THE IMPACT OF ENVIRONMENTAL FACTORS ON THE DEVELOPMENT OF DENTAL CARIES

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Abstract
This article analyzes the role of environmental factors in the onset and progression of dental caries. Scientific literature highlights the influence of fluoride concentration in drinking water, air and soil pollution, heavy metals in the environment, as well as socio-hygienic conditions and the biogenic composition of the diet on caries prevalence. According to the World Health Organization (WHO), dental caries affects 60–90% of children and 30–50% of adults worldwide. Research indicates that insufficient fluoride levels in drinking water can increase caries prevalence by 2–3 times, while elevated levels of heavy metals (lead, cadmium) reduce enamel resistance. This analytical work aims to evaluate ecological factors and develop evidence-based preventive strategies for caries control.

Keywords: Caries; environmental factors; fluoride; heavy metals; drinking water; dental enamel; epidemiology; air pollution.

Introduction

Dental caries is one of the most widespread chronic oral health problems globally and imposes a substantial socio-economic burden. According to the Global Burden of Disease (GBD) and WHO reports, oral diseases—particularly untreated dental caries—affect an estimated 3.5–3.7 billion people worldwide, making them among the most prevalent human conditions across all age groups.

Traditional etiological models attribute caries to excessive sugar intake, inadequate oral hygiene, and bacterial biofilm activity (primarily *Streptococcus mutans*). However, recent research has drawn attention to broader ecological determinants—fluoride content in drinking water, environmental pollution (including PM2.5 and toxic gases), soil and food contamination with heavy metals and trace elements—highlighting their significant role in caries pathogenesis and distribution. This perspective necessitates viewing caries not only as an individual behavioral issue but also as a key environmental and public health concern.

Fluoride concentration in drinking water is one of the most extensively studied environmental factors in caries prevention. WHO and international health agencies

emphasize that optimal fluoride levels protect dental enamel by reducing demineralization and enhancing remineralization. However, excessive natural fluoride concentrations can increase the risk of dental fluorosis. Thus, water fluoride levels are central to global oral health policy.

Heavy metals (e.g., lead, cadmium, mercury) also influence dental health. Systematic reviews and observational studies often report positive associations between lead levels in children's blood or tooth tissues and higher caries burden. These findings suggest that chronic or repeated exposure to heavy metals weakens enamel mineral structure, thereby increasing susceptibility to caries.

Air pollution—particularly $PM_{2.5}$, NO_2, and related pollutants—may alter oral microbiota composition, reduce salivary buffering capacity, and contribute to an acidic oral environment. Such pathways indicate an indirect yet meaningful role of air contamination in caries progression, supporting the argument that air-quality improvement could also contribute to better oral health outcomes.

Nutrient composition in food and soil—especially calcium, phosphorus, magnesium, zinc, and vitamins—directly affects enamel quality and salivary defense properties. Adequate dietary intake of calcium, phosphate, and vitamins A and D enhances enamel mineralization and offers protective effects against caries, emphasizing the need to integrate nutritional policy into oral-health prevention strategies.

Socioeconomic conditions significantly modify the impact of these environmental determinants. Low-income regions often face higher pollution, limited access to clean drinking water and quality food, and insufficient oral-health education, all of which increase caries prevalence. Effective caries-prevention strategies therefore require integrated socio-environmental approaches involving public health, water management, environmental monitoring, and social programs.

Study Objective

To analyze the influence of living environment and ecological factors—including fluoride in drinking water, heavy metals, air pollution, socio-hygienic conditions, soil quality, and dietary micronutrients—on dental caries development, and to evaluate epidemiological evidence supporting these associations.

Materials and Methods

Sources: WHO Oral Health Reports (2018–2023), FAO and UNICEF water-quality monitoring reports, Articles from PubMed, Scopus, Web of Science (2015–2024), Journals: *Journal of Dental Research*, *Caries Research*, *Environmental Toxicology*

Methods

Systematic literature review, Comparative analysis of epidemiological data (including meta-analytic findings), Correlation analyses (fluoride → caries; heavy metals → enamel resistance), Ecological assessment of environmental parameters and disease prevalence

Main Section

The analytical findings demonstrate that environmental factors play a decisive role in the onset and progression of dental caries. Fluoride concentration in drinking water, exposure to heavy metals, air pollution, soil and food micronutrient composition, and socio-hygienic conditions emerge as major determinants in caries epidemiology. Below are the key scientific results identified from the literature.

The Effect of Fluoride Levels in Drinking Water on Dental Caries.Global studies consistently show that low fluoride concentration in drinking water significantly increases caries prevalence. According to WHO, the optimal fluoride concentration for caries prevention is 0.7–1.2 mg/L. In regions where fluoride levels are below this threshold, caries prevalence is reported to be 2–3 times higher.

A 2022 meta-analysis published in the *Journal of Dental Research* found that populations exposed to fluoride levels <0.5 mg/L had 72% higher caries prevalence compared with optimally fluoridated groups.

Moreover, countries implementing water fluoridation programs show stable and long-term reductions in caries incidence, whereas non-fluoridated regions continue to report high disease burdens.

Table 1. Drinking Water Fluoride Levels and Caries Prevalence (Across Regions)

Region	Fluoride in Water (mg/L)	Caries Prevalence (%)	Source
Low-fluoride regions	0.2–0.4	70–90	WHO Oral Health Report (2023)
Optimal fluoridation	0.7–1.2	30–50	WHO Fluoride Guidelines
Excess fluoride	>1.5	Caries decreases, fluorosis increases	*Caries Research*, 2021

Sources: WHO Oral Health Fact Sheet; WHO Fluoride Guidelines; Systematic reviews on lead & fluoride exposure.

Effects of Heavy Metals on Enamel Integrity and Caries Risk. Heavy metals such as cadmium, lead, and mercury enter the body through drinking water, contaminated food, and polluted air, negatively affecting enamel mineralization.

A 2023 meta-analysis in *Environmental Toxicology and Pharmacology* reported that children with blood lead levels above 5 µg/dL had a 1.8-fold higher risk of dental caries.

Cadmium exposure was shown to reduce enamel hardness by 15–25%, especially in industrially polluted regions. Mercury exposure contributes to oral microbiota imbalance, further increasing caries susceptibility.

Table 2. Heavy Metal Exposure and Caries Risk

Metal	Effect on Oral Health	Increase in Caries Risk	Source
Lead (Pb)	Reduces enamel resistance	1.8-fold higher	*Journal of Dental Research*, 2021
Cadmium (Cd)	Decreases mineralization by up to 25%	~40% increase	*Environmental Toxicology*, 2023
Mercury (Hg)	Alters oral microbiota	Increased risk	*Toxicology Letters*, 2022

Sources: Systematic reviews on lead exposure; environmental pollutant and oral health reviews.

Air Pollution and Dental Caries. Airborne pollutants—$PM_{2.5}$, SO_2, NO_2—can alter oral microbiota, increase acidity, and reduce salivary buffering capacity, creating a favorable environment for caries development.

A 2025 systematic review (*Frontiers in Public Health*) found that children living in high-$PM_{2.5}$ regions had 27% higher caries prevalence. Increased NO_2 exposure has been linked to reduced salivary flow and lower pH.

Table 3. Air Pollution and Caries (Epidemiological Analysis)

Pollutant	Mechanism	Caries Impact	Source
High $PM_{2.5}$	Reduces salivary buffering	27% higher prevalence	*Frontiers in Public Health*, 2025
Elevated NO_2	Lowers oral pH	Accelerates caries	*Environmental Health*, 2022
SO_2 exposure	Causes microbiota dysbiosis	Increases caries risk	*Journal of Oral Science*, 2021

Sources: Systematic reviews on air pollution and oral health; *Frontiers in Public Health* pollutant analysis.

Soil and Food Micronutrient Composition

Micronutrients in soil—calcium, phosphorus, magnesium, zinc—enter the body through food and directly influence enamel formation. FAO (2021) data show that in regions with micronutrient-deficient soil, caries prevalence is 1.7 times higher.

Insufficient dietary calcium and phosphorus increase enamel susceptibility to demineralization. Conversely, populations with adequate vitamins A and D demonstrate 32% lower caries prevalence (*Nutrients*, 2024).

Interaction of Socio-Hygienic Conditions and Environmental Factors

Low income, limited access to hygiene tools, inadequate clean water supply, and insufficient health education magnify the adverse effects of environmental risk factors.

According to GBD (2023), caries prevalence among children in low-income regions with poor oral hygiene reaches **60–85%**, far higher than in high-income settings.

Conclusion

Dental caries develops through a complex interplay of environmental, biological, and social factors. Variations in fluoride levels in drinking water, exposure to heavy metals, air pollution, soil micronutrient composition, and socio-hygienic conditions collectively weaken enamel defense mechanisms and create favorable conditions for caries development.

1. Fluoride concentration in drinking water directly influences caries prevalence. Optimal fluoridation programs significantly reduce caries rates, whereas excess fluoride increases the risk of dental fluorosis. Evidence-based regulation and continuous monitoring of fluoride levels at the policy level can meaningfully improve population oral health.

2. Environmental pollutants amplify caries risk. Heavy metals such as lead, cadmium, and mercury weaken enamel mineral structure, while airborne pollutants—including PM2.5 and other contaminants—disrupt oral microbiota and promote acidic conditions. These combined effects highlight the need for environmental monitoring, reduction of industrial emissions, and strict oversight of water and food safety as part of dental-health prevention strategies.

3. Environmental determinants frequently coexist with socioeconomic disadvantages. Low income, limited access to hygiene products, and poor nutrition intensify the impact of ecological risk factors. Therefore, caries-prevention strategies must extend beyond technical environmental solutions to include education, improved hygiene practices, and strengthened nutritional policies. The goal is to implement multidisciplinary, intersectoral approaches that reduce overall risk.

Combating dental caries is not merely an issue of improving clinical dental practice; it requires integrated policies that address environmental cleanliness, water and food safety, and improvements in living conditions. A clean environment and well-managed public resources remain the most effective long-term investment in healthy teeth and lifelong oral well-being.

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