














## Research Article

# Iodine Concentration in Brazilian Drinking Water and Its Possible Contribution to Iodine Intake for Different Physiological Groups

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**Objective.** The objective is to analyze the concentration of iodine in Brazilian drinking water and its possible contribution to iodine intake for different groups. **Methods.** Water samples collected from primary healthcare units in eight locations distributed across all five macroregions of Brazil were analyzed. The quantification of iodine in the water samples was done by spectrophotometry (leuco crystal violet method). To classify the degree of iodine concentration, the recommendation of the Ministry of Health (China) was followed since Brazil lacks a classification standard. To verify the possible contribution of drinking water to iodine intake for different groups, the recommended water intake for each group according to the United States Institute of Medicine (2004) was considered. The percentage of iodine in drinking water and its contribution to iodine intake for different physiological groups were calculated based on the estimated average requirement (EAR) of iodine. A descriptive statistical analysis was performed using SPSS version 21.0 and Statistical Analysis Systems (SAS) version 9.2. **Results.** Significant differences were found between the maximum and minimum concentrations of iodine in water samples from the same location. In Pinhais (south region), the difference was  $44.32 \mu\text{g} \cdot \text{L}^{-1}$ ; in Viçosa (southeast region), it was  $27.86 \mu\text{g} \cdot \text{L}^{-1}$ ; in Rondonópolis (midwest region), it was  $12.66 \mu\text{g} \cdot \text{L}^{-1}$ ; in São Luís (northeast region), it was  $11.82 \mu\text{g} \cdot \text{L}^{-1}$ ; in Brazilian Federal District (midwest region), it was  $10.98 \mu\text{g} \cdot \text{L}^{-1}$ ; in Macaé (southeast region), it was  $10.14 \mu\text{g} \cdot \text{L}^{-1}$ ; in Palmas (north region), it was  $4.22 \mu\text{g} \cdot \text{L}^{-1}$ ; and in Vitória (southeast region), it was  $1.69 \mu\text{g} \cdot \text{L}^{-1}$ . The maximum concentrations of iodine found in the drinking water of Pinhais and Viçosa can contribute more than 70.0% and 50.0%, respectively, to daily iodine intake for all groups. **Conclusion.** Monitoring the concentration of iodine in drinking water from different locations in each city or Federal District is a preventive measure against inadequate iodine intake and possible adverse changes in population health.

## 1. Introduction

Iodine is an essential micronutrient and a principal component of thyroid hormones. Inadequate, insufficient, or excessive iodine intake can modify the thyroid gland function [1, 2].

Iodine deficiency causes goiter, irreversible brain damage in fetus, known as cretinism, and developmental and physical growth delays in children. Among pregnant women, the main outcomes are abortion, stillbirth, congenital anomalies, and increased perinatal mortality [3]. On the other hand, excessive iodine intake can result in thyroid diseases, such as nodular goiter, hyperthyroidism, and Hashimoto's thyroiditis [1, 4].

Cases of goiter due to excess iodine in drinking water were initially reported by China [5]. Excess iodine in drinking water, especially concentrations of 300 to  $1.300 \mu\text{g}\cdot\text{L}^{-1}$ , has been associated with excessive iodine intake and high prevalence of endemic goiter in individuals aged 8 to 10 years [6–8].

Shen et al. [5] undertook a Chinese national investigation to map the geographical distribution of drinking water containing high levels of iodine. In the study, iodine concentrations above  $300 \mu\text{g}\cdot\text{L}^{-1}$  were related to a high concentration of urinary iodine, resulting in a high prevalence of goiter (11.0%) in schoolchildren aged 8 to 10 years. Also, regions whose drinking water contained high and excess levels of iodine were identified. Based on the scenario of these specific regions, the study recommended three actions: (1) the sale of iodized salt should be stopped; (2) drinking water should be replaced and pipeline water with an adequate concentration of iodine should be supplied; and (3) iodine concentration in water should be monitored as well as the prevalence of goiter. Thus, the establishment of specific public policies on iodine in drinking water is driven by the identification of regions with insufficient, sufficient, or excess iodine in drinking water, as observed for China.

To date, no study has specifically monitored the concentration of iodine in Brazil's drinking water although some concentrations are well-known to be detrimental to nutritional status and thyroid function. However, most studies in the literature regarding the concentration of iodine in water are carried out in China [6–16].

Thus, the present study analyzed the concentration of iodine in the drinking water of all regions in Brazil and its possible contribution to iodine intake for different groups.

## 2. Materials and Methods

**2.1. Analysis of Water Samples.** Water samples from primary healthcare units (UBS) in seven municipalities and the Federal District, distributed across the five Brazilian macroregions (midwest, northeast, north, southeast, and south), were analyzed. The samples were collected during summer between 21/12/2018 and 19/03/2019. The locations, regions, and number of water samples are shown in Table 1.

TABLE 1: Location, Brazilian region, and number of water samples analyzed at each site.

Location	Brazilian region	Number of samples
Brasília	Midwest	12
Rondonópolis	Midwest	15
São Luís	Northeast	12
Palmas	North	10
Macaé	Southeast	9
Viçosa	Southeast	14
Vitória	Southeast	3
Pinhais	South	10

The water samples were placed in 200 mL polyethylene bottles by local research team members and were kept frozen ( $-18^{\circ}\text{C}$ ) at the research centers of each location until dispatch to the Chemistry and Food Analysis laboratory of the Department of Food Technology, Federal University of Viçosa. All the samples (frozen) were transported in thermal boxes. Upon arrival at the laboratory, they were kept at  $4^{\circ}\text{C}$  until analysis.

**2.2. Determination of Iodine Concentration in Drinking Water.** The concentration of iodine in the water samples was quantified by a spectrophotometric method based on leuco crystal violet, which determines aqueous iodine in the form of elemental iodine and hypoiodous acid as described in the Standard Methods for the Examination of Water and Wastewater (4500-I B) [17].

An analytical curve was constructed daily for the analysis. For this purpose, a  $10 \text{ mg iodine}\cdot\text{L}^{-1}$  solution was freshly prepared from a KI stock solution ( $1 \text{ mg iodine}\cdot\text{mL}^{-1}$ ).

Aliquots of  $250 \mu\text{L}$  to  $2.500 \mu\text{L}$  were pipetted from the  $10 \text{ mg}$  solution of  $\text{iodine}\cdot\text{L}^{-1}$  and subsequently transferred to  $100 \text{ mL}$  volumetric flasks. The flasks were completed with ultrapure water. Then,  $50 \text{ mL}$  of the prepared solution was transferred to the other  $100 \text{ mL}$  volumetric flasks. Here,  $1 \text{ mL}$  of citric buffer solution and  $0.5 \text{ mL}$  of potassium peroxydisulfate solution were added and stirred for approximately 1 minute. After that,  $1 \text{ mL}$  of leucocrystal violet was added and the volumetric flask was filled with ultrapure water. Thus, the standard iodine solutions for the analytical curve had concentrations of  $0.0125$ ;  $0.0250$ ;  $0.0375$ ;  $0.0500$ ;  $0.0625$ ;  $0.0750$ ;  $0.0875$ ;  $0.1000$ ;  $0.1125$ ; and  $0.1250 \text{ mg}$  of  $\text{iodine}\cdot\text{L}^{-1}$ .

The absorbance readings at  $592 \text{ nm}$  were done with an ultraviolet-visible spectrophotometer (model UV/VIS 9200, Rayleigh brand,  $10 \text{ mm}$  cuvette) at room temperature against a blank (concentration  $0 \text{ mg}\cdot\text{L}^{-1}$ ) under the same conditions. From these readings, absorbance and iodine concentration data were plotted to construct an analytical curve with eleven concentrations, where each point was the average of two measurements. The construction of this curve validates the leucocrystal violet method for the determination of iodine concentration.

For the analysis of the water samples,  $50 \text{ mL}$  of the same was measured in a beaker and transferred to a  $100 \text{ mL}$  volumetric flask. In this flask,  $1 \text{ mL}$  of citric buffer solution and  $0.5 \text{ mL}$  of potassium peroxydisulfate were added. The

solution was stirred for approximately 1 minute. Then, 1 mL of leucocrystal violet was added and the volume was filled with ultrapure water. The analysis was conducted in triplicate, and the absorbance readings were taken within five minutes after the addition of leucocrystal violet for reliable results. The absorbance readings were performed under the same conditions as the standard solution. Based on the analytical curve, the results were expressed in  $\mu\text{g}$  of iodine  $\text{L}^{-1}$ .

With each new series of analyses, an iodine standard curve was built to guarantee the reliability of the results.

The legislation of China was adopted as a reference to assess the concentration of iodine in drinking water, with cutoff points being:  $<10 \mu\text{g/L}$  (water with low iodine concentration);  $10\text{--}150 \mu\text{g/L}$  (water with adequate iodine concentration);  $>150 \mu\text{g/L}$  (water with high iodine concentration), and  $>300 \mu\text{g/L}$  (water with excess iodine) [18, 19].

**2.3. Water Intake.** Using the minimum and maximum iodine concentrations found in the drinking water from different locations, iodine intake in  $\mu\text{g}$  was calculated for the following physiological groups: children, adolescents, adults/ elderly, pregnant women, and nursing mothers. For this purpose, the recommended water intake for each physiological group according to the United States Institute of Medicine was considered: 1 to 3 years (1.3 L); 4 to 8 years (1.7 L); 9 to 13 years (2.1 L); 14 to 18 years (2.3 L); 19 to over 70 years (2.7 L); pregnant women (3 L); and nursing mothers (3.8 L) [20]. The assessment considered iodine intake from drinking water among females in order to highlight pregnant women and nursing mothers, groups vulnerable to iodine deficiency.

To calculate the percentage of iodine present in the water samples from different locations and their possible contribution to iodine intake for different physiological groups, the estimated average requirement (EAR) of iodine by the Institute of Medicine was used as a reference [21].

**2.4. Statistical Analysis.** The concentration of iodine in the water samples was estimated by the average analytical curve adjusted by linear regression analysis (95% confidence) using the Statistical Analysis Systems (SAS) program (Statistical Analysis System-SAS Institute, Cary, NC, USA) version 9.2, licensed to the Federal University of Viçosa.

Data analysis was performed using the Statistical Package for Social Science (SPSS) version 21.0 and a significance level of 0.05. A descriptive statistical analysis of the data was conducted, and the results were expressed in absolute and relative frequencies. The concentration of iodine in drinking water was expressed as median, minimum, and maximum values.

**2.5. Ethical Aspect.** This study is part of a project entitled "Nutritional status of iodine, sodium, and potassium in the Brazilian maternal and infant group: a multicenter study," which was approved by the Human Research Ethics

Committee of the Federal University of Viçosa, approval number 2.496.986.

### 3. Results

Figure 1 shows the analytical curve used for calculating iodine concentration in the water samples ( $\text{mg}\cdot\text{L}^{-1}$ ).

Regarding the classification of iodine concentration in drinking water, 100% of the samples from the municipalities of Palmas ( $n = 10$ ) and Vitória ( $n = 3$ ) presented low iodine concentration. Eighty percent (80.0%) ( $n = 8$ ) of the Pinhais samples had an adequate iodine level. It is important to note that none of the water samples from the different locations in the five Brazilian macroregions showed a high or excess iodine concentration following the classification of the Ministry of Health of China (Table 2).

The median, minimum, and maximum iodine concentrations in the water samples from different locations belonging to the Brazilian macroregions are shown in Table 3.

Significant differences were observed between the maximum and minimum iodine concentrations in water samples from the same location, being  $44.32 \mu\text{g}\cdot\text{L}^{-1}$  in Pinhais;  $27.86 \mu\text{g}\cdot\text{L}^{-1}$  in Viçosa;  $12.66 \mu\text{g}\cdot\text{L}^{-1}$  in Rondonópolis;  $11.82 \mu\text{g}\cdot\text{L}^{-1}$  in São Luís;  $10.98 \mu\text{g}\cdot\text{L}^{-1}$  in Brasília;  $10.14 \mu\text{g}\cdot\text{L}^{-1}$  in Macaé;  $4.22 \mu\text{g}\cdot\text{L}^{-1}$  in Palmas; and  $1.69 \mu\text{g}\cdot\text{L}^{-1}$  in Vitória.

Table 4 shows the percentages of iodine found in drinking water from different locations and their contribution (minimum and maximum) to micronutrient intake among different physiological groups.

The maximum concentrations of iodine found in the drinking water of Pinhais and Viçosa can contribute more than 50% of the recommended daily intake of iodine for all physiological groups (Table 4).

In the municipality of Viçosa, the drinking water can provide 73.9% of the recommended daily intake of iodine for individuals aged four to eight years, 81.2% for those aged nine to 13 years, and 80.3% for individuals aged 19 to 50 years. Regarding the municipality of Pinhais, the drinking water can contribute 93.0% of the recommended daily intake of iodine for all physiological groups, being more than 100.0% for individuals aged four to eight years (130.2%), nine to 13 years old (143.2%), 14 to 18 years old (120.5%), and 19 to 50 years old (141.5%) (Table 4).

### 4. Discussion

In Brazil, none of the water samples from the different locations of the five Brazilian macro regions showed a high ( $>150 \mu\text{g}\cdot\text{L}^{-1}$ ) or excess ( $>300 \mu\text{g}\cdot\text{L}^{-1}$ ) iodine concentration according to the classification of the Ministry of Health of China [19]. However, samples from identical locations presented significant differences in minimum and maximum concentrations, resulting in discrepant contributions to iodine intake among the different physiological groups.

The municipalities of Pinhais and Viçosa had the highest percentage of iodine in drinking water and, consequently, the highest contributions to iodine intake. The maximum concentration of iodine in the drinking water of these places

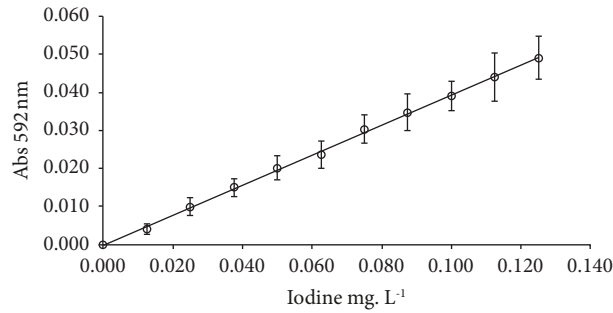


FIGURE 1: Adjusted analytical curve for iodine quantification in the water samples collected from locations in five Brazilian macroregions. Linear regression model  $\hat{y} = 0.3949 \times x - 0.00015$ ;  $R^2 = 0.9989$ ;  $p < 0.0001$ .

TABLE 2: Percentage of iodine based on the classification of iodine concentration in the water samples collected from Primary Healthcare Units (PHU) in locations situated in the macro regions of Brazil.

Location/region	Iodine concentration in water							
	Low		Adequate		High		Excess	
	$<10 \mu\text{g}\cdot\text{L}^{-1*}$		$10\text{--}150 \mu\text{g}\cdot\text{L}^{-1*}$		$>150 \mu\text{g}\cdot\text{L}^{-1**}$		$>300 \mu\text{g}\cdot\text{L}^{-1**}$	
	N	%	n	%	N	%	n	%
Brasília (midwest)	10	83.3	2	16.7	—	—	—	—
Rondonópolis (midwest)	14	93.3	1	6.7	—	—	—	—
São Luís (northeast)	11	91.7	1	8.3	—	—	—	—
Palmas (north)	10	100.0	—	—	—	—	—	—
Macaé (Southeast)	7	77.8	2	22.2	—	—	—	—
Viçosa (southeast)	12	85.7	2	14.3	—	—	—	—
Vitória (Southeast)	3	100.0	—	—	—	—	—	—
Pinhais (south)	2	20.0	8	80.0	—	—	—	—

\*[18]; \*\*[19].

TABLE 3: Median, minimum, and maximum iodine concentrations in water samples from Primary Healthcare Units (PHUs) in macroregions of Brazil.

Drinking water	Location/region							
	Midwest		Northeast	North	Southeast		South	
	Brasília	Rondonópolis	São Luís	Palmas	Macaé	Viçosa	Vitória	Pinhais
Median concentration ( $\mu\text{g}\cdot\text{L}^{-1}$ )	1.65	3.76	1.65	2.49	2.91	3.33	2.07	17.26
Minimum concentration ( $\mu\text{g}\cdot\text{L}^{-1}$ )	0.38	0.38	0.38	0.38	1.22	0.38	1.22	5.45
Maximum concentration ( $\mu\text{g}\cdot\text{L}^{-1}$ )	11.36	13.04	12.20	4.60	11.36	28.24	2.91	49.77

could contribute more than 50% of the recommended intake of iodine for all physiological groups. Besides iodine ingested from drinking water, it is important to note the iodine ingestion from iodized salt and food. Considering a scenario where an eight-year-old child from the municipality of Pinhais drinks 1.7 L of water per day, he would have an iodine intake of  $84.6 \mu\text{g}$ . Given a recommended daily salt intake of 5 grams per day (Brazilian Ministry of Health) [22], with an average iodine concentration of  $30 \text{ mg/kg}$  of salt, one can anticipate an iodine intake of  $150.0 \mu\text{g}$ . Therefore, the child's total iodine intake is  $234.6 \mu\text{g}$  per day, which would be 3.6 times higher than the estimated average requirement ( $65 \mu\text{g/day}$ ) of iodine for children aged one to eight years [21].

However, if we consider salt consumption estimated by the Family Budget Survey (POF) [23], of 12 grams of salt per day, then the child's iodine intake would be  $360.0 \mu\text{g/day}$ .

Thus, maintaining 1.7 L of drinking water, the total consumption of iodine is now  $444.6 \mu\text{g/day}$ . This points to excessive intake ( $\geq 300 \mu\text{g/day}$ ) of iodine, which is almost seven times (6.8) higher than the estimated average requirement of iodine for this physiological group.

Data from the National Survey for the Evaluation of the Impact of Salt Iodization (PNAISAL) conducted with 19,600 schoolchildren between six and 14 years old showed that 25.2% of them had urinary iodine concentrations between 200 and  $299 \mu\text{g/day}$  (more than the recommended intake) and 44.6% had urinary iodine concentrations  $\geq 300 \mu\text{g/day}$  (excessive intake) [24]. Although we did not evaluate urinary iodine, the example of the eight-year-old child suggests that iodine intake can be greater than the recommended value and excessive if water with a higher concentration of iodine is ingested in addition to the use of iodized salt (5 grams or 12 grams of salt per day). This excessive iodine intake can

TABLE 4: Values of minimum and maximum iodine concentrations ( $\mu\text{g}$ ), percentages of iodine in drinking water from different locations, and their minimum and maximum contribution to iodine intake among different physiological groups.

Physiological groups	Estimated average requirement (EAR)*	Values of minimum and maximum ( $\mu\text{g}$ ), percentages of iodine in drinking water, and their minimum and maximum contribution to iodine intake							
		Location							
		Brasília		Rondonópolis		São Luís		Palmas	
		Minimum <sup>1</sup>	Maximum <sup>2</sup>	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
1–3 years	65 $\mu\text{g}$	0.49 $\mu\text{g}$ 0.75%	14.77 $\mu\text{g}$ 22.72%	0.49 $\mu\text{g}$ 0.75%	16.95 $\mu\text{g}$ 26.08%	0.49 $\mu\text{g}$ 0.75%	15.86 $\mu\text{g}$ 24.40%	0.49 $\mu\text{g}$ 0.75%	5.98 $\mu\text{g}$ 9.20%
4–8 years	65 $\mu\text{g}$	0.65 $\mu\text{g}$ 1.00%	19.31 $\mu\text{g}$ 29.71%	0.65 $\mu\text{g}$ 1.00%	22.17 $\mu\text{g}$ 34.11%	0.65 $\mu\text{g}$ 1.00%	20.74 $\mu\text{g}$ 31.91%	0.65 $\mu\text{g}$ 1.00%	7.82 $\mu\text{g}$ 12.03%
9–13 years	73 $\mu\text{g}$	0.80 $\mu\text{g}$ 1.09%	23.86 $\mu\text{g}$ 32.68%	0.80 $\mu\text{g}$ 1.09%	27.38 $\mu\text{g}$ 37.50%	0.80 $\mu\text{g}$ 1.09%	25.62 $\mu\text{g}$ 35.09%	0.80 $\mu\text{g}$ 1.09%	9.68 $\mu\text{g}$ 13.26%
14–18 years	95 $\mu\text{g}$	0.87 $\mu\text{g}$ 0.92%	26.13 $\mu\text{g}$ 27.51%	0.87 $\mu\text{g}$ 0.92%	29.99 $\mu\text{g}$ 31.57%	0.87 $\mu\text{g}$ 0.92%	28.06 $\mu\text{g}$ 29.53%	0.87 $\mu\text{g}$ 0.92%	10.58 $\mu\text{g}$ 11.13%
19–50 years, 51–70 years, and >70 years	95 $\mu\text{g}$	1.03 $\mu\text{g}$ 1.08%	30.67 $\mu\text{g}$ 32.28%	1.03 $\mu\text{g}$ 1.08%	35.21 $\mu\text{g}$ 37.06%	1.03 $\mu\text{g}$ 1.08%	32.94 $\mu\text{g}$ 34.67%	1.03 $\mu\text{g}$ 1.08%	12.42 $\mu\text{g}$ 13.07%
Pregnant women (14–50 years)	160 $\mu\text{g}$	1.14 $\mu\text{g}$ 0.71%	34.08 $\mu\text{g}$ 21.30%	1.14 $\mu\text{g}$ 0.71%	39.12 $\mu\text{g}$ 24.45%	1.14 $\mu\text{g}$ 0.71%	36.60 $\mu\text{g}$ 22.88%	1.14 $\mu\text{g}$ 0.71%	13.80 $\mu\text{g}$ 8.63%
Nursing mothers (14–50 years)	200 $\mu\text{g}$	1.44 $\mu\text{g}$ 0.72%	43.17 $\mu\text{g}$ 21.59%	1.44 $\mu\text{g}$ 0.72%	49.55 $\mu\text{g}$ 24.78%	1.44 $\mu\text{g}$ 0.72%	36.60 $\mu\text{g}$ 18.30%	1.44 $\mu\text{g}$ 0.72%	17.48 $\mu\text{g}$ 8.74%

Physiological groups	Estimated average requirement (EAR)*	Values of minimum and maximum ( $\mu\text{g}$ ), percentages of iodine in drinking water and their minimum and maximum contribution to iodine intake							
		Location							
		Macaé		Viçosa		Vitória		Pinhais	
		Minimum <sup>1</sup>	Maximum <sup>2</sup>	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
1–3 years	65 $\mu\text{g}$	1.59 $\mu\text{g}$ 2.45%	14.77 $\mu\text{g}$ 22.72%	0.49 $\mu\text{g}$ 0.75%	36.71 $\mu\text{g}$ 56.47%	1.59 $\mu\text{g}$ 2.45%	3.78 $\mu\text{g}$ 5.82%	7.09 $\mu\text{g}$ 10.91%	64.70 $\mu\text{g}$ 99.54%
4–8 years	65 $\mu\text{g}$	2.07 $\mu\text{g}$ 3.18%	19.31 $\mu\text{g}$ 29.71%	0.65 $\mu\text{g}$ 1.00%	48.00 $\mu\text{g}$ 73.85%	2.07 $\mu\text{g}$ 3.18%	4.95 $\mu\text{g}$ 7.61%	9.27 $\mu\text{g}$ 14.26%	84.61 $\mu\text{g}$ 130.17%
9–13 years	73 $\mu\text{g}$	2.56 $\mu\text{g}$ 3.51%	23.86 $\mu\text{g}$ 32.68%	0.80 $\mu\text{g}$ 1.09%	59.30 $\mu\text{g}$ 81.23%	2.56 $\mu\text{g}$ 3.51%	6.11 $\mu\text{g}$ 8.37%	11.45 $\mu\text{g}$ 15.68%	104.52 $\mu\text{g}$ 143.18%
14–18 years	95 $\mu\text{g}$	2.81 $\mu\text{g}$ 2.96%	26.13 $\mu\text{g}$ 27.51%	0.87 $\mu\text{g}$ 0.92%	64.95 $\mu\text{g}$ 68.37%	2.81 $\mu\text{g}$ 2.96%	6.69 $\mu\text{g}$ 7.04%	12.54 $\mu\text{g}$ 13.20%	114.47 $\mu\text{g}$ 120.49%
19–50 years, 51–70 years, and >70 years	95 $\mu\text{g}$	3.29 $\mu\text{g}$ 3.46%	30.67 $\mu\text{g}$ 32.28%	1.03 $\mu\text{g}$ 1.08%	76.25 $\mu\text{g}$ 80.26%	3.29 $\mu\text{g}$ 3.46%	7.86 $\mu\text{g}$ 8.27%	14.71 $\mu\text{g}$ 15.48%	134.38 $\mu\text{g}$ 141.45%
Pregnant women (14–50 years)	160 $\mu\text{g}$	3.66 $\mu\text{g}$ 2.29%	34.08 $\mu\text{g}$ 21.30%	1.14 $\mu\text{g}$ 0.71%	84.72 $\mu\text{g}$ 52.95%	3.66 $\mu\text{g}$ 2.29%	8.73 $\mu\text{g}$ 5.46%	16.35 $\mu\text{g}$ 10.22%	149.31 $\mu\text{g}$ 93.32%
Nursing mothers (14–50 years)	200 $\mu\text{g}$	4.64 $\mu\text{g}$ 2.32%	43.17 $\mu\text{g}$ 21.59%	1.44 $\mu\text{g}$ 0.72%	107.31 $\mu\text{g}$ 53.66%	4.64 $\mu\text{g}$ 2.32%	11.06 $\mu\text{g}$ 5.53%	20.71 $\mu\text{g}$ 10.36%	189.13 $\mu\text{g}$ 94.57%

\* [21]. Values for individuals aged 0–12 months were not determined. <sup>1</sup>Minimum: minimum concentration of iodine in drinking water based on location;

<sup>2</sup>Maximum: maximum concentration of iodine in drinking water based on location.

cause goiter, hypothyroidism and overt hyperthyroidism, hypothyroidism, subclinical hyperthyroidism, autoimmune thyroid disease, iodine allergies, and decreased intelligence [1, 25–28].

Regarding an adult residing in Pinhais or Viçosa who consumes 2.7 mL of water, the daily iodine intake will be 134.4  $\mu\text{g}$  or 76.3  $\mu\text{g}$ , respectively. An intake of 5 grams of salt per day, according to the recommendation of the Ministry of Health [22], contributes to a daily iodine intake of 150  $\mu\text{g}$ . Accordingly, the total iodine intake is 234.4  $\mu\text{g}/\text{day}$  and 226.3  $\mu\text{g}/\text{day}$  for Pinhais and Viçosa, respectively. This daily intake of iodine considering the consumption of drinking

water with a higher concentration of iodine plus iodized salt intake would represent a more than adequate intake of 200–299  $\mu\text{g}/\text{day}$ . On the other hand, considering 12 grams of salt per day is normally consumed by Brazilians [23], the individual would have an iodine intake of 360.0  $\mu\text{g}/\text{day}$ , totaling 494.4  $\mu\text{g}/\text{day}$  (Pinhais) and 436.3  $\mu\text{g}/\text{day}$  (Viçosa), which represents excessive intake of iodine ( $\geq 300 \mu\text{g}/\text{day}$ ) being 5.2 and 4.6 times higher than the estimated average requirement of this group (95  $\mu\text{g}/\text{day}$ ) [21] exposing the adult population to the risks associated with excess iodine intake.

Pregnant women and nursing mothers rarely have excessive iodine intake because their physiological

conditions demand greater iodine levels [29]. In this study, pregnant women and nursing mothers in the municipality of Viçosa would have a daily iodine intake of 84.7  $\mu\text{g}$  and 107.3  $\mu\text{g}$ , respectively, if they drank 3 L (pregnant women) and 3.8 L (nursing mothers) of water containing a higher concentration of iodine. If we consider water intake and the ingestion of iodized salt (5 grams of salt per day), pregnant women and nursing mothers would have a daily iodine intake of 234.7  $\mu\text{g}$  and 257.3  $\mu\text{g}$ , respectively, exceeding the estimated average requirement of iodine, being 160  $\mu\text{g/day}$  for pregnant women and 200  $\mu\text{g/day}$  for nursing mothers [21]. In the case of 12 grams of salt per day and water intake, pregnant women would have a daily iodine intake of 444.7  $\mu\text{g}$  and nursing mothers 467.3  $\mu\text{g}$ , being almost 2.8 and 2.4 times higher, respectively, than the estimated average required for these population groups.

In the municipality of Pinhais, pregnant women and nursing mothers would have an iodine intake of 299.3  $\mu\text{g/day}$  and 339.1  $\mu\text{g/day}$ , considering the consumption of drinking water with a higher concentration of iodine and the ingestion of 5 grams of salt daily, exceeding the estimated average requirement for these groups [22].

On the other hand, if we consider the ingestion of 12 grams of salt per day plus the consumption of drinking water, pregnant women and nursing mothers in Pinhais would have a daily iodine intake of 509.3  $\mu\text{g}$  and 549.1  $\mu\text{g}$ , respectively, representing an excessive intake, being almost 3.2 and 2.8 times higher than the estimated average iodine requirement, respectively.

An important aspect to be considered in the interpretation of our results refers to the choice of the EAR for calculating the percentage of iodine present in the water samples from different locations and their possible contribution to iodine intake for different physiological groups. The EAR choice is to be considered as a conservative and hypothetical requirement in our study, considering that there is variability in the individual requirements, which is unknown [30]. However, this should give us an idea of the contribution of the iodine content in the water in relation to these hypothetical needs. Another possibility would be to use the Recommended Dietary Allowance Intake (RDA) for this evaluation. In such a case, the percentage of iodine present in the water would therefore contribute less to the individual requirements.

Given the above considerations, the concentration of iodine in drinking water must be taken into account when assessing the nutritional status of iodine among the population. Depending on the location, excessive iodine intake can occur in the different physiological groups which can change the health status of the population.

## 5. Conclusions

The concentrations of iodine in the water samples showed discrepant contributions to iodine intake, and in some places

they could contribute to excess intake among the different physiological groups.

Therefore, monitoring the concentration of iodine in drinking water from different locations is recommended for the establishment of specific strategies according to the location and physiological group. This approach may prevent excessive iodine intake and consequent changes in the functioning of the thyroid gland that may impact population health.

## Data Availability

Data are available in Excel spreadsheets.

## Conflicts of Interest

The authors declare that there are no conflicts of interest.

## Authors' Contributions

C.A.P. and S.E.P. designed the study; C.A.P. conducted the study; C.A.P., E.A.F.F., and S.E.P. analyzed and interpreted the data. C.A.P. wrote the article. All authors provided critical and conceptual contributions and critically reviewed the manuscript. All authors approved the final manuscript.

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## Supplementary Materials

Two files have been included in "Supplementary Files". The files refer to the databases of the analysis of iodine in water in the summer season (File 1) and data from the analytical curves to build the adjusted analytical curve (File 2). (*Supplementary Materials*)

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