analyzed and interpreted the data, and wrote the article. AC FRIAS analyzed and interpreted the data, and wrote and critically reviewed the article. HJ MENDES conceived and designed the study, analyzed and interpreted the results, and wrote and critically reviewed the article. KPK OLYMPIO designed the study, analyzed and interpreted the data, and wrote and critically reviewed the article.

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