Analysis of fluorides and chlorides in the drinking water distribution system of the city of Latacunga.

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Abstract

The present study evaluated the concentrations of free residual chlorine and fluoride in the drinking water distribution system of the Latacunga canton, Cotopaxi province, Ecuador, in order to verify compliance with the Ecuadorian Technical Standard NTE INEN 1108:2011 and the guidelines of the World Health Organization (WHO, 2017). Thirteen georeferenced sampling points were selected, covering the stages of intake, treatment, storage, and distribution. The samples were analyzed using spectrophotometry and colorimetric methods, ensuring accuracy and reproducibility in accordance with NTE INEN 2169:2013. The results showed residual chlorine concentrations between 0.074 and 0.891 mg/L (average 0.33 mg/L) and fluoride concentrations between 0.001 and 0.003 mg/L (average 0.002 mg/L). Although both parameters comply with regulatory values, a spatial variability of residual chlorine was observed, associated with manual dosing, transit time, and mixing conditions in tanks. Fluoride concentrations were uniform but below the recommended preventive range (≈0.7 mg/L), which limits their protective effect against dental caries. The system shows acceptable efficiency, although it requires automation of chlorine dosing, continuous monitoring, and hydraulic sectorization to stabilize the disinfectant residual. Based on the results, it is recommended to rehabilitate the distribution system and provide operational training to the operators to ensure a safe, stable supply in accordance with national and international drinking water standards.

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Introduction

Access to safe drinking water is a human right and an essential requirement for public health. In Ecuador, the Ecuadorian Technical Standard NTE INEN 1108 (2011) regulates water quality parameters, establishing that free residual chlorine must be kept between 0.3 and 1.5 mg/L, and fluoride (F^-) must not exceed 1.5 mg/L, following the guidelines of the WHO (2017). These values seek to balance protection against pathogenic microorganisms and the reduction of chemical and organoleptic risks.

In the national context, studies have shown relevant variations. In Cuenca, concentrations of trihalomethanes (THMs) were recorded in permissible ranges, although they increased when the water remained in distribution tanks (B. Hernández et al., 2025). In Guayllabamba, fluoride levels above the limit were identified (Meza, 2024), while in rural parishes of Azuay values below the recommended values were found (Duque, 2024). Likewise, it has been shown that seasonality influences water quality, increasing chlorine variations and the presence of coliforms in the rainy season (Dugarte et al., 2024).

In Latacunga, the absence of recent fluoride and residual chlorine measurements is a critical gap (Puente, 2020). In addition, in the Juan Montalvo parish, partial compliance with the residual chlorine parameters was reported, evidencing risks of variability in disinfection and the need to expand fluoride control (Cando & Coro, 2019).

The international literature reinforces these concerns. In Mexico Bashash et al. (2017) they found varying concentrations of fluoride in rural communities; in China, Zhou et al. (2021) documented neurotoxic effects in children due to fluoride exposure; in Brazil, Rosário et al. (2021) reported fluoride deficiencies in several cities; and in Chile, Fernández et al. (2024) They identified overexposure to fluoride in arid areas of the north. In a complementary way, research in Canada has linked prenatal exposure to fluoride with childhood cognitive deficits (Green et al., 2019; Till et al., 2020).

In summary, national and international evidence shows that both chlorine and fluoride play essential roles in disinfection and dental health, but their excess or deficiency represents chronic risks such as fluorosis, endocrine alterations and mutagenic effects associated with by-products of these chemical components (Ahmad et al., 2022; Sotomayor & William, 2022). In the absence of updated research in Latacunga, this study is justified to evaluate these parameters in the plant and distribution tanks, verifying compliance with current regulations, as a basis for strengthening monitoring systems, implementing technical correctives and consolidating citizen confidence in the quality of water in the canton.

Study Area

The present study was carried out in the drinking water distribution system of the Latacunga canton, Cotopaxi province, Ecuador. It is located in the inter-Andean region of the country, at an average altitude of 2,800 meters above sea level, with approximate coordinates 0°56′ S and 78°36′ W. Latacunga is a strategic area due to its role as the urban and economic center of the province, in addition to being the main water supply area for a population of more than 150,000 inhabitants (Oña, 2025)

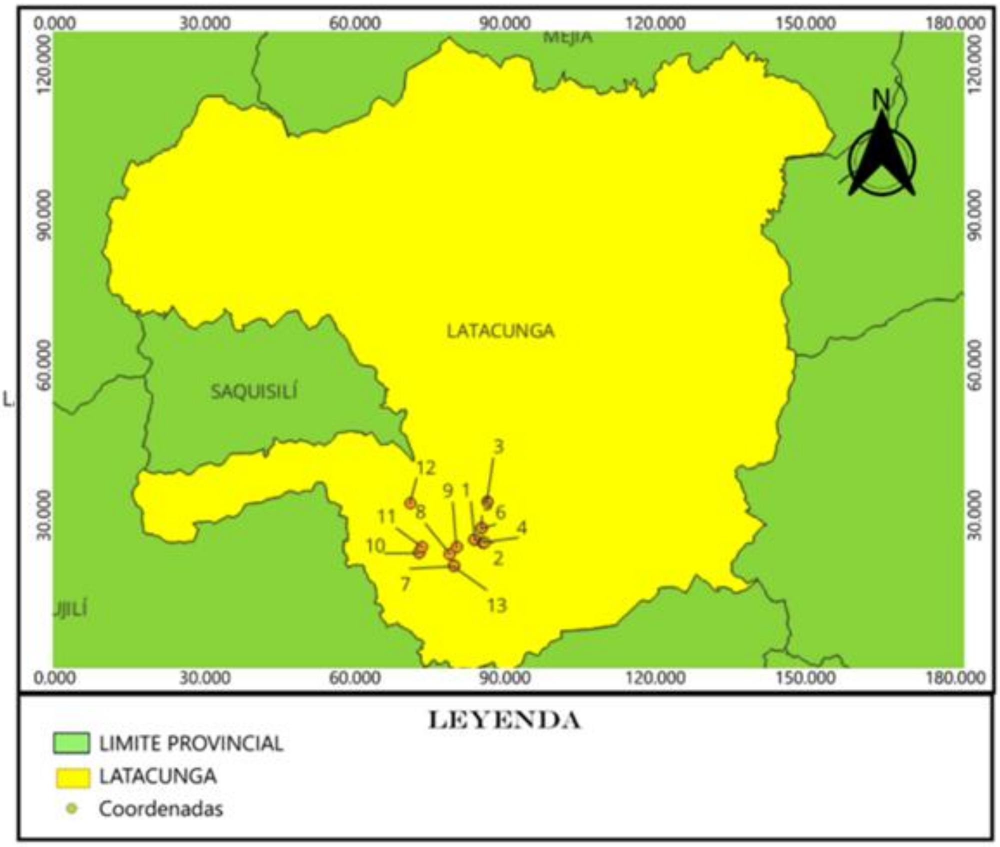

Figure 1. Map of the sampling points

The study was carried out in the drinking water supply network, which is composed of a main treatment plant and a set of tanks, catchments and urban distribution points. Thirteen georeferenced sampling points (UTM Zone 17S, Datum WGS84) were selected, strategically distributed from the Loma de Alcocer Drinking Water Treatment Plant (PTAP) to representative sectors of the distribution network (Figure 1).

The sites included both entry and exit points of the PTAP, as well as intermediate catchments (El Calzado Locoa and Illigua), storage tanks (Gualundún and San Martín), and treated water taps in different urban neighborhoods (San Carlos, San Rosa de Pichul, San Felipe and Los Arupos). Likewise, the four ponds in the El Calvario sector, identified as pools 1 to 4, were incorporated in order to evaluate the variability of chlorine and fluoride in the storage stage. This distribution made it possible to cover the different phases of the process such as collection, treatment, storage and distribution, ensuring a spatial representativeness of the physical-chemical conditions of the water within the Latacunga supply system. The coordinates and characteristics of each point are presented in Table 1.

Table 1. Sampling sites in the Latacunga drinking water system

ITEM	SAMPLE	LOCATION		DESCRIPTION
		X	And	
1	PTAP LOMA DE ALCOCERES	767595.13 m E	9897826.00 m S	Raw water (ingress)
2	PTAP LOMA DE ALCOCERES	767595.48 m E	9897821.00 m S	Treated water (outlet)
3	CAPTURE OF LOCOA FOOTWEAR	768207.82 m E	9897617.00 m S	Treated water (outlet)
4	CAPTURE OF LOCOA FOOTWEAR	768277.65 m E	9897627.00 m S	Raw water (ingress)

5	ILLIGUA	768053.14 m E	9898603.00 m S	Raw water (ingress)
6	ILLIGUA	768052.69 m E	9898603.00 m S	Treated water (outlet)
7	SAN CARLOS	766053.75 m E	9895897.00 m S	Treated water (tap water)
8	THE ORDEAL	765772.75 m E	9896821.00 m S	Treated water (pool 1)
8.1	THE ORDEAL	765773.20 m E	9896824.00 m S	Treated water (pool 2)
8.2	THE ORDEAL	765771.64 m E	9896821.00 m S	Treated water (pool 3)
8.3	THE ORDEAL	765773.42 m E	9896824.00 m S	Treated water (pool 4)
9	GUALUNDUN	766266.81 m E	9897258.96 m S	Treated Water (Large Tank)
9.1	GUALUNDUN	766266.92 m E	9897258.96 m S	Treated Water (Large Tank)
9.2	GUALUNDUN	767189.22 m E	9897623.52 m S	Treated Water (Small Tank)
10	SAN MARTÍN	763564.11 m E	9896833.99 m S	Treated water (tank)
11	SAN ROSA DE PICHUL	763822.86 m E	9897273.99 m S	Treated water (tap water)
12	SAN FELIPE	762933.51 m E	9900390.79 m S	Treated water (tap water)
13	THE ARUPOS	766058.08 m E	9895885.67 m S	Treated water (tap water)

Materials and methods

Harvesting

A total of 13 representative sampling points in different areas of the city were selected, with the aim of evaluating the concentrations of fluoride (F^-) and free residual chlorine (Cl_2) in drinking water. The sampling points were established in accordance with technical criteria defined in the Ecuadorian Technical Standard NTE INEN 1108 (2011), such as the geographical distribution of the reserve tanks, the storage capacity and the population density supplied, which guaranteed a representative sample of the different areas of the canton (Hernández, 2023).

The water samples were collected in sterilized containers to avoid any type of external contamination. The collection was carried out applying the Ecuadorian Technical Standard NTE INEN 2169:2013 on sampling of drinking water, which guarantees the reliability of the results (INEN, 2013). These samples were extracted from both taps and water storage reservoirs, following the methodology described by Torres et al. (2020). At each sampling point, several samples were taken to ensure representativeness, considering the different times of the day and the variability of water consumption.

Measuring chlorine and fluorine concentrations

The measurement of the concentrations of fluoride and free residual chlorine was carried out by spectrophotometry, an analytical technique that allows the presence of these compounds in water to be quantified with high precision, a method that has been widely used in similar studies due to its high sensitivity and reliability (Santana & Becerra, 2025). For residual chlorine, the guidelines of Prada et al. (2021), who use the colorimetric method, used to differentiate and quantify free and combined chlorine in drinking water. In the case of fluoride, the protocol described by (Zhou et al.,

2021) was followed, based on the spectrophotometric method, which is based on the formation of a colored complex whose intensity is proportional to the concentration of fluoride present in the sample.

Results

The results obtained were compared with the limits established by the Ecuadorian Technical Standard NTE INEN 1108 (2011), which regulates the parameters of water quality in the country, in order to determine compliance with drinking standards. In this way, it sought to evaluate the quality of drinking water in Latacunga and provide a solid basis for future interventions in the distribution system. The results obtained from the analysis of free residual chlorine and fluorine at the thirteen sampling points are presented in Table 2.

Table 2. Free residual chlorine and fluoride concentrations at sampling points

ITEM	SAMPLE	Chlorine (mg/L)	Fluoride (mg/L)	DESCRIPTION
1	PTAP LOMA DE ALCOCERES	0,085	0,002	
2	PTAP LOMA DE ALCOCERES	0,111	0,002	Raw water (ingress)
3	CAPTURE OF LOCOA FOOTWEAR	0,315	0,001	Treated water (outlet)
4	CAPTURE OF LOCOA FOOTWEAR	0,074	0,001	Treated water (outlet)
5	ILLIGUA	0,701	0,001	Raw water (ingress)
6	ILLIGUA	0,891	0,001	Raw water (outlet)
7	SAN CARLOS	0,084	0,002	Treated water (outlet)
8	THE ORDEAL	0,831	0,002	Treated water (tap water)
8.1	THE ORDEAL	0,749	0,001	Treated water (tank 1)
8.2	THE ORDEAL	0,163	0,003	Treated water (tank 2)
8.3	THE ORDEAL	0,200	0,002	Treated water (tank 3)
9	GUALUNDUN	0,096	0,001	Treated water (tank 4)
9.1	GUALUNDUN	0,096	0,002	Treated Water (Large Tank)
9.2	GUALUNDUN	0,754	0,002	Treated Water (Large Tank)
10	SAN MARTÍN	0,100	0,003	Treated Water (Small Tank)
11	SANTA ROSA DE PICHUL	0,099	0,002	Treated water (tank)
12	SAN FELIPE	0,228	0,002	Treated water (tap water)
13	THE ARUPOS	0,528	0,002	Treated water (tap water)

In the case of free residual chlorine, concentrations ranged from 0.074 to 0.891 mg/L, while fluoride levels remained between 0.001 and 0.003 mg/L.

Regarding free residual chlorine, the highest values were detected in points 5 (0.701 mg/L), 6 (0.891 mg/L), 8 (0.831 mg/L), 8.1 (0.749 mg/L), 9.2 (0.754 mg/L) and 13 (0.528 mg/L). In contrast, the lowest concentrations were observed in samples 4 (0.074 mg/L), 7 (0.084 mg/L), and 9 (0.096 mg/L). The general average recorded was 0.33 mg/L.

Regarding fluoride, all values were below 0.005 mg/L and showed little variation between the points analyzed. The highest concentrations were found in samples 8.2 and 10 (both with 0.003 mg/L), while the lowest were recorded in points 3, 4, 5, 6, 7 and 9, with 0.001 mg/L. The general average was 0.002 mg/L.

Discussion

The observed differences in free residual chlorine concentrations between the different sampling points are mainly due to the type of point evaluated. At the system inlet or in raw water, chlorine is usually absent or at very low levels; at the plant outlet and in tanks, concentrations are highest right after dosing; and in domestic drinking water distribution systems far from the network, a decrease in waste is observed, related to the longer time it takes for the water to arrive and to the reactions that reduce its concentration along the way. This pattern has been confirmed by Kulmedov et al. (2025) who modeled the decay of chlorine in an urban network and found a significant negative correlation between distance and residual chlorine concentration, similar to what was observed in Latacunga.

This behavior refers to high values at the starting points and lower values at the end nodes has been widely documented both in real systems and in hydraulic-quality coupled models (such as EPANET, WNTR and hybrid models), which demonstrate that water dynamics and its path directly influence the level of available chlorine (Kwio & Onyutha, 2024). Comparable results obtained Batista et al. (2024) by modeling chlorine decay using neural networks in Brazilian rural communities, confirming that the topology and flow rate condition the consumption of disinfectant throughout the network.

In addition to the sampling point, the configuration of the network and the way the tanks operate also influence the stability of the chlorine. Mesh nets and well-mixed tanks tend to preserve the disinfectant better, while branches with long retention times favor its loss (Pinheiro et al., 2021). García et al. (2024) They support this premise, as they highlight the importance of properly managing transit times in the network and renewal cycles in tanks, proposing mixing and replacement strategies as key tools to avoid areas with low residual and reduce contrasts in the network. In addition, the decrease in chlorine responds to reactions both in the volume of the water and in the walls of the pipes. The latter becomes more relevant in systems with old pipes or with the presence of biofilm (Bhadula et al., 2025).

Operationally, finding low levels of chlorine in remote areas is a common phenomenon in extensive and old networks. Maphanga et al. (2024) recommends practices such as rechlorination (booster) and transit time management as effective measures, always considering the balance with the formation of disinfection by-products (DBPs). Pilot plant trials and recent reviews confirm that any reinforcement strategy must also consider the effects that DBPs can have during distribution (Riyadh et al., 2024).

As for fluoride, the concentrations were consistently low, i.e., well below the optimal reference level for population programs, so they would hardly have a significant preventive effect against caries if a specific dosage is not applied. This difference contrasts directly with the current and updated health recommendation, which establishes an operational target of close to 0.7 mg/L to maximize benefits and reduce the risk of fluorosis (Ahmad et al., 2022). Equivalent findings were reported in northeastern Brazil, where Romão et al. (2023) They found average levels of 0.05 mg/L of fluoride, well below the recommended preventive threshold of 0.7 mg/L. For its part, in Chile it is mentioned that, for bottled waters, without fluoridation, the water available for consumption may not reach the preventive threshold (Fernández et al., 2024).

Conclusions

According to the Ecuadorian Technical Standard INEN 1108:2014, the maximum permissible limits for water intended for human consumption establish a value of 0.3 mg/L for chlorides and 1.5 mg/L for fluoride. The results obtained in the Latacunga supply system show that areas such as Illigua:5 and 6 recorded values of 0.701 mg/L in the inlet of raw water and 0.891 mg/L in the outlet, both significantly above the established limit. Similarly, in Gualundún: 9.2 (large tank) 0.754 mg/L was obtained and in the Los Arupos sector: 13 (water tap) a value of 0.528 mg/L, which also exceeds the maximum allowed. Although fluoride concentrations remain within the acceptable range, the high levels of chlorides in the four points analyzed show the urgent need to strengthen monitoring, adjust treatment processes and apply corrective measures to ensure that the water distributed meets the safety parameters required to protect the health of users.

The focus of operational control should be on residual chlorine, through dosage adjustments, improvements in mixing within the tanks and replacement strategies in the branches with longer retention time, with the aim of ensuring a homogeneous distribution of the disinfectant and minimizing the loss of concentration in the system. For this, it is essential to consider the distances between the PTAP LOMA DE ALCOCERES, and the different distribution points, such as SAN CARLOS which is located at 2,469.19 m, EL CALVARIO which is located at 2,081.13 m, GUALUNDUN which is located at 1,444.19 m, SAN MARTÍN which is located at 4,151.29 m, SANTA ROSA DE PICHUL which is located at 3,812.44 m, SAN FELIPE, which is located at 5,320.61 m, and LOS ARÁPOS, which is located at 2,475.36 m, all these branches that affect the distribution and retention time of chlorine in the system. This will optimize dosing and ensure that the disinfectant reaches all consumption areas efficiently.

Fluoride, by remaining stable and at reduced levels, does not pose a risk of overexposure or provide preventive benefits in the absence of specific dosing for dental care.

The diagnosis shows that the precarious dosing in the Latacunga supply system is mainly due to the absence of dosing equipment that allows precise and continuous control of chlorine. This lack results in manual and unstable application of chlorine, resulting in varying residual concentrations in various sectors. In addition, there are limitations in the representativeness and frequency of data, which makes it difficult to accurately assess residual chlorine and fluoride in previous study periods.

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