J Oral Res
research in oral sciences

ORIGINAL ARTICLE

FLUORIDE CONCENTRATION IN DRINKING WATER SOURCES AND ASSOCIATED HEALTH RISKS

Concentración de fluoruro en fuentes de consumo y riesgos asociados para la salud

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ABSTRACT

Background: Studies have shown that fluoride is present in various natural sources and plays a key role in preventing tooth decay. However, excessive exposure has been linked to adverse health effects. In recent years, cases of dental fluorosis have been reported in areas of Mexico City, including the Tláhuac municipality, where it had not previously been observed. **Objective:** To determine fluoride concentrations in tap water and assess associated health risks in the Tláhuac municipality.

Material and Methods: Twenty-four neighborhoods within the Tláhuac municipality were selected and divided into three zones: North, Central, and South. Fluoride levels were quantified using the ion-selective potentiometric method with the Orion 4 Star instrument (Thermo Electron Corporation). Health risk assessment was conducted using the US-EPA model, considering both adult and child populations in the study area.

Results: The mean fluoride concentration in Tláhuac was 0.700 ± 0.0934 mg/L, ranging from 0.539 to 0.934 mg/L. The estimated risk values were 0.24 ± 0.02 mg/L for adults and 1.5 ± 0.15 mg/L for children.

Conclusions: The findings indicate that fluoride concentrations in Tláhuac's drinking water exceed recommended safe intake levels for children. The hazard quotient for children was greater than one, suggesting a potential risk of adverse health effects.

Keywords: *Fluoride; Drinking water; Fluoridation; Cities; Risk assessment; Dental fluorosis.*

Received: June 17, 2025. | **Accepted:** August 11, 2025. | **Published online**: December 01, 2025.

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doi:10.17126/joralres.2025.035

RESUMEN

Introducción: Estudios han determinado que al fluoruro se lo puede hallar en diversas fuentes naturales y es clave para la prevención de la caries dental. Sin embargo, se ha establecido que una exposición excesiva puede ocasionar problemas de salud. En los últimos años, se han detectado casos de fluorosis dental en localidades de la Ciudad de México, incluyendo la alcaldía Tláhuac, donde anteriormente no habían sido reportados. **Objetivo:** Determinar la concentración de fluoruro en agua de grifo y riesgos asociados para la salud en la alcaldía Tláhuac.

Material y métodos: Se seleccionaron 24 colonias de la alcaldía, divididas en tres zonas: norte, centro y sur. La cuantificación de fluoruro se realizó utilizando el método potenciométrico de ión selectivo, con el equipo Orión 4 Star de Thermo Electron Corporation. La evaluación del riesgo para la salud se efectuó mediante el modelo de la US-EPA, considerando a la población adulta y a los niños de la zona de estudio.

Resultados: La concentración media de fluoruro en Tláhuac fue de 0,700 ± 0,0934 mg/L, con un rango de 0,539 a 0,934 mg/L. Los valores de evaluación del riesgo para los adultos fueron de 0,24 ± 0,02 mg/L, mientras que para los niños fueron de 1,5 ± 0,15 mg/L.

Conclusiones: Los resultados evidencian que las concentraciones de fluoruro en el agua de la alcaldía Tláhuac exceden los valores recomendados para la ingesta segura en población infantil. El cociente de peligro calculado para los niños fue mayor a uno, lo que indica un riesgo potencial de efectos adversos para la salud.

Palabras clave: *Fluoruro; Agua potable; Fluoración; Ciudades; Medición de riesgo; Fluorosis dental.*

INTRODUCTION

The presence of fluoride in the environment poses a public health challenge. While it plays an important role in preventing dental caries, excessive exposure can lead to adverse health effects.[1] This inorganic ion, widely distributed in nature, is found in rocks, rivers, seas, and groundwater, as well as in everyday consumer products such as fluoridated salt, fortified milk, and various processed beverages.[2,3]

Since drinking water is the primary route of human exposure to fluoride, assessing its concentration in this source is essential for identifying potential risks, particularly invulnerable communities or those lacking strict supply control.[4] In dentistry, dental fluorosis is a condition caused by excessive fluoride exposure during tooth development. It is characterized by hypomineralization and increased enamel porosity. In mild cases, it presents as white spots on the tooth surface, while more severe forms may include color changes, enamel loss, and a greater susceptibility to caries. At significantly higher fluoride levels, skeletal fluorosis may also occur.[5]

At the systemic level, chronic fluoride intake can affect various organs and tissues, including the kidneys and other filtering body systems, and may induce hypercalcemia. Some studies have also reported effects on neurological development, especially during childhood, with associations to learning disorders and reduced IQ in school-aged children.[6]

The World Health Organization (WHO) recommends a maximum fluoride concentration of 0.7 mg/L in drinking water. In Mexico, the Manual for the Use of Fluoride in the Mexican Republic establishes the same value as the desirable limit, considering that the country has maintained a national salt fluoridation program for over three decades.[7,8]

In recent years, cases of dental fluorosis have been detected in areas of Mexico City where it had not previously been reported, such as the Tláhuac municipality. This issue is particularly relevant given that the Dental Clinic of the Metropolitan Autonomous University (UAM), Xochimilco campus, is located in this district. Therefore, the purpose of this study was to determine the fluoride concentration in tap water in this municipality and assess the potential health risks to its population.

MATERIALS AND METHODS

A descriptive, cross-sectional study was conducted to measure fluoride concentrations in drinking water in the Tláhuac municipality of Mexico City. The protocol was approved by the Research Commission of the Metropolitan Autonomous University, Xochimilco campus (No. 34504096).

The study area is situated on a volcanic rock formation, covering an area of 86.3 km², with a population density of 4,128.7 inhabitants per km². This municipality accounts for 6.7% of Mexico City's territory and is home to 392,313 inhabitants.[9] The Dental Clinic of the Metropolitan Autonomous University in Tláhuac has reported cases of mild to moderate dental fluorosis in children. Initially, 30 neighborhoods were identified across the municipality based on geographic accessibility and safety criteria, using an 85% confidence level and a 7% margin of error. The final sample consisted of 24 neighborhoods, which were grouped into three geographic zones (North, Central, and South), with eight neighborhoods in each zone.

The selected neighborhoods are consolidated urban areas, without a rural character or specific ethnic groupings. Although they have varying levels of urban infrastructure, all are connected to the public drinking water distribution system managed by Sistema de Aguas de la Ciudad de México (SACMEX) (Mexico City Water System). They share the same central distribution system, providing a common source for most households.

However, it is important to note that, although the samples originate from the same general supply, the hydraulic system delivers water to different pumping stations at varying depths. Differences in infrastructure and the geological characteristics of each collection point can affect the final fluoride concentration. Consequently, heterogeneity in the results may be observed even in geographically close areas within the same municipality.

Neighborhoods were selected based on criteria such as sufficient population density to identify at least eight households per neighborhood, accessibility for the field team, and safety conditions during sample collection. Households were identified by visiting each residence and applying predefined inclusion criteria, including the presence of school-aged children and willingness to participate.

Samples were collected directly from household tap water, considered the primary source of drinking water. Twenty-milliliter plastic test tubes, previously rinsed with deionized water, were used for collection. Each sample was labeled with the name of the corresponding neighborhood. Collection took place in April 2024, and the samples were subsequently stored at 4°C until analysis.

Fluoride quantification was performed using the potentiometric method with an ion selective electrode, employing an Orion 4 Star potentiometer (Thermo Electron Corporation). TISAB solution was added to control pH, adjust ionic strength, and maintain free fluoride ions in the solution. Both sample collection and analysis were conducted in the Fluoride Laboratory of the Metropolitan Autonomous University, Xochimilco campus. A calibration curve was constructed using 21 standard solutions ranging from 0.01 to 10 mg/L, with increments of 0.5 mg/L. Each sample was measured in triplicate.

The method was validated by assessing linearity, repeatability, sensitivity, accuracy, and sample stability. Linearity was evaluated over six days by preparing a calibration curve in triplicate and measuring the instrument response in millivolts (mV) under constant conditions. Repeatability was determined by analyzing samples using four calibration curves, each prepared in triplicate on the same day under identical conditions. Sensitivity was established based on the slope obtained from each curve over six consecutive days. Accuracy was assessed using a certified reference standard (High Purity Standard of 100 mg/L F-), from which four concentrations were prepared per dilution: 0.125, 0.25, 0.75, 1.0, and 2.0 mg/L, within the working range.

To assess the potential health risk associated with fluoride exposure through drinking water, the method proposed by the United States Environmental Protection Agency (US-EPA)[10] was applied, using the calculation of the Hazard Quotient (HQ). This indicator is obtained by dividing the estimated exposure dose by the reference dose (RfD).

The Estimated Daily Intake (EDI) was calculated using the following formula:

$$HQ = \frac{EDI}{RfD}$$

The Estimated Daily Intake (EDI) was calculated using the following equation:

$$EDI = \frac{C \times IR}{BW}$$

Where: **C:** fluoride concentration (mg/L); **IR:** water ingestion rate: 2.0 L/day for adults and 1.4 L/day for children; **BW:** body weight: 70 kg for adults and 10.5 kg for children.

These values are based on standard estimates used in studies conducted in the same geographic region and reflect the conditions of the Mexican population.

The reference dose (RfD) corresponds to the estimated daily exposure considered to pose no significant risk over a lifetime. The US-EPA's Office of Water has established an RfD of 0.08 mg/kg/day for adults and 0.06 mg/kg/day for children, aiming to protect 99.5% of the vulnerable population from severe dental fluorosis, fractures, and other skeletal effects.[10]

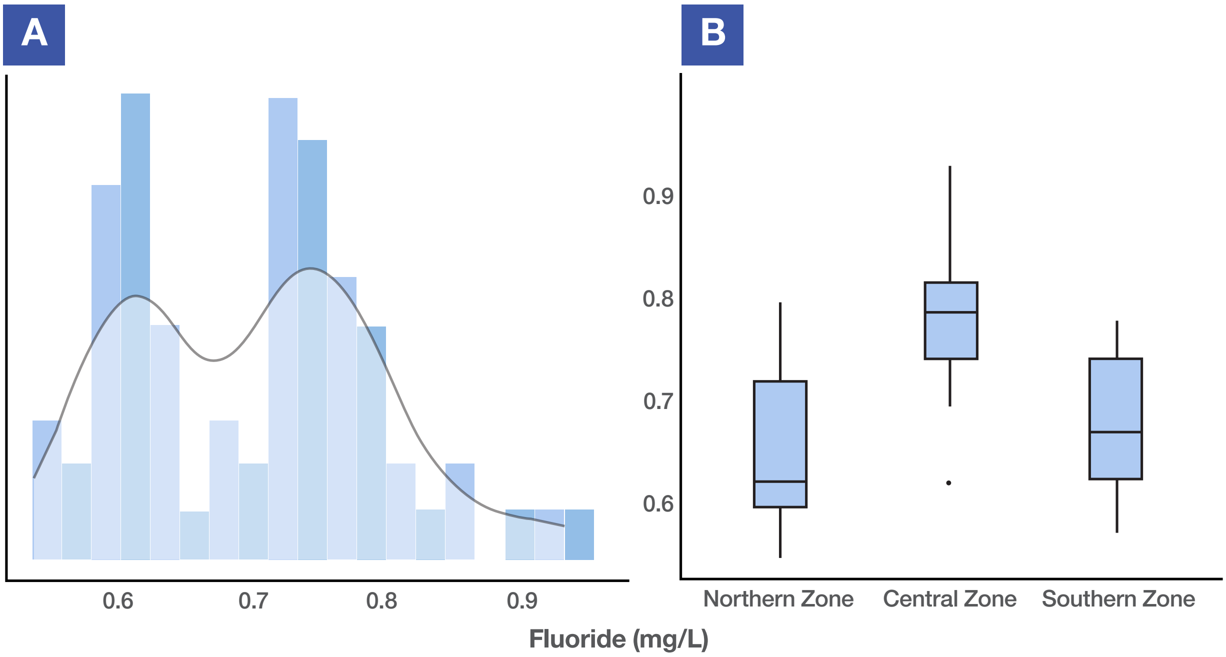
When the HQ exceeds a value of 1, the estimated exposure is considered to surpass the safety threshold and may therefore represent a potential risk of severe fluorosis.[13]

RESULTS

Fluoride concentration in tap water in the Tláhuac municipality is 0.700±0.0934 mg/L, with a range of 0.539 to 0.934 mg/L, which exceeds the optimal limit of 0.7 mg/L in some neighborhoods, (Figure 1). The Northern Zone had a mean concentration of 0.642±0.0714 mg/L, with a range of 0.539 to 0.795 mg/L. The lowest concentration was recorded in Colonia del Mar, with a mean concentration of 0.546 mg/L, the lowest of the three zones, and the highest was recorded in Miguel Hidalgo, with a mean of 0.732 mg/L (Table 1).

Figure 1

Fluoride concentration in water from the Tláhuac municipality



A: Distribution of fluoride values (mg/L) in tap water samples from the Tláhuac municipality.
B: Distribution of fluoride values (mg/L) in tap water samples from the Tláhuac municipality across the three study areas.

Table 1

Statistical parameters of fluoride concentration (mg/L) in the Northern Zone

Northern Zone		Statistical values			95% Confidence Interval (95% CI)	
Neighborhood name	Minimum	Maximum	Mean	SD*	Lower	Upper
Nopalera	0.714	0.750	0.731	0.01808	0.686	0.776
Santa Ana sur	0.588	0.623	0.608	0.01818	0.563	0.653
Agrícola metropolitana	0.647	0.739	0.701	0.04804	0.582	0.820
Ampl. Los Olivos	0.581	0.653	0.607	0.03970	0.509	0.706
Miguel Hidalgo	0.679	0.795	0.732	0.05864	0.586	0.878
Villa Centroamericana	0.604	0.619	0.612	0.00751	0.593	0.630
Colonia del Mar	0.539	0.554	0.546	0.00755	0.527	0.565
Colonia Los Olivos	0.594	0.606	0.601	0.00611	0.585	0.616

***: SD:** Standard Deviation.

Table 2

Statistical parameters of fluoride concentration (mg/L) in the Central Zone

Central Zone		Statistical values			95% Confidence Interval (95% CI)	
Neighborhood name	Minimum	Maximum	Mean	SD*	Lower	Upper
Barrio la Asunción	0.739	0.755	0.744	0.00924	0.721	0.767
Barrio San Juan	0.765	0.795	0.775	0.01732	0.732	0.818
Barrio la Guadalupe SPT	0.616	0.732	0.680	0.05903	0.534	0.827
Guadalupe Tlaltenco	0.803	0.827	0.815	0.01201	0.785	0.845
Amp. López Portillo	0.778	0.792	0.787	0.00808	0.767	0.807
Colonia Triángulo	0.800	0.857	0.834	0.03005	0.759	0.909
Ampl. Selene	0.697	0.717	0.709	0.01079	0.683	0.736
Santiago Centro	0.896	0.934	0.919	0.02022	0.869	0.969

***: SD:** Standard Deviation.

Table 3

Statistical parameters of fluoride concentration (mg/L) in the Southern Zone

Southern Zone		Statistical values			95% Confidence Interval (95% CI)	
Neighborhood name	Minimum	Maximum	Mean	SD*	Lower	Upper
Barrio San Bartolomé	0.583	0.621	0.596	0.02139	0.543	0.649
La lupita	0.618	0.632	0.623	0.00757	0.605	0.642
El Rosario	0.722	0.752	0.742	0.01732	0.699	0.785
Francisco Villa	0.686	0.737	0.719	0.02862	0.648	0.790
Barrio Los Reyes	0.722	0.778	0.758	0.03099	0.681	0.835
Barrio San Agustín PSJ	0.602	0.645	0.628	0.02268	0.571	0.684
Barrio Santa Cruz	0.686	0.760	0.730	0.03894	0.633	0.827
Barrio San Miguel PSAM	0.564	0.642	0.601	0.03911	0.504	0.698

***: SD:** Standard Deviation.

Table 4

Risk assessment of fluoride exposure by zone

Zone	Mean fluoride concentration	Adults		Children (1-3 years old)	
		Estimated daily intake	Hazard quotient (mg/L)	Estimated daily intake	Hazard quotient (mg/L)
Northern Zone	0.642 mg/L	0.0183	0.22	0.085	1.4
Central Zone	0.783 mg/L	0.022	0.27	0.104	1.7
Southern Zone	0.675 mg/L	0.019	0.24	0.09	1.5
Mean	0.700 mg/L	0.020	0.25	0.093	1.5

The Central Zone had a mean concentration of 0.783±0.0752 mg/L with a range of 0.616 to 0.934 mg/L, presenting the highest concentration of fluoride (Table 2). Finally, the Southern Zone presented a mean concentration of 0.675±0.0694 mg/L, with a range of 0.564 to 0.778 mg/L. The lowest mean concentration in this zone was found in the San Bartolomé neighborhood with a concentration of 0.596 mg/L and the highest in El Rosario with 0.742 mg/L (Table 3).

The Estimated Daily Intake (EDI) and Hazard Quotient (HQ) for fluoride exposure through drinking water in adults and children are presented in Table 4. Daily fluoride intake varied by area, ranging from 0.018 to 0.022 mg/kg/day for adults and 0.085 to 0.104 mg/kg/day for children. Overall, HQ values were 0.25 mg/L for adults and 1.5 mg/L for children. While the daily intake and HQ values for adults remain within acceptable limits, those for children exceed the recommended safety threshold of 1.4–1.7 mg/L.

DISCUSSION

The results of this study show that fluoride concentrations in the analyzed water samples presented a mean of 0.700 ± 0.0934 mg/L, with the Central Zone being the most affected. These findings partially coincide with previous studies carried out in Mexico City, such as that of Hernández-Guerrero *et al.*,[14] which reported a mean concentration of 0.70 ± 0.20 mg/L in drinking water, with values ranging from 0.26 to 1.38 mg/L in different areas of the city. This concordance underscores the need for periodic monitoring in the region, since prolonged exposure to high levels of fluoride can cause dental fluorosis, especially in children.

Specifically, the most recent data available for the Tláhuac municipality, published in 2011 by Galicia-Chacón *et al.*,[15] reported a mean concentration of 0.86 ± 0.19 mg/L. Updating these values is important, as the present study confirms comparable levels and indicates that the Central Zone remains the most affected, with a maximum concentration of 0.934 mg/L.

In some neighborhoods, fluoride levels exceeded the optimal limit of 0.7 mg/L,[8] with slight increases particularly in the Central Zone, where a large child population is concentrated. This situation is concerning, as preschool-aged children are in critical stages of dental and skeletal development and are therefore especially vulnerable to the effects of fluoride. Additionally, these areas often experience drinking water shortages, which has led to the drilling of deep wells that tap aquifers with higher concentrations of this halogen.

Although some neighborhoods recorded concentrations close to 0.7 mg/L, within acceptable limits, it is important to consider the cumulative risk derived from other sources of fluoride intake, such as food, fluoridated salt, processed beverages, and oral hygiene products, because exposure is not limited to tap water. According to NOM-040-SSA1-1993,[16] when fluoride concentrations in drinking water exceed 0.7 mg/L, the use of iodized-fluoridated salt is not recommended. However, such salt continues to be distributed in this municipality, reinforcing the need for a comprehensive assessment of all sources of exposure.

Multiple national and international studies have shown that children are particularly vulnerable to the effects of fluoride due to their developmental stage. In the present study, the hazard quotient (HQ) for adults remained within safe limits (HQ≤1, range 0.22 to 0.27). By contrast, the HQ values for children exceeded these limits (1.4 to

1.7), in line with findings from previous research conducted in San Luis Potosí and Guanajuato.[17,18] This indicates a significant risk of dental fluorosis or systemic effects, especially among children aged 1 to 3 years, a critical period for tooth and bone development.

These results highlight the need to implement prority preventive measures for children in regions with elevated fluoride levels. Comprehensive risk assessments should be carried out, taking into account all potential sources of exposure, such as the widespread consumption of processed beverages in the Mexican population. Furthermore, expanding monitoring efforts to other municipalities in Mexico City would help identify regional variations in exposure and associated health risks.

Although the risks identified for the adult population are low, the levels detected in children underscore the urgent need for intervention strategies. Recommended actions include continuous monitoring of fluoride concentrations in drinking water sources across the municipality and other regions of Mexico, implementing targeted preventive measures for children, such as educational campaigns, and enforcing stricter regulations on fluoridated products. Additionally, it is important to evaluate other sources of fluoride exposure, such as processed beverages and oral hygiene products, and to extend these studies to other municipalities in Mexico City to identify exposure patterns and specific risks across different geographic areas.

Limitations of this study include: data collection conducted only over a single month, without accounting for seasonal variations. The risk assessment relied on standard estimates of water consumption and body weight, which may not accurately represent the specific characteristics of the population. Additionally, only fluoride exposure through tap water was evaluated, while other sources, such as fluoridated salt and oral hygiene products, were not considered.

CONCLUSIONS

The fluoride concentrations detected in the drinking water of the Tláhuac municipality do not pose a significant risk to the adult population, as the hazard quotient (HQ) remained within safe limits (HQ≤ 1). In contrast, the values observed in the child population exceeded the safety threshold (HQ>1), indicating a substantial health risk.

This increased risk in children can be attributed to their greater biological susceptibility to fluoride, due to factors such as lower body weight, higher proportional intake of water and food per kilogram of body weight, increased physiological requirements, and, most importantly, their presence in a critical stage of dental and skeletal development.
These findings underscore the urgent need to implement preventive measures specifically aimed at protecting children.

Such measures should include continuous monitoring of fluoride levels in drinking water sources, stricter regulation of fluoride content in commonly used products (such as toothpaste and mouthwash), and the development of educational campaigns for parents, caregivers, and schools to reduce fluoride exposure during childhood.

CONFLICT OF INTERESTS

The authors have no conflicts of interest.

ETHICS APPROVAL

The study was reviewed and approved by the Research Commission of the Autonomous Metropolitan University of Xochimilco with (No. 34504096).

FUNDING

National Council of Humanities, Sciences and Technologies (CONAHCYT), No. 1257490/PNPC-CONAHCYT PFP 006077

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José Gamarra: Conceptualization; Formal Analysis; Methodology; Investigation; Writing, Original Draft; Writing, Review & Editing.
Nelly Molina-Frechero: Conceptualization; Methodology; Investigation; Supervision; Writing, Original Draft; Writing, Review & Editing.
Enrique Gaona: Data Curation; Supervision; Writing, Original Draft; Writing, Review & Editing.
Salvador García-López: Formal Analysis; Methodology; Writing, Original Draft.
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Alberto Pierdant-Rodríguez: Data Curation; Formal Analysis; Writing, Original Draft; Writing, Review & Editing.

ACKNOWLEDGEMENTS

The authors thank the National Council of Humanities, Sciences and Technologies (CONAHCYT), Grant No. 1257490/PNPC-CONAHCYT PFP 006077, for funding during the development of this project, and the Autonomous Metropolitan University, Xochimilco Campus.

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PUBLISHER'S NOTE

All statements expressed in this article are those of the authors alone and do not necessarily represent those of the publisher, editors, and reviewers.

PEER REVIEW

This manuscript was evaluated by the editors of the journal and reviewed by at least two peers in a double-blind process.

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This manuscript was analyzed Compilatio plagiarism detector software. Analysis report of document ID.bbe55167e6438c18eec11c946f822f622fbe6a6f

ISSN PRINT 0719-2460 - ISSN ONLINE 0719-2479
https://joralres.com/index.php/JOralRes

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