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External control of fluoridation in public water supply systems in the state of Goiás, Brazil

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Abstract *The addition of fluoride to the public water supply is a method used for reducing tooth decay. In this sense, the control of fluoridation is important for maintaining its efficiency and, at the same time, for avoiding the risk of fluorosis as a result of the consumption of water with excess of fluoride. The objective of this study was to evaluate the adequacy of fluoride levels in the water distributed to populations of the state of Goiás, Brazil. Towards this aim, 5,039 water samples collected between 2011 and 2013 in 225 municipalities of the state of Goiás were analyzed for fluoride level. The results were assessed with regard to season, type of water source and geographic location. Fluoride levels were found to vary between complete absence and 2.5 mg F/L, with 28.2% of the samples being between 0.6 and 0.8 mg F/L, and 39.1% between 0.55 and 0.84 mg F/L. The rainy season produced a greater number of atypical results and higher values than the dry period. The systems supplied by groundwater sources were shown to have a limited control of fluoride concentration compared to systems supplied by surface water sources. Lower concentrations of fluoride were found in samples collected in the North and East Mesoregions of Goiás, with less than 7.5% being between 0.6 and 0.8 mg F/L, which systems are mainly supplied by groundwater sources with fluoride addition.*

Key words *Fluorosis, Fluoride, Caries, Water treatment*

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Introduction

During the last century, fluoridation has been a public health measure used in the control of dental caries in countries throughout the world and is recognized as an important factor in their decline in the prevalence. The first research on the use of fluoride focused on water because it is a resource that is easily accessible to the population; however, with technical-scientific development and improved conditions of hygiene, this practice has been reduced in many countries. However, the USA and Brazil have continued the practice of adding fluoride to the water intended for public supply[1], which is recommended because of its safety, ease of administration, low cost and population coverage, making it one of the most effective means of keeping the presence of fluoride in the oral cavity, which is fundamental to the control of dental caries[1,2]. However, entities such as WHO warn of the risk that concentrations greater than 1.5 mg F/L[3,4] can cause the appearance of fluorosis in human health.

In Brazil, fluoride has also been added to more than 90% of the dentifrices since 1989[5], increasing the risk of fluorosis due the association of daily exposure to fluoride by these two sources, as verified by Lima and Cury[6]. Despite the risks, water fluoridation has been justified by the rates of reduction of the caries index reported in more than 160 works distributed over more than 10 countries[7]. Despite these advances, the Central-West Region of Brazil still has frequencies of dental caries in permanent dentition reaching 73% of children of 12 years of age, and 90% of adolescents of 15 to 19 years old (Carious, Missing and Filled Permanent Teeth - COP-D ≥ 1) [8]. In studies conducted by Freire et al.[9], a COP-D ≥ 1 was found in 64% of 1947 12-year old children analyzed in the city of Goiâna (GO). According to Clarkson and McLoughlin[10], in order to maximize benefits and minimize risks, there must be mechanisms that allow the addition of fluoride in adequate concentrations so that it exerts the greatest possible impact on the prevention and control of caries, without increasing the prevalence of dental fluorosis since, as observed by Cangussu et al.[11], milder forms of dental fluorosis occur at the places where fluoridation systems had been implemented and more severe forms occur were the source water has high fluoride content. It should be taken into consideration that, in the case of Brazil, some municipalities do not have the means to add fluoride or the surveillance mechanisms to control its concentration in public water supply systems. In this sense, external control appears to be an important instrument for managing the level of fluoride in water supplies, and should be applied in all the supply systems.

Heterocontrole is a term used in Brazilian public health and is commonly applied to studies related to water fluoridation[12-18]. According to Narvai[19], the term was used for the first time by this author in a course of "Preventive Dentistry" that was the object of the VII Congresso Universitário Brasileiro de Odontologia (CUBO; 7th Brazilian University Congress of Odontology)[20]. *Heterocontrole*, or external control in English, is understood to be "the principle that any good or service that implies risk or represents a protection factor for public health requires, in addition to control by the producer, control by State institutions over the process of its production, distribution and consumption". Thus, the objective of the present study was to evaluate the adequacy of fluoride levels in the water distributed to cities of the state of Goiás, managed by Companhia Estadual de Saneamento (Saneago; State Sanitation Company), and to assess variation in fluoride levels among types of water sources, seasons and mesoregions.

Materials and methods

According to data from the Instituto Brasileiro de Geografia e Estatística (Brazilian Institute of Geography and Statistics)[21], the state of Goiás possesses 6,004,045 inhabitants in 246 municipalities, of which 225 have their sanitation services provided by Saneago, and are the objects of the present study (Figure 1b). The remainder of the municipalities have direct public administration[22] of sanitation services and are not considered in this study.

Of the 225 municipalities studied, 5,039 samples of treated water were collected and analyzed over a period of 24 months between 2011 and 2013. In order to establish the number of samples to be collected in each municipality, they were segregated into 3 groups (Figure 1b) based on their population size as published in IBGE, and also used by Scalize et al.[23] for evaluating turbidity in the water supply. Group I is comprised of municipalities with populations greater than 250,000 inhabitants, and where 20 to 30 samples were collected every three months. Together, the three municipalities of Group I have 2,092,659 inhabitants, which represents 34.9%

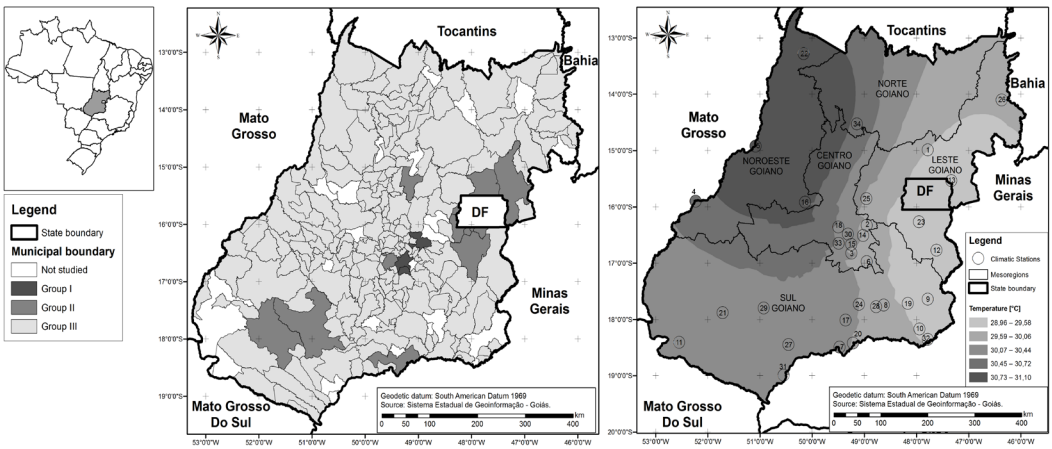


Figure 1. Location of the state of Goiás in Brazil (a); the distribution of the municipalities included in the study according to population group (Group I, II and II; see methods) and the municipalities that were not included (b); and the five geographic mesoregions of the state with the ranges of the average maximum temperatures, and locations of the 34 climatic stations referenced in the text (c).

of the population of the state of Goiás. Group II is comprised of municipalities with populations between 50,000 and 250,000 inhabitants, and where 15 to 20 samples were collected every three months. Together, the thirteen municipalities in this group have 1,384,299 inhabitants, which represents 23.1% of the total population of the state. The third group, Group III, is comprised of municipalities with populations less than 50,000 inhabitants, and where 3 to 8 samples were collected every six months. Although this group contains 208 municipalities, its total population is less than the combined total of the other two groups. Considering that there was practically no decrease in fluoride concentration throughout the distribution of water[24], the number of samples was determined in the same way as Moimaz et al.[25], which collected at least 3 samples in each system, composed of one at the beginning of the water distribution network, one in the intermediate area of the network and a third at the end, in order to be able to assess the entire system at the time the treated water is made available for consumption. Other points of collection were added according to the size of the municipality, with sampling points being added at places where there is a great flow of people, such as hospitals, health posts, schools and day care centers[26].

The collection and preservation of samples were performed according to the Guia Nacional de Coleta e Preservação de Amostras (National Guide for the Collection and Preservation of Samples)[27]. Samples were then submitted to a single analysis (simple analysis) of fluoride using the Spadns method, as recommended by Standard Methods[28], using a Hach DR 890 colorimeter.

The data were analyzed considering the type water source (surface water or groundwater) and mesoregion as determined by the IBGE classification regulated by Presidential Resolution of the Republic (PR) No. 11, of 05 June, 1990, which included ranges of the average maximum temperatures and the 34 climatic stations used in the research (Figure 1c). The temperature ranges were obtained from mean monthly maximum temperature data from the climatic stations provided by the Sistema Estadual de Geoinformação – SIEG (State System of Geoinformation)[29]. For the calculation of isotherms, the annual average of the maximum temperatures was determined and interpolated by Kriging Simple interpolation. The results serve to illustrate differences in maximum temperatures throughout the state of Goiás, but this should not be considered a valid geostatistical model due to the few data points included and their spatial distribution. The management, handling, analysis and representation of cartographic data were performed using ArcGis 10.2.

Data were evaluated considering all the results obtained and using the values established in Ordinance No. 635/GM/MS of 30 January,

1976[30], which establish an optimum content of 0.70 mg F/L (±0.10 mg F/L) as a function of the average temperature of the region, complemented with the ranges proposed by Ramires[31] and used by Panizzi and Peres[32] and Ramires at al.[13], which admit variation in the optimum fluoride concentration of 0.15 mg F/L for the lower limit and 0.14 mg F/L for the upper limit, making the maximum permissible content 1.50 mg F/L established by Ordinance MS 2914[26], which is also the value recommended by WHO[3]. Thus, the ranges of fluoride content used were: < 0.54 mg F/L = Unacceptable; 0.55 mg F/L = Acceptable Minimum; 0.55 to 0.59 = Subfluoride; 0.60 to 0.80 = Optimum; 0.81 a 0.84 = Superfluoride; 0.84 = Acceptable Maximum; 0.85 to 1.5 = Inadequate; > 1.50 = Unacceptable.

Aiming to assess seasonal interference in the maintenance of fluoride content in the water distributed to the public, the results were analyzed considering two seasonal periods: a rainy period (January to March and October to December) and a drought period (April to September). Thus, of the 5,039 samples, 2,226 were collected during the rainy period and 2,813 during the drought period.

The results of the fluoride analyses were treated statistically with XLSTAT, by obtaining the following statistics: mean, median, standard deviation and coefficient of variation, for which boxplot type graphs were constructed with a confidence interval of 95%, enabling the verification of discrepant values for each parameter analyzed .

Results and discussions

General analysis

In general, fluoride content was found to vary greatly among the analyzed samples, with a high incidence of fluoride levels below the minimum established for effectiveness in caries prevention, with only 28.2% of the analyzed samples (Figure 2a) having fluoride content within the range of 0.60 to 0.80 mg F/L[30].

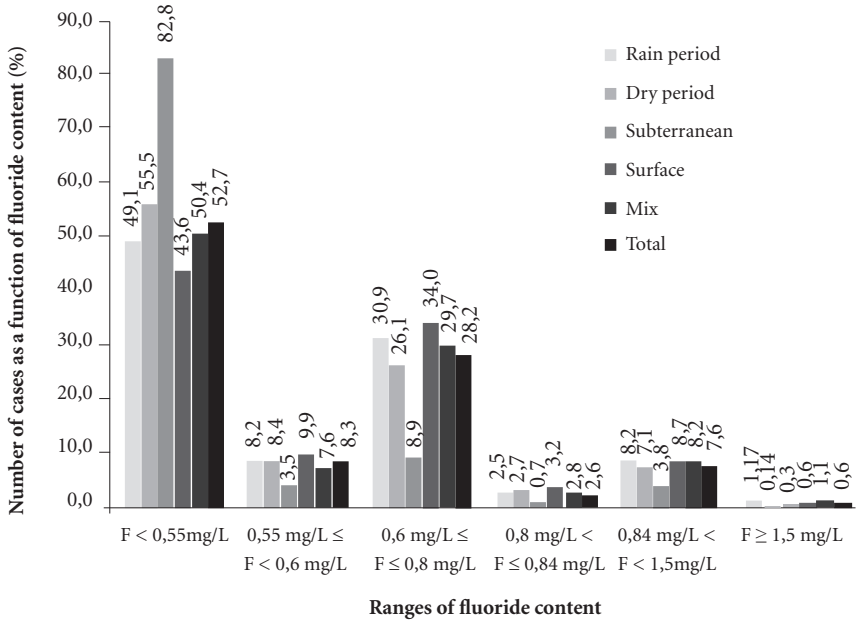
The overall analysis of the fluoride concentration of the 5,039 samples found it to vary from being absent to concentrations of 2.50 mg F/L, with values above 1.22 mg F/L are considered atypical samples as a function of the amount and content of fluoride found in the evaluated samples. The overall mean fluoride concentration was 0.50 mg F/L with a median of 0.53 mg F/L (Figure 2b). Of all the samples, 3,617 (71.8%), had fluoride contents lower or higher than the limits of Ordinance No. 635[30], with 3,073 samples (61.0%) being below 0.60 mg F/L and 544 samples (10.8%) being above 0.80 mg F/L. The percentage of samples below 0.55 mg F/L and above 0.84 mg F/L, were 52.7% and 8.2% respectively. A further 0.60% of the samples were found to have levels above the maximum limit established by the Ordinance No. 2914[26], which is 1.50 mg F/L, reaching a maximum of 2.5 mg F/L. According to Frazão et al.[5], the limit of 1.50 mg F/L is adopted by most countries in South America and by the WHO. Peixoto et al.[16], considered values above 1.45 as being at a very high risk for the developmental of dental fluorosis. These values may be lower depending on the climate of a particular region, because increased water consumption in warmer regions means increased fluoride exposure. This was the conclusion made by Craig et al.[33] in a study carried out in Ghana (average temperature of 29°C), where the limit was 0,60 mg F/L for children 6 to 8 years old, less than 0.60 mg F/L for children less than 2 years old and 1.0 mg F/L for older children and adults.

The average fluoride content of 0.50 mg F/L (Figure 2b) in the present study is close to the mean of 0.55 mg F/L found by Peixoto et al.[16], who evaluated fluoride concentrations in the water supply of the municipality of Juguaribara, Ceará, and the mean of 0.57 mg F/L found in research performed with 5,157 water samples from the municipality of Araçatuba, São Paulo, by Daré et al.[34]. Ramires et al.[13], analyzed 737 water samples from throughout the population of the city of Bauru, São Paulo, and found monthly mean fluoride concentrations to vary between 0.37 and 1.00 mg F/L, with about 85% of the sample means being between 0.55 and 0.84 mg F/L, and an average value of 0.75 mg F/L. This variation demonstrates the difficulty in maintaining fluoride content within standards, as was also reported by Leivas et al.[35] in the city of Canoas, Rio Grande do Sul, and indicates the need for greater operational control.

Analysis of the type of water source and seasonality

According to the results of the analyses of the samples divided by season (rainy and dry periods), higher fluoride content was found to predominate in the samples collected in the rainy season, with the highest values being > 0.60 mg F/L (Figure 2a), resulting in an average of 0.52

(a)



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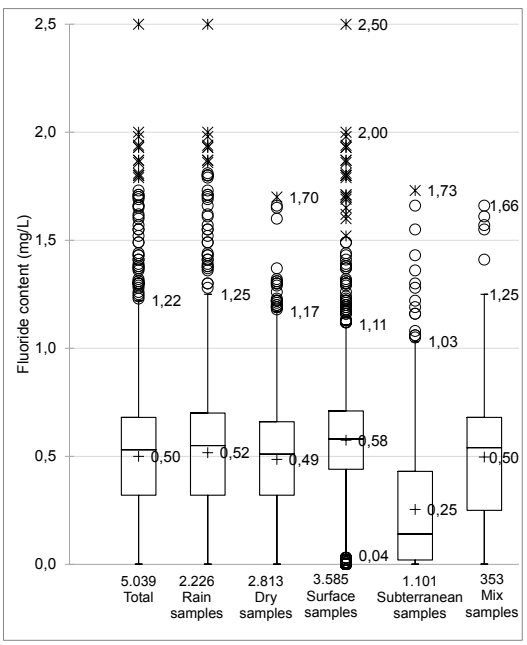

Figure 2. Results of the analysis of samples according to fluoride concentration, seasonality and water source.

mg F/L, with atypical samples from 1.25 mg F/L to a maximum of 2.5 mg F/L (Figure 2b). In the dry period, the results were lower, with an average of 0.49 mg F/L and atypical samples from 1.17 mg F/L to a maximum of 1.7 mg F/L (Figure 2b). In the rainy period, 1.17% of the samples were found to have fluoride content higher than the limit of 1.5 mg F/L, established by Ordinance No. 2914[26]. This value is well above the 0.14% detected during the dry season (Figure 2a), demon-

strating the greater difficulty to control the fluoride level in the rainy season.

As for the analysis of the type of water source, 86.3% of the analyzed samples from locations supplied by groundwater catchments with the addition of fluoride possessed concentrations below 0.60 mg F/L (Figure 2a). Such low levels are probably due to the difficulty in maintaining fluoridation without having a treatment operator on site or the implementation of some system that allows it to be controlled. This problem does not occur in the Water Treatment Station (WTS), which precede the systems of water supply from surface water sources because they constantly have operators in the stations. However, Lima et al.[12], verified that constancy in monthly fluoride concentration was almost impossible in most of the WTS analyzed. The lack of operator training, variation in flow throughout the distribution network and problems with the hydraulic equipment are factors that contribute to these oscillations[36]. Indeed, 53.5% of the samples collected at sites receiving water supply from surface water sources had a fluoride content below 0.60 mg F/L, and 34% were between 0.6 and 0.8 mg F/L, with a mean value of 0.58 mg F/L (Figure 2b), which is slightly below that found by Moimaz et al.[25], which were between 0.61 and 0.66 mg F/L for surface water sources. Yet, in systems where there is a simultaneous supply of ETA and groundwater these waters mix, either inside the reservoir or in the distribution network, which allows greater control of the fluoride content, and keeps it close to that achieved in systems supplied only by water from WTS.

Regardless of the source of supply, the dry period has a higher incidence of samples with fluoride contents below 0.60 mg F/L, with a displacement of the values above 0.80 mg F/L, for the range between 0.60 and 0.80 mg F/L (Figure 3a). It can be seen in Figure 3b that in the dry season there was, in addition to lower values, a lower number of atypical results than in the rainy season, with mean values approaching the median in both situations. Lima et al.[12] found that variation in fluoride concentration usually occurs in the treatment units and, therefore, the effect of temperature and the type of material used in the dosages tend to be more significant than other physical phenomena, such as absorption or adsorption to the walls of the pipes of the distribution system.

Analysis by mesoregion considering the type of water source and seasonality

The analysis of fluoride content among the 5 mesoregions showed that the lowest concentrations for treated surface water sources are in the North and East mesoregions of Goiás with, respectively, 60% and 59.5%, of the samples having concentrations below 0.55 mg F/L (Figure 4a). Likewise, these same mesoregions also had higher incidences of samples below 0.55 mg F/L for treated water of groundwater sources, with 86.7% and 95.1%, respectively (Figure 5a). The mean concentrations found for these sources ranged from 0.48 to 0.62 mg F/L for treated water for surface sources (Figure 4b) and from 0.15 to 0.41 mg F/L treated water from groundwater sources (Figure 5b). It should be noted that the monthly mean of the means of the maximum daily temperatures registered in the climatic station of the North mesoregion of Goiás were between 31.3°C (January) and 35.0°C (September), which indicates a higher volume of water consumed daily, necessitating a lower fluoride content in the water. However, the content is still low compared to the values recommended by the Ordinance No. 635/GM/MS[30].

Analysis of the size of the supplied population

When analyzing the results according to population size, it was found that municipalities of Group I had greater quantities of samples with values between 0.60 and 0.80 mg/L (36.38%). In this group, 49.21% of the samples had values between 0.55 and 0.84 mg/L, while for the municipalities of Groups II and III the percentages were 27.43% and 42.39%, respectively. This difference in values reflects the greater attention of the managing body in larger municipalities. The municipalities of Group II had a low number of samples within this range, with 61.97% below 0.55 mg/L, because some municipalities of this group are supplied with non-fluoridated water from a groundwater source.

Final considerations

Most studies that involved monitoring dosages described great variation in fluoride concentrations. This fact, according to Ramires and Buzulaf[1], makes it difficult to evaluate the protection provided for caries and the occurrence of fluo-

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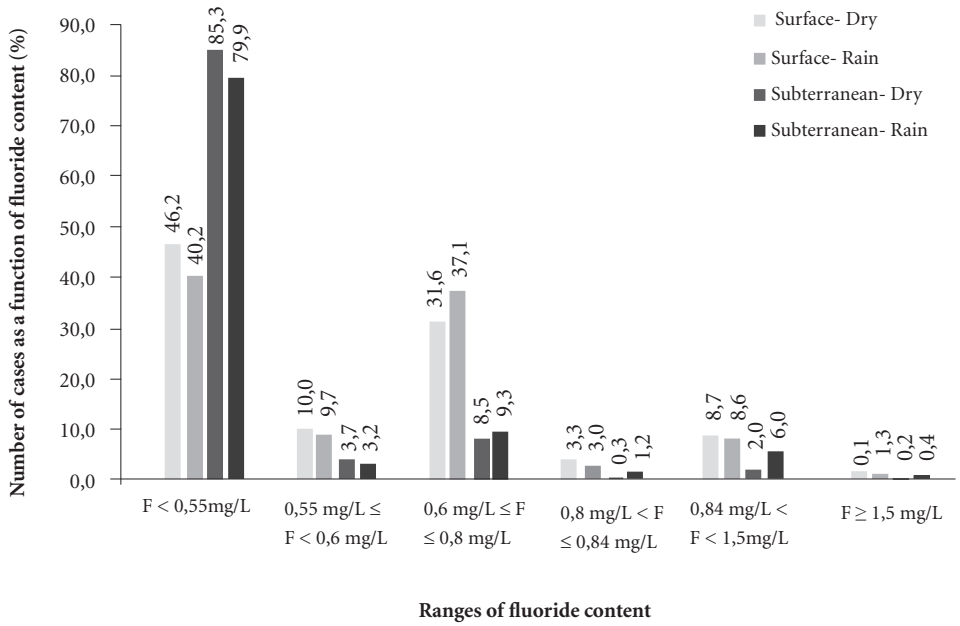

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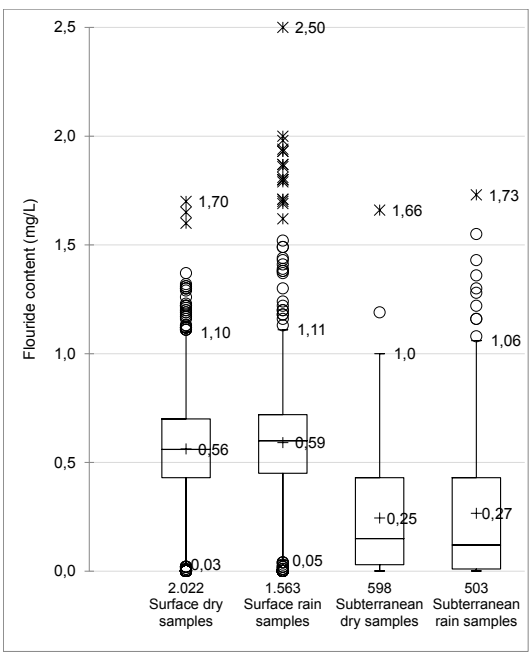

Figure 3. Results of the analysis of samples according to fluoride concentration, type of water source used for treatment and seasonality.

rosis in a population served by a municipality. In addition, the distribution of water with a less than optimal fluoride concentration implies a waste of public resources and inefficient efforts of prevention. These shortcomings demonstrate the need for effective external control, corroborating Panizzi and Peres[32], who report that after a political-legal intervention carried out by the

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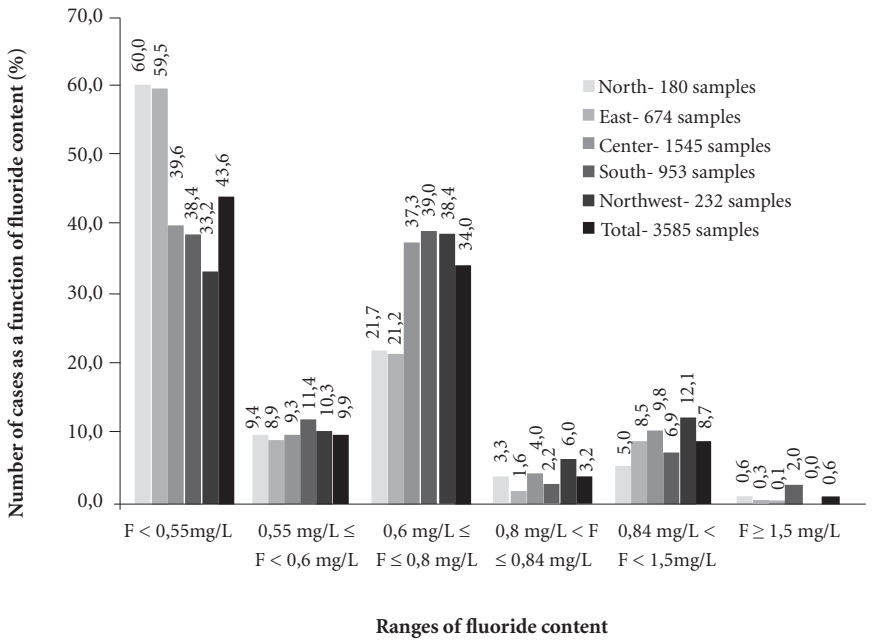

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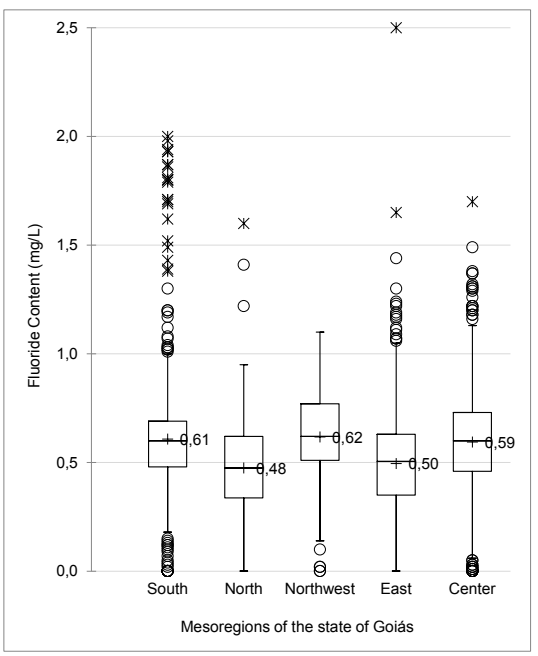
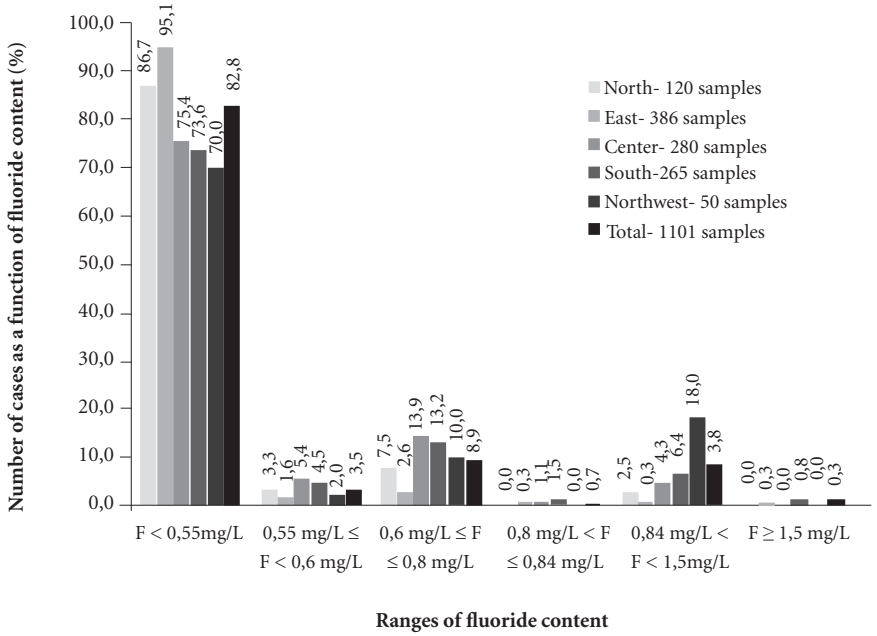


Figure 4. Results of the analysis of samples collected in water supply networks of systems supplied by surface sources, according to mesoregions and ranges of fluoride concentration.

sanitary surveillance system in the municipality of Chapecó, Santa Catarina, changes occurred in the operating and maintenance system that resulted in significant improvements, with a change of 26% to 49% of the samples having fluoride content within the range of 0.7 a 0.9 mg F/L, established by Ordinance No. 635/GM/MS[30] for that region, which admits variation of 0.10

(a)



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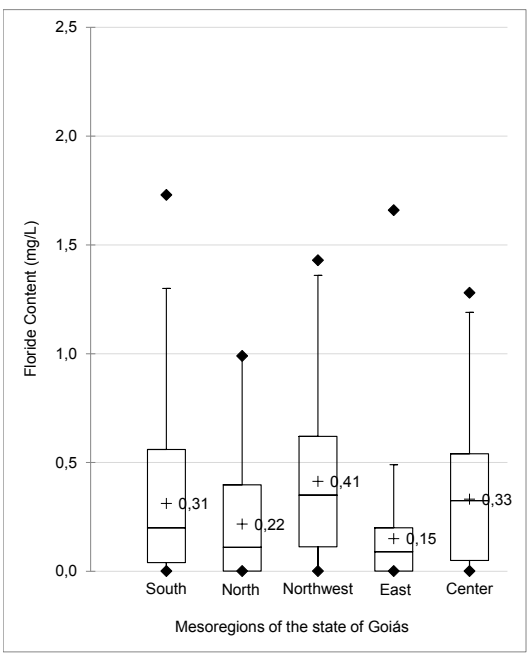

Figure 5. Results of the analysis of samples collected in water supply networks of systems supplied by groundwater sources, according to mesoregions and ranges of fluoride concentration.

mg F/L as a function of the optimum content according to the local temperature range. In the present study, the increase in efficiency of fluoridation ranged from 40% to 63% and from 36% to 61%, for the ranges of 0.7 to 1.0 mg F/L and 0.65 mg F/L to 0.94 mg F/L, respectively.

External control in the state of Goiás could be carried out by the Agência Goiana de Regulação

(AGR; Goiás Agency of Regulation), which is responsible for regulating the services provided by the Companhia Estadual de Saneamento (Saneago; State Sanitation Company). In this way, control would be in line with the recommendations of Panizzi and Peres[32], who suggest the operation by public or private entities or institutions, or both, other than water supply companies.

However, it should also be noted that Ordinance No. 635/GM/MS[30] was supported by the equation proposed by Galagan and Vermillion[37], who considered the conditions of water consumption by the Brazilian population to be the same as that of the population of the USA, being based only on the average of the daily maximum temperatures. In this context, some studies have proposed adjustments to the equation to take into account local situations and conditions. This circumstance was validated by Ramadan and Hilmi[38], who inserted a coefficient of adjustment of 0.56, considering that the only liquid source of fluoride for the population was water, and discounted the portion (44%) of liquid obtained from milk included by Galagan and Vermillion[37]. This resulted in an ideal fluoride content for the population of Sudan of between 0.32 and 0.35 mg F/L, which differed widely from the 0.61 mg F/L initially calculated only considering the mean maximum local temperature of 35.58°C. The same was done in Chile by Villa et al.[39], who concluded that the ideal range was 0.50 to 0.60 mg F/L for a local average of maximum temperatures ranging from 18 to 22°C.

Conclusions

The present work allowed us to conclude that:
- there are difficulties in maintaining fluoride concentrations in the municipalities studied, which reinforces the need for external control with public entities helping in the regulation of water supply systems for effective control of water fluoride content;

- a greater number of samples had fluoride contents above 0.60 mg F/L (42.8%) in the rainy season than in the dry season (36%);

- systems supplied with water from only groundwater sources with the addition of fluoride had the lowest levels of fluoride in the water supplied to the population;

- the five mesoregions of Goiás differed in the fluoride content of their water samples, with lower values being found in the North and East Regions of Goiás;

- there is a need for broader research aimed at determining the ideal ranges of fluoride concentration throughout the state of Goiás due to the intimate connection among water consumption, influence of temperature and humidity, and oral hygiene and dietary habits.

Collaborations

PS Scalize was responsible for designing the work, confection of the graphs, analysis and interpretation of the data. The critical writing was in charge of A Albuquerque who also contributed in the discussion of the results and conclusion of the work. RVN Pinheiro and HC Huggeri Junior were responsible for reviewing the bibliography and discussing the data and completing the work. G Sanz Lobon was in charge of the elaboration of the thematic maps and aid in the experimental design and also the discussion of the results. PN Arruda assisted in the discussion of the data.

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