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Original Article

External Control over Fluoridation of the Public Water Supply in São Luís, MA, Brazil

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Abstract

Objective: To to monitor fluoride concentrations in the public water supply of São Luís, Maranhão, Brazil, from February 2008 to January 2009. **Material and Method:** Forty sampling points representing 39 neighborhoods of São Luís were conveniently selected. The points were selected based on the sites where the public water supply is provided by the local water supply company and also considering the proximity of elevated water reservoir tanks. The analysis of the fluoride concentration was performed in triplicate using an ion-specific electrode for fluoride connected to a previously calibrated potentiometer. After analysis, the samples were considered adequate when the fluoride concentration was within recommended limits from 0.60 up to 0.80 ppm F (criterion I) or within the stipulated range from 0.55 ppm up to 0.84 ppm F (criterion II). **Results:** The results showed a large variation between minimum and maximum concentrations. Considering all samples, the average values (± SD) for the municipality was 0.58 ppm F (± 0.24) and median value was 0.61 ppm F, with minimum and maximum value of 0.02 and 1.33 ppm F, respectively. Of the 480 samples, 62.9% was considered inadequate by criterion I, while using criterion II, the percentage was 48.3%. **Conclusion:** The fluoridation program in São Luís-MA needs improvement. Therefore, surveillance based on external control and operational control becomes essential to ensure that the method is efficient and effective.

Keywords: Fluoride; Fluoridation; Water treatment; Surveillance.

Introduction

The knowledge on the action of fluoride on the dynamics of the caries process became widely used as a preventive method. So, it has been considered as one of the factors responsible for the decline of the disease in Brazil and in other countries [1,2], although its use alone does not prevent the development of the disease, but only reduces its progression. In contrast, an increase in reports of dental fluorosis has been observed [3.4].

The major mechanism of action of fluoride in caries control is based on its effect on the dynamics of demineralization / remineralization process [5], when it is kept steadily in the oral environment. In this context, fluoridation of public water supply is one of the most important preventive public health methods and of best cost-benefit or cost-effectiveness relationship to keep this condition [6,7].

Fluoridation of public water supply is governed by specific legislation in Brazil since 1974. The law 6,050 of May 24, 1974 provides for the fluoridation of water supply systems when there is water treatment plant [8] was regulated by Decree No. 76,872 of December 22, 1975 [9].

The importance of fluoridating drinking water is focused on the scope of this measure, affecting the population equally, regardless of social class [6] or access to other forms of prevention and use of fluoridated toothpaste. Communities with social and economic deprivation are documented to having worse oral health conditions, so they can regularly receive the benefits of fluoride through water [10].

Fluoride concentrations in drinking water of supply systems below recommended values do not prevent the development of caries and on the other hand, concentrations above recommended values can expose individuals to the development of dental fluorosis. Thus, it is important to check the fluoride concentration in the water constantly. In this study, external control is the monitoring of fluorine concentrations by external companies and not by regular water treatment companies [11].

In São Luís-MA, the history of fluoridation of water supply systems can be divided into two distinct periods: in 1986, when the first addition of fluoride was performed by the Water and Sewerage Company of Maranhão (CAEMA), being interrupted in 1992 due to the lack of product, and, more recently, in February 2006, when the program was restarted using sodium fluossilicate.

Due to the scope and effectiveness offered by preventive methods of adding fluoride to water supply systems, especially in underdeveloped socio-economic areas, it becomes necessary to know the current status of fluoridation in São Luís, Maranhão, Brazil.

Material and Methods

Study area

The study was conducted in São Luís, Maranhão, with land area of 827.141 km². According to the last population count, the municipality has 957,515 inhabitants.

In this municipality, the Water Supply System consists of the following Water Treatment Plants (WTP): Italuís, Sacavém, Olho D'Água and Cururuca; Paciência system (battery of deep wells); in addition to isolated deep wells. However, water supply systems receiving fluoride dosages are: Italuís, Sacavém, Olho D'Água and Paciência System. Localities that are supplied by isolated wells do not receive fluoride in water.

The company responsible for the public water supply divides its network of operations into five metropolitan areas or regions called Operational Business Units: Anjo da Guarda Operational Business Unit (OMG), Downtown Operational Business Unit (OMC), Vinhais Operational Business Unit (OMV); Cohab Vinhais Operational Business Unit (OMH); Cidade Operária Operational Business Unit (OMP).

Sampling and selection of sampling points

The sampling design of this study was based on Ordinance no. 518/2004 (12). According to this ordinance, the minimum number of monthly samples for quality control of the public water supply system for purpose of physicochemical analysis is a function of municipality population size. Thus, taking into account the population census and estimated population of the city of São Luís, MA, and number of sampling points, a minimum of 39 sampling sites was determined for that municipality.

These points were selected based on the five operational business units and also due to the proximity to the existing elevated water reservoir tanks. In each of these operational business units, neighborhoods were chosen by convenience to cover all regions of the city. Each neighborhood represented a sampling point, except for downtown, which, given its size and to the presence of two large elevated water reservoir tanks, consisted of two points, each of them near one of these water reservoirs.

The sites selected were preferably public places of easy access, containing a tap directly connected to the network and in the same way water was consumed by the population. These locations corresponded to public schools, except neighborhoods where there was no public educational institution or when there was no access to the collections of water samples. In these situations, the sampling points were selected in private homes or business premises.

After site selection, formal and personal contacts were performed with owners in order to obtain permission to access, certify the origin of the water used, identify the tap, introduce the team responsible for the monthly collection of water samples, as well to explain the importance of monitoring the fluoridation of the public water supply of São Luís, MA.

Sample collection

To collect water samples, 10 ml plastic bottles previously washed with distilled and deionized water and properly labeled, identifying location and date, were used. The collections

were performed by the same team in the last week of each month for twelve months, two samples per point, one of which was stored for control.

After collection, samples were frozen and sent for analysis at the Laboratory of Oral Biology, Federal University of Paraíba - UFPB.

Analysis of samples

Analysis of fluoride concentration was performed using ion-specific electrode for fluoride (9409BN, Orion, USA) combined with a reference electrode (900200, ORION, United States), connected to a 710 A potentiometer (ORION, United States). The measurement was provided in millivoltage (mV), which corresponds to a potential difference between the liquid that is inside the electrode and the solution being analyzed. The calibration of ion-selective electrode for fluoride was previously performed. To this end, standard solutions from 0.20 ppm F to 6.40 ppm F by serial dilution from stock standard solution of 100 ppm F (Orion, USA) with distilled and deionized water were prepared. The volume of 1 mL of each standard was pipetted, and added of 1 ml of Total Ionic Strength Adjustor Buffer solution (TISAB II).

The millivoltage potentials obtained were converted into ppm F with the aid of the Windows Excel ® software. Standard curve and correlation coefficient $r2 \geq 0.99$ were used. Only calibration curves with maximum variation of 10% were accepted.

After calibration, the reading of samples was performed in triplicate according to the same methodology, namely, the reading of 1 mL of sample added to 1 mL of TISAB II solution. All solutions, including samples, were previously shaken and kept at room temperature (25 ° C) at the time of reading.

The reading of controls was performed at the Laboratory of Oral Biology, University of São Paulo (USP), Bauru, Brazil.

Data Analysis

Fluoride concentration was obtained by the average of three readings of samples analyzed for each collection point. According to the measured fluorine concentration (ppm), the samples were classified according to two criteria:

Criterion I - current legislation [13] establishes that the limits for fluoride ion concentration are standardized according to the average daily maximum temperatures. For locations with average daily maximum air temperatures from 26.7ºC to 32.5ºC, the minimum and maximum recommended limits for fluoride ion concentration in mg / L should be 0.60 and 0.80, respectively.

Upon request to the State Center for Meteorology and Water Resources (NEMRH) - State University of Maranhão, it was shown that the annual average daily maximum temperatures in São Luís, MA for the years 2006, 2007 and 2008 were 33.3ºC; 34.1ºC and 32.0ºC respectively. Data provided by NEMRH allowed establishing the average for the first half of 2009, which, until June

30, showed value of 30.0°C. Thus, suitable samples were those in which the fluoride concentration ranged from 0.60 to 0.80 ppm F; inadequate low when concentrations were below 0.60 ppm F and inadequate high when concentrations were above 0.80 ppm F.

Criterion II - in line with methodology applied in the Technical Document for the Classification of Public Water Supply According to the Fluoride Content published by the Ministry of Health in Oral Health Surveillance (CECOL) [14].

Descriptive statistics was conducted to calculate mean, median and standard deviation according to the sampling points listed in chronological order of months and years.

Results

Overall, 480 water samples were collected during the period from February 2008 to January 2009; twelve samples at each of the 40 points were included in the study. The analysis of samples was performed in triplicate, for a total of 1,440 readings.

Table 1 shows the mean (and standard deviation) of fluoride concentration during the twelve months analyzed in each collection point. Large variation between minimum and maximum concentrations in many locations was observed. The average value was within recommended limits, according to criterion I in 23 collection points. For criterion II, 30 points showed mean values within recommended limits. However, considering all samples, the mean value for São Luís-MA was 0.58 ppm F and median value was 0.61 ppm F, with minimum value was 0.02 ppm F and maximum value of 1.3 ppm F.

Table 1. Median and mean fluoride concentration (ppm F) of the public water supply from February 2008 to January 2009 in São Luís, Maranhão, Brazil.

Collection Point	Median (min-max)	Mean (standard deviation)
Parq. dos Nobres	0.66 (0.37-1.05)	0.68 ± 0.19
Alemanha	0.72 (0.59-0.94)	0.74 ± 0.11
Outeiro da Cruz	0.49 (0.32-0.76)	0.52 ± 0.13
Ivar Saldanha	0.64 (0.45-0.99)	0.68 ± 0.17
Centro (ponto1)	0.54 (0.33-0.72)	0.56 ± 0.11
Centro (ponto 2)	0.52 (0.36-0.61)	0.48 ± 0.08
Monte Castelo	0.47 (0.39-0.66)	0.50 ± 0.09
Liberdade	0.42 (0.26-0.80)	0.49 ± 0.18
Bairro de Fátima	0.63 (0.42-1.33)	0.68 ± 0.25
Diamante	0.54 (0.35-1.02)	0.57 ± 0.17
Lira	0.50 (0.37-0.69)	0.50 ± 0.11
Coroado	0.62 (0.37-0.96)	0.64 ± 0.17
Sacavém	0.71 (0.38-0.98)	0.71 ± 0.16
Filipinho	0.68 (0.51-1.09)	0.75 ± 0.19
São Francisco	0.62 (0.59-1.00)	0.68 ± 0.12
Renascença I	0.69 (0.57-0.79)	0.68 ± 0.08
Ponta do Farol	0.57 (0.34-1.16)	0.63 ± 0.25
Calhau	0.06 (0.03-0.72)	0.12 ± 0.19
Angelim	0.78 (0.46-0.92)	0.73 ± 0.14
Cohama	0.79 (0.59-1.03)	0.80 ± 0.14
Cohafuma	0.83 (0.66-1.09)	0.82 ± 0.12

Vinhais	0.80 (0.50-1.06)	0.77 ± 0.14
Bequimão	0.79 (0.58-1.02)	0.77 ± 0.13
Ipase	0.75 (0.46-1.13)	0.73 ± 0.19
Olho D'Água	0.70 (0.49-1.04)	0.71 ± 0.14
Habitacional Turu	0.04 (0.02-0.47)	0.09 ± 0.12
Turu	0.09 (0.06-0.14)	0.09 ± 0.02
Cohab II	0.47 (0.16-0.72)	0.47 ± 0.19
III Conjunto Cohab	0.66 (0.16-0.87)	0.61 ± 0.18
Cohatrac I	0.59 (0.15-0.96)	0.57 ± 0.21
Cohatrac IV	0.58 (0.15-1.05)	0.59 ± 0.24
Cohatrac-Itaguará	0.69 (0.52-1.02)	0.72 ± 0.16
Cohapan	0.15 (0.08-0.26)	0.17 ± 0.05
São Cristóvão	0.50 (0.23-0.95)	0.56 ± 0.21
Cidade Operária	0.24 (0.08-0.55)	0.26 ± 0.15
Santo Antônio	0.67 (0.41-0.96)	0.68 ± 0.14
Anjo da Guarda	0.56 (0.34-0.83)	0.58 ± 0.14
Vila Nova	0.65 (0.31-0.84)	0.64 ± 0.14
Sá Viana	0.62 (0.43-0.89)	0.63 ± 0.13
Vila Bacanga	0.67 (0.48-0.77)	0.65 ± 0.09
Total	**0.61 (0.02-1.33)**	**0.58 ± 0.24**

The analysis of samples according to the various operating units of CAEMA revealed that of the total sample, 35% (n = 168) belonged to OMC; 32.5% (n = 156) to OMV; 12.5% (n = 60) to OMH; 10% (n = 48) to OMP and 10% (n = 48) to OMG.

The percentage analysis of samples that were below the recommended fluoridation levels, at optimal level and above the recommended level, according to the first criterion used in each of the operational business units established by CAEMA is in Table 2. According to the fluoride levels recommended by criterion I, most samples were considered inadequate (62.9% or n = 302), whereas 37.1% (n = 178) were considered adequate.

Table 2. Distribution of water samples in the different operating units of CAEMA according to the fluoride concentration established by criterion I in São Luís, Maranhão, Brazil. February 2008 to January 2009.

	Criterion I Limits recommended for fluoride ion concentration							
Operational Unit	< 0.6 ppm F		0,6 to 0.8 ppm F		> 0.8 ppm F		Total	
	n	%	n	%	n	%	n	%
OMC	86	51.2	57	33.9	25	14.9	168	100
OMV	59	37.8	60	38.5	37	23.7	156	100
OMH	27	45.0	26	43.3	07	11.7	60	100
OMP	34	70.8	10	20.8	04	8.3	48	100
OMG	19	39.6	25	52.1	04	8.3	48	100
Total	**225**	**46.9**	**178**	**37.1**	**77**	**16.0**	**480**	**100**

Table 3 shows the percentage of samples that were below recommended fluoridation levels, in optimum level and above recommended levels by criterion II in each of the operational business units established by CAEMA. It was observed that, when considering the classification of fluoride levels, according to criterion II, the percentage of inadequate samples is reduced. According to this

criterion, 48.3% (n = 232) of samples were considered inadequate, while more than half, 51.7% (n = 248) were considered adequate.

Table 3. Distribution of water samples in the different operating units of CAEMA according to the fluoride concentration established by criterion II in São Luís, Maranhão, Brazil. February 2008 to January 2009.

	Criterion II							
	Limits recommended for fluoride ion concentration							
Operational Unit	< 0.55 ppm F		0.55 to 0.84 ppmF		> 0.84 ppm F		Total	
	n	%	n	%	n	%	n	%
OMC	62	36.9	84	50.0	22	13.1	168	100
OMV	46	29.5	83	53.2	27	17.3	156	100
OMH	23	38.3	32	53.3	05	8.3	60	100
OMP	32	66.7	14	29.2	02	4.2	48	100
OMG	12	25.0	35	72.9	01	2.1	48	100
Total	**175**	**36.4**	**248**	**51.7**	**57**	**11.9**	**480**	**100**

The distribution of water samples according to the month of collection and to the fluoride concentrations established by criteria I and II are shown in Figure 1.

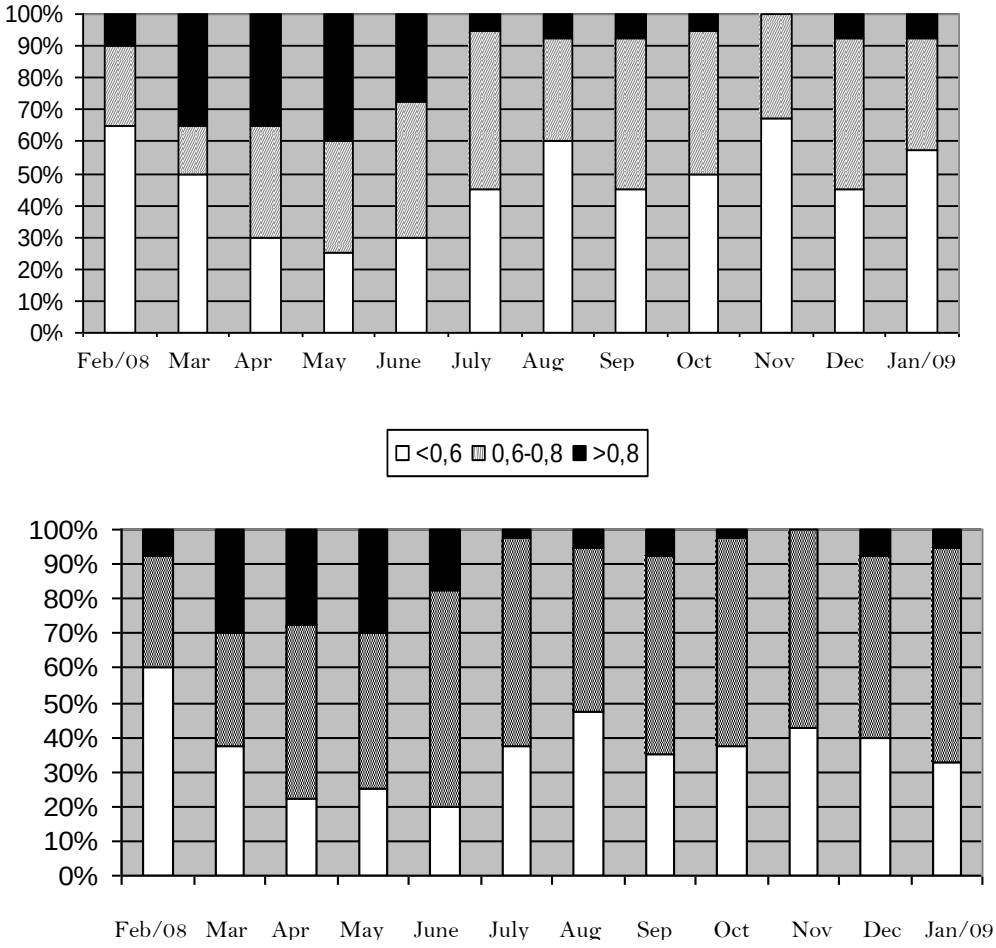

Figure 1. Percentage of water samples according to fluoride concentration established by criteria I and II throughout the twelve month of evaluation. São Luís, Maranhão, Brazil. February 2008 to January 2009.

Longitudinal analysis according to the month of evaluation is in figure 2.

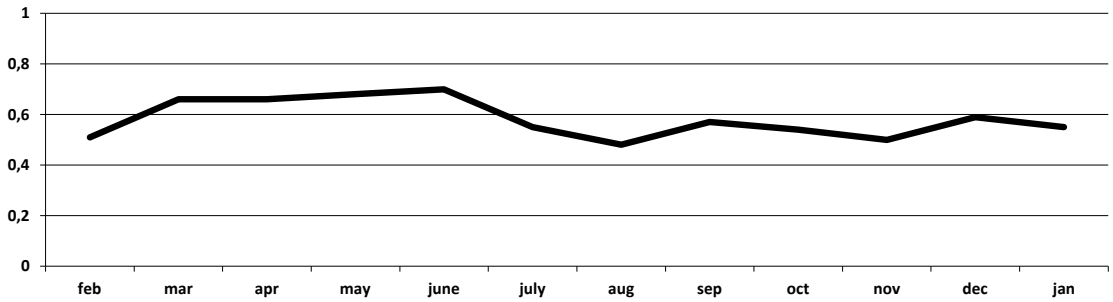

Figure 2. Mean (ppm F) fluoride levels in public water supplies according to the month of evaluation. São Luís, Maranhão, Brazil. February 2008 to January 2009. Gray area (0.6 to 0.8) is the optimal range of fluoride levels.

Discussion

The public water supply of São Luís-MA is complex due to the existence of a set of systems including treatment plants and battery of interconnected and isolated wells, and not all systems receive fluoride dosages by the water supply company. Thus, it has been speculated that there is some difficulty in fluoridate waters and also to perform the monitoring of fluorine in all these systems. A limitation found in this study was to distinguish locations that do or do not receive fluoride in the water.

By analyzing the fluoride levels in the public water supply artificially fluoridated in São Luís, MA, two important aspects should be highlighted: (a) variations in fluoride concentrations observed in some locations over the twelve months of study, emphasizing the need for research related to factors that interfere with the maintenance of an optimal and constant concentration; (b) variations in the fluoride levels in the water, with considerable percentage of inadequate samples.

In relation to variations in fluoride concentrations, it is emphasized that these only become problems when variations are significant. Small oscillations are acceptable within a range considered adequate. Water supply companies must control these oscillations. Figure 1 shows that the population is somehow exposed to fluoride. Low fluoride concentrations can also benefit the population, but maximum benefit will not be achieved under these conditions.

Regarding fluoride levels over the months studied, Figure 2 shows that samples with fluoride levels above 0.80 ppm F were more concentrated in the months of March, April, May and June, according to both criteria for data analysis. This phenomenon is probably related to rainfall regime in the region and to the supply of water for the population. In periods of rain, water becomes turbid and treatment is slower. In addition, the consumption is reduced and the water tanks have lower flow.

Data from the 2000 National Basic Sanitation Survey [15] indicated that the neighborhoods supplied with fluoridated water in São Luís-MA exhibit fluoride concentrations in water from 0.60 to 0.80 ppm. When compared to results of this study, controversies were found because according to criterion I used in the data analysis; 46.9% of the samples showed fluoride levels below 0.6 ppm F and 16% above 0.8 ppm F. Moreover, according to CAEMA reports, the completion of the first fluoridation stage in the city occurred in 1992, while the second stage only started in February 2006, and thus, there was no fluoridation in 2000.

Considering the totality, the mean fluoride concentrations established for the municipality of São Luís, MA during the study period was 0.58 ppm F. It was observed that this average is below the minimum recommended fluoridation levels according to criterion I. However, considering criterion II, this value is within adequate limits. A study conducted in Chapecó-SC also found mean levels (0.89 ppm F) within the three parameters adopted in its methodology [16]. In contrast, the mean annual fluoride content in treated water from the WTP of Niterói-RJ was 0.45 ppm F, well below the value considered appropriate for that municipality [17].

Regarding the median fluoride concentration determined in this study; 0.61ppm F, it was observed that this value is within adequate levels according to both criteria adopted, with a variation from 0.02 ppm F to 1.33 ppm F among samples. Considerable variations in fluoride levels were also identified in other studies. The minimum and maximum fluoride values found in Pelotas were 0.05 ppm F and 1.72 ppm F [18]. In Chapecó, SC, wide variation was reported along the ten years of study, with minimum value of 0.08 ppm F and maximum value of 2.05 ppm F [16]. The variations observed in these results led to reduction of fluoridation benefits.

In the present study, considerable percentage of inadequate samples was observed (62.9% and 48.3%) according to classification criteria adopted. The fluoride levels in the water of São Luís and São José de Ribamar, Maranhão, were evaluated in 2006 for a period of one month [19]. The authors reported that 46.43% of the samples were within normal limits, while 53.57% reported inadequate fluoride levels. Regarding other studies on external control performed in different regions of the country, most showed unfavorable results in relation to the maintenance of optimal fluoride concentration in water by supply companies.

The percentage of samples or sampling points showing inadequate fluoride concentration revealed in surveys performing external control or that just reported fluoride levels in water depending on references adopted or criteria and according to the studied area, were: 96% of samples of Niterói-RJ [17]; approximately 50% of sampling points of Pelotas [18]; 46.7% of sampling points of Teresina-PI [20]; 92.2% of samples of Teresina; 95.3% of Floriano and 99.5% of Parnaíba, both in the state of Piauí [21]; 45.8% of samples of Lages-SC [22]; 36.2% of samples tested of eight cities in the state of São Paulo, one city in the state of Minas Gerais and another in the state of Ceará [23]; 54%, 68% and 57% of samples of Chapecó-SC, over a period of ten years [16] and 36.5% of samples of Campo Grande [24].

These studies emphasized the need for improved operational control, as well as the regularity of a health surveillance program based on permanent of external control measurements, both due to irregularities in fluoride concentrations and to variations of fluoride levels of public water supplies.

However, fluoride concentrations were more adequate in other surveys. In São Paulo-SP, in the period from 1990 to 1999, percentage of acceptable samples greater than or equal to 79.8% [11] were found. Comparing the results of this work to the study conducted in Bauru-SP [19], there is a significant difference in the percentage of samples considered adequate between the two locations: 37.1% and 51.7% in São Luís-MA and 85 % in the city in the state of São Paulo.

External control studies that propose longer collection time result in larger samples and more accurate results. The methodology used in this study recommended the collection frequency of 12 months aimed at external control, followed by surveillance fluoridation protocol for collection, preservation and analysis of samples. Moreover, according to the proposed methodological standards, part of samples was sent to other reference laboratory [25].

Surveillance systems on fluoride levels in the public water supply network are crucial to ensuring that the benefits of fluoridation can be effectively achieved. These systems cannot be characterized by practices which occur only once, or as those covering only specific times. These measures must be continuous and permanent for the maintenance of adequate fluoride concentrations (25). In this context, the external control of water fluoridation is a surveillance system based on systematic observations and continuity and permanence of fluoride content analyses performed by external companies and not by regular water treatment companies [11].

The importance of this research in monitoring the fluoridation of the public water supply in the city of São Luís-MA is focused on contributing to possible improvements related to fluoridation so that the desired benefits by this public health measure can be achieved. In the study concerning the external control of the fluoride levels in water, the following critical areas were considered: Turu, Habitacional Turu, Calhau, Cohapan and Cidade Operária. In the context of the difficulty of distinguishing fluoridated areas or not, an identification bias may have occurred in these locations. However, it is possible that the waters of these points come from wells, although residents have informed that the water comes from the public water supply system.

Conclusion

There is need for special attention on areas that remained with inadequate fluoride levels throughout the months of the study. Under these circumstances, monitoring should be conducted before the detection of any irregularity. The company responsible for fluoridation should systematically verify the fluoride concentrations in the water supplied to the population, providing appropriate levels and controlling variations. Acknowledgement is made to companies that use the fluoridation method and are interested in the best operationalization of this measure and, finally, understand the importance of fluoridation and its contribution to the oral health of the population.

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