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Dental Fluorosis in Children from Aguascalientes, Mexico: A Persistent Public Health Problem

Osiel González Dávila [1,2]

[1] Program for Longitudinal Studies, Experiments and Surveys, Center for Research and Teaching in Economics (CIDE), Sede Región Centro, Aguascalientes 20313, Mexico; osiel.gonzalez@cide.edu
[2] Mexican National Council of Science and Technology (CONACYT), Mexico City 03940, Mexico

Abstract: This paper estimates the prevalence and severity of dental fluorosis among participants in the first wave of The Aguascalientes Longitudinal Study of Child Development (EDNA). The analytical sample includes 1052 children in 100 public elementary schools. Dental fluorosis is determined using the Modified Dean's Index. There is a 43% general dental fluorosis prevalence, and the estimated Community Fluorosis Index is 0.99. Five municipalities report average groundwater fluoride concentrations above the official Mexican guideline value of 1.5 mg/L. In those municipalities, there is a 50% average dental fluorosis prevalence. An ordered logistic regression analysis indicates that obesity in participants increases the likelihood of suffering more severe dental fluorosis symptoms compared with normal-weight participants (OR = 1.62, $p < 0.05$). Households consuming tap water are more likely to have children suffering more severe dental fluorosis symptoms (OR = 1.63, $p < 0.05$). Children aged 8 years are more likely to present more severe dental fluorosis symptoms than their peers aged 7 years (OR = 1.37, $p < 0.05$). Dental fluorosis will persist as a public health problem in Aguascalientes State unless appropriate technologies for fluoride removal from water are installed and operated.

Keywords: dental fluorosis; water contamination; Mexico; children

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1. Introduction

Dental fluorosis and skeletal fluorosis are major public health concerns around the world. Regions with a high prevalence of such illnesses have been recently documented in Asia, particularly in China [1–4], India [5–8], Pakistan [9–11], and Sri Lanka [12–14]. In Africa, dental fluorosis is prevalent mainly in Sub-Saharan countries, including Kenya, Tanzania, Uganda, Ethiopia, Eritrea, Sudan, Ghana, Malawi, Niger, Nigeria, Mozambique, and South Africa [15–17]. In Latin America, dental fluorosis has been documented in Brazil [18–21], Argentina [22,23], and Mexico [24–27]. It is well-established in the public health literature that fluoride, commonly used in dental preparations (e.g., toothpaste, gels, and varnishes) or added to certain vehicles such as water, milk, and salt, is effective in preventing dental caries and the minimum fluoride concentration for obtaining such protection is 0.5 mg/L [28–30]. Communities where naturally occurring fluoride in water is very low may benefit from exposure to slightly higher fluoride concentrations to reduce caries prevalence [31,32], and might reduce bone fracture risk [33,34]. The U.S. Public Health Service suggests an optimal fluoride concentration in water of 0.7 mg/L, since this level has a protective effect against dental caries and reduces the risk of dental fluorosis [35]. Nevertheless, chronic exposure to high fluoride levels through water, food, and fluoridated dental preparations increases the likelihood of suffering dental and skeletal fluorosis [5,28,36,37]. The first edition of the Guidelines for Drinking-Water Quality published by the World Health Organization (WHO) in 1984 [38] recognized that dental fluorosis is associated with fluoride levels in drinking water above 1.5 mg/L. However, the WHO Guidelines for Drinking-Water Quality fourth edition states that fluoride drinking water concentrations between 0.9 and 1.2 mg/L may provoke mild dental fluorosis depending on fluoride exposure to other sources (with a 12% to 33% prevalence). Further, skeletal fluorosis may occur in regions where drinking-water fluoride concentrations range between 3 and 6 mg/L, and crippling skeletal fluorosis may develop if fluoride levels in drinking water exceed 10 mg/L [28].

In Mexico, some states report high fluoride concentrations in groundwater, and dental fluorosis is prevalent in such areas [24,39,40]. Aguascalientes is a state located in North-Central Mexico (see Figure 1) with an average altitude of 1951 m above sea level. Several studies have reported fluoride concentrations in groundwater above the limit of 1.5 mg/L, established in the official Mexican guideline (NOM-127-SSA1-1994 [41]) in some aquifers in the state (see [40,42–45]). In the early 2000s, dental fluorosis was identified as a critical public health problem in the state [42,43,45]. Using the 2001 National Dental Caries Survey, Betancourt-Lineares et al. [45] found an 83.8% dental fluorosis prevalence in Aguascalientes in a sample of 903 children aged 12 and 15 years old and estimated a 1.02 Community Fluorosis Index. Hernández-Montoya et al. [43] reported in 2003 a dental fluorosis prevalence higher than 50% in children living in zones where fluoride levels in drinking water were below the guideline value of 1.5 mg/L. Almost twenty years after those research papers were published, it is essential to assess the current dental fluorosis situation in the latest generation of children. This study aimed to assess the current prevalence and severity of dental fluorosis among elementary school children and determine if dental fluorosis is still a public health problem. This study also analyzed the association between socioeconomic variables, other risk factors, and dental fluorosis. The analysis data were obtained from the participants in The Aguascalientes Longitudinal Study of Child Development (EDNA). These data are unique because access to schoolchildren and their families is difficult. Additionally, the sample size allowed for conducting state-level analysis.

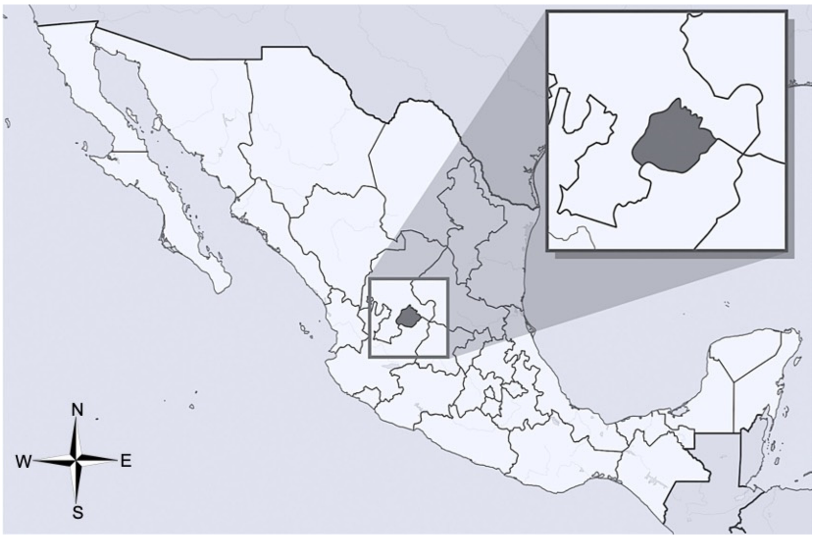

Figure 1. Aguascalientes location.

2. Materials and Methods

EDNA is a prospective, multi-thematic, and multidisciplinary longitudinal study following the cohort of children starting first grade in public primary schools of Aguascalientes, Mexico, in August 2016. This analysis used cohort data from the baseline survey conducted between 2017 and 2018 when the children were in their second elementary school year. The analytical sample for this analysis included 1052 children for whom information on dental fluorosis was collected. EDNA has a classic two-stage proportional-to-size design. The unequal selection probabilities of schools in the first stage are offset by the students' unequal selection probabilities in the second stage so that each student in the population has the same probability of entering the sample. Recontact is planned every two years for at least three waves. For further information on the sample design, see Miranda et al. [7]. Three professional and previously trained female examiners were in charge of individual interviews and dental assessments of children at their schools. They arrived by 8:00 a.m., beginning the morning shift, or by 1:00 p.m., beginning the afternoon shift, to prepare the facilities. Dental examinations occurred under daylight. The children's parents provided written informed consent, and the children provided verbal assent before the interview and dental examination. The prevalence of dental fluorosis was estimated using the Modified Dean's Index, which categorizes dental fluorosis using a zero to four scale. A value of zero means that the participant shows no fluorosis symptoms or that they are questionable. A value of one means very mild symptoms, two means mild symptoms, three means moderate symptoms, and four means severe symptoms. The frequency and distribution of dental fluorosis among participants were analyzed, and the Community Fluorosis Index (CFI) was estimated. Information about water fluoride concentrations was from the Mexican National Water Commission's water quality website [46]. The child's weight and height were also measured and recorded. Using the WHO Child Growth Standards of BMI-for-age z-scores, we assessed the children's nutritional status. The z-scores are also known as standard deviation (SD) scores and estimate how far a measurement is from the median. The WHO standards classify the children's nutritional status as follows: A BMI-for-age z-score < -2 SD is classified as underweight, a BMI-for-age z-score $> +1$ SD is classified as overweight, and a BMI-for-age z-score $> +2$ SD is classified as obesity [47,48]. Further socioeconomic information (household income per capita and principal caregiver's educational attainment) was obtained from a separate interview with the child's principal caregiver.

3. Results

The dental examination included 1052 children: 523 boys and 529 girls. Dental fluorosis symptoms were present in 46% of girls and 40% of boys. At the time of examination, 738 children were seven years old, and 314 were eight years old. Dental fluorosis symptoms were present in 44% of girls aged seven and 51% of girls aged eight years. On the other hand, 37% of boys aged seven and 48% of boys aged eight years showed dental fluorosis. Nevertheless, prevalence was similar across sex and age groups ($P \geq 0.06$). There was a 43% general dental fluorosis prevalence, with an estimated CFI of 0.99. Differences were observed across municipalities ($P < 0.05$) (Table 1). The average groundwater fluoride concentrations in ppm during the period 2012–2019 reported in the Mexican National Water Commission's water quality website [46] are next to the municipalities' name in Table 1. Average fluoride concentrations ranged from 1.16 to 6.27 F^{-} ppm. Five municipalities reported fluoride concentrations above the Mexican Official Norm during this period: Aguascalientes, Cosío, Jesús María, San José de Gracia, and Tepezalá. The average dental fluorosis prevalence there was 50%. Alarmingly, San José de Gracia reported an average concentration of 6.27 F^{-} ppm, which is four times the established limit. In participants from this municipality, there was a dental fluorosis prevalence of 78%.

Table 2 reports the dental fluorosis severity distribution according to sex, age, and the municipality of residence. In general, mild symptoms were the most prevalent (33%), then moderate (8%) and severe symptoms (2%). Severity was similar across sexes ($p > 0.10$). However, there were differences in severity across municipalities and age groups ($p < 0.05$).

Table 3 shows the results of an ordered logistic regression. The dependent variable is dental fluorosis using the Modified Dean's Index. The explanatory variables included are sex, age, the child's BMI, and the consumption or not of tap water in the child's household. The households' income per capita was divided into quintiles and was the first socioeconomic variable included. The second variable was the primary caregiver's educational attainment. Finally, the municipality of residence was included to control for regional effects. Children aged 8 years were 1.37 times more likely to present more severe dental fluorosis symptoms (95% CI 1.03–1.82) than their peers aged 7 years. Obesity in participants increased the likelihood of suffering more severe dental fluorosis symptoms compared with normal-weight participants (OR 1.62, 95% CI 1.08–2.42). Households consuming tap water were more likely to have children suffering more severe dental fluorosis symptoms (OR 1.63, 95% CI 1.03–2.60). In terms of regional differences, children residing in the municipality of Jesús María were less likely to suffer more severe dental fluorosis symptoms than children living in Aguascalientes, the capital municipality (OR 0.54, 95% CI 0.34–0.91). There were no statistical differences in terms of the principal caregiver's educational attainment and household income per capita.

Table 1. Prevalence of dental fluorosis by sex, age, and municipality.

Variables	With and without Dental Fluorosis *n*	Without Dental Fluorosis		With Dental Fluorosis		*P*-Value
		n	(%)	*n*	(%)	
Sex						
Male	523	312	(59.66)	211	(40.34)	χ^2 = 3.58
Female	529	285	(53.88)	244	(46.12)	*P* = 0.06
Age (years)						
Seven						
Male	369	232	(62.87)	137	(37.13)	χ^2 = 3.51
Female	369	207	(56.10)	162	(43.90)	*P* = 0.06
Eight						
Male	154	80	(51.95)	74	(48.05)	χ^2 = 0.32
Female	160	78	(48.75)	82	(51.25)	*P* = 0.57
Municipality						
Aguascalientes (1.90 F^- ppm)	625	359	(57.44)	266	(42.56)	χ^2 = 19.23
Asientos (1.32 F^- ppm)	49	29	(59.18)	20	(40.82)	*P* = 0.02
Calvillo (1.34 F^- ppm)	85	46	(54.12)	39	(45.88)	
Cosío (1.75 F^- ppm)	9	4	(44.44)	5	(55.56)	
Jesús María (1.77 F^- ppm)	100	68	(68.00)	32	(32.00)	
Pabellón de Arteaga (1.40 F^- ppm)	45	28	(62.22)	17	(37.78)	
Rincón de Romos (1.16 F^- ppm)	67	30	(44.78)	37	(55.22)	
Francisco de los Romo (1.34 F^- ppm)	31	12	(38.71)	19	(61.29)	
San José de Gracia (6.27 F^- ppm)	9	2	(22.22)	7	(77.78)	
Tepezalá (1.65 F^- ppm)	32	19	(59.38)	13	(40.62)	
Total	1052	597	(56.75)	455	(43.25)	

Table 2. Severity of dental fluorosis distribution according to sex, age, and the municipality of residence.

Variables	Healthy		Mild		Moderate		Severe		*P*-Value
	n	(%)	*n*	(%)	*n*	(%)	*n*	(%)	
Sex*									
Male	312	(59.66)	155	(29.64)	48	(9.18)	8	(1.53)	*P* = 0.113
Female	285	(53.88)	191	(36.11)	40	(7.56)	13	(2.46)	
Age (years) *									
Seven	439	(59.49)	233	(31.57)	54	(7.32)	12	(1.63)	*P* = 0.002
Eight	158	(50.32)	113	(35.99)	34	(10.83)	9	(2.87)	
Municipality †									
Aguascalientes (1.90 F^- ppm)	359	(57.44)	211	(33.76)	43	(6.88)	12	(1.92)	χ^2 = 20.03
Asientos (1.32 F^- ppm)	29	(59.18)	15	(30.61)	4	(8.16)	1	(2.04)	*P* = 0.018
Calvillo (1.34 F^- ppm)	46	(54.12)	26	(30.59)	12	(14.12)	1	(1.18)	
Cosío (1.75 F^- ppm)	4	(44.44)	4	(44.44)	1	(11.11)	0	(0.00)	
Jesús María (1.77 F^- ppm)	68	(68.00)	24	(24.00)	8	(8.00)	0	(0.00)	
Pabellón de Arteaga (1.40 F^- ppm)	28	(62.22)	13	(28.89)	2	(4.44)	2	(4.44)	
Rincón de Romos (1.16 F^- ppm)	30	(44.78)	24	(35.82)	10	(14.93)	3	(4.48)	
Fco. de los Romo (1.34 F^- ppm)	12	(38.71)	16	(51.61)	3	(9.68)	0	(0.00)	
San José de Gracia (6.27 F^- ppm)	2	(22.22)	5	(55.56)	1	(11.11)	1	(11.1)	
Tepezalá (1.65 F^- ppm)	19	(59.38)	8	(25.00)	4	(12.50)	1	(3.12)	
Total	597	(56.75)	346	(32.89)	88	(8.37)	21	(2.00)	

* Mann–Whitney, † Kruskal–Wallis.

Table 3. OLR analysis for dental fluorosis.

Variables	OR (95% CI)	*p* Value
Sex		
Male	1r	
Female	1.15 (0.89–1.49)	0.280
Age (years)		
Seven	1r	
Eight	1.37 (1.03–1.82)	0.032
BMI		
Underweight	1.16 (0.71–1.92)	0.553
Normal weight	1r	
Overweight	1.09 (0.70–1.70)	0.691
Obese	1.62 (1.08–2.42)	0.019
Water consumption		
Consumes tap water	1.63 (1.03–2.60)	0.038
Quintile		
1	1r	
2	1.29 (0.87–1.92)	0.212
3	1.38 (0.90–2.14)	0.143
4	1.35 (0.89–2.05)	0.159
5	1.37 (0.87–2.13)	0.170
Education		
None	0.94 (0.29–3.12)	0.925
Elementary	1.32 (0.93–1.86)	0.117
Junior High School	1r	
High School	0.98 (0.69–1.41)	0.928
Professional	0.73 (0.43–1.29)	0.284
Municipality		
Aguascalientes	1r	
Asientos	0.53 (0.24–1.01)	0.068
Calvillo	1.10 (0.66–1.74)	0.709
Cosío	1.21 (0.19–8.07)	0.842
Jesús María	0.54 (0.34–0.91)	0.014
Pabellón de Arteaga	0.67 (0.37–1.44)	0.239
Rincón de Romos	1.68 (1.00–2.84)	0.054
Francisco de los Romo	1.52 (0.78–3.02)	0.221
San José de Gracia	2.65 (0.79–9.59)	0.125
Tepezalá	0.78 (0.39–1.80)	0.543

4. Discussion

The Mexican Health Ministry considers dental fluorosis a public health problem when the Community Fluorosis Index (CFI) is higher than 0.6 [49]. In this study, the estimated CFI is 0.99, which is slightly below the 1.02 CFI found in the state in 2001 by Betancourt-Lineares et al. [45]. Therefore, in Aguascalientes State, dental fluorosis is still a public health problem. There is a 43% general dental fluorosis prevalence. The prevalence is higher (50% or more) in municipalities with groundwater fluoride concentrations above the 1.5 mg/L limit. Notably, some of the results obtained in this study are in line with other studies conducted in Mexico and around the world. For example, it is well-established in the literature that the consumption of tap water with fluoride levels above 1.5 mg/L increases the likelihood of suffering more severe dental fluorosis [28]. This relationship has been found in studies in different states of Mexico (see [50–53]) and around the world (see [54–56]). Therefore, it is essential to provide information to affected households about the increased risk of developing dental fluorosis associated with tap-water consumption. Tap water is reported as being consumed by 9.9% of the households. The children of those families are more likely to develop more severe dental fluorosis symptoms. However, it is well-documented in the literature that some other factors, such as high altitude and high fluoride concentration levels in water supplies, increase the likelihood of dental fluorosis in communities living in regions with such characteristics [57–60]. Therefore, people living in the state are at higher risk of developing dental fluorosis because the average altitude is 1951 m above sea level, and on average, the reported fluoride concentrations in groundwater is 1.99 mg/L.

In contrast, some other variables were not significantly associated with the presence of dental fluorosis. For example, some studies have found that dental fluorosis prevalence is lower among children whose parents have higher educational attainment, higher income level, or higher socioeconomic status (for examples in Mexico, see [50,61]; for examples around the world, see [62,63]). Although such variables were included in this analysis, the association was weak. It might be the case that information on dental-fluorosis-averting activities and fluoride reduction technologies is not available for households with higher socioeconomic status or that dental fluorosis is not considered a high-priority health problem for these households. There are, of course, limitations to this study. The data collected for EDNA´s first wave did not include information on some other relevant factors that may affect the prevalence and severity of dental fluorosis. Information about teeth brushing habits and, in general, about the consumption of food and beverages that are known to have high fluoride concentrations (e.g., tea and canned fish [30]) should be collected in the next wave. EDNA's questionnaire to the principal caregiver included a binary question about milk formula consumption during the child's lactation period. This variable was not included in the analysis as there was no information on the feeding frequency or the age at which children stop consuming milk formula. Some studies also reported an association between fluoride exposure and increased BMI z-score ([64,65]). However, further research is necessary to understand why obesity increases the likelihood of suffering more severe dental fluorosis symptoms. There may be other fluoride exposure routes through processed food or bottled beverages consumption. Thus, it is also imperative to analyze fluoride concentrations in such items, allowing the development of future dose–response studies. In terms of behavioral data, future research lines include the elicitation of time preferences and risk preferences in order to test if such preferences are associated with averting behaviors such as the use of water filters, low-fluoride-concentration toothpaste, or the consumption of bottled water, which may decrease the prevalence of dental fluorosis in the region.

Finally, federal, state, and municipal water authorities are aware of the high concentration levels of fluoride in several aquifers. There are publicly available governmental databases that report water quality at the municipal level (see [46]). Nevertheless, in the last ten years, no new water purification plants in Aguascalientes have been installed, and the existing plants' operation decreased by 33%. According to the National Inventory of Water Treatment and Purification Plants 2009, only three water purification plants using conventional clarification and filtration processes were operating in Aguascalientes State [66]. Regrettably, the Inventory's latest publication in 2019 reports only two water purification plants operating [67]. If no action is taken to treat fluoride-contaminated groundwater in the foreseeable future, dental fluorosis will continue to be a public health problem. There is evidence in the literature that decreasing fluoride concentrations in drinking water below the 1.5 mg/L guidelines in fluorosis endemic areas can decrease dental and skeletal fluorosis prevalence. For example, Wang et al. [68] reported that after reducing water fluoride concentration from 2.72 to 0.54 mg/L in endemic regions of China, the dental fluorosis prevalence in children decreased from 54.5% to 36.2%. Further, the skeletal fluorosis prevalence in adults decreased from 13.7% to 4.2%. Mohd et al. [69] found that a reduction in fluoride concentration from 0.7 to 0.5 mg/L in the public water supply in Malaysia decreased the dental fluorosis prevalence in children from 38.4% to 31.9%. Therefore, it is strongly recommended to install water treatment plants with the appropriate technology for fluoride remotion.

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Institutional Review Board Statement: Current Mexican law does not require academic institutions to operate IRB boards, and most institutions do not have one. In particular, CIDE had no IRB board during EDNA's first round. Despite this, EDNA complies with the strictest ethical standards. Every research topic included in the study has a clear social benefit, and all questions pose minimal risk to research participants. All interviewers received rigorous training, which included implementing safety protocols during fieldwork. All instruments were peer-reviewed and sensitive questions were carefully crafted to ensure minimal risk.

Informed Consent Statement: Informed consent was obtained from all participants involved in the study. Parents signed an informed consent form, and children gave their verbal assent before the interview and dental examination.

Data Availability Statement: All databases are published on EDNA's website (www.cide-edna.org (accessed on 16 February 2021)).

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