Environmental risk factors associated with tooth decay in children: a review of four studies in Indonesia

Riesgos ambientales asociados con la caries dental en niños: una revisión de cuatro estudios en Indonesia

Fatores de risco ambientais associados à cárie dentária nas crianças: uma revisão de quatro estudos na Indonésia.

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Abstract

There is growing concern over studying the environmental impacts on human health. Among the world's population, children are particularly vulnerable to environmental threats.

Currently, in certain areas of Indonesia, there are significant problems with water quality, especially as many consume surface water for drinking. There is evidence that this contributes to tooth decay – the process of dental caries. Furthermore, teeth provide an excellent chronological record of nutritional status and trace metal exposure during human development.

This paper provides an overview of risk factors for dental caries and reviews four epidemiological and laboratory studies that have addressed these issues in Indonesia. First, Winanto in 1993 showed that acidity and high tin (Sn) concentrations in drinking water are associated with the erosion of permanent teeth in children living close to a tin mining area. Second, Wulandari in 2009, using Graphite Furnace Atomic Absorption Spectrometry (GFAAS), showed that deciduous teeth containing high concentration of lead (Pb) have 3 times higher risks of contracting caries. Third, Satrio in 2010 compared the dental status of children who consumed rain water with those using other sources of drinking water: this revealed that low concentration of Fluoride in drinking water contributes 19 times higher risk of dental caries and low pH 22 times the risk compared to water of neutral pH. Fourth, Musadad in 2009 undertook an ecological study on the effect of drinking water quality in relation to dental caries and revealed significant associations with acidity, total water consumption, household expenditure and the distance from a subject's residence to the nearest dental health provider.

Thus, in Indonesia, tooth decay is not only associated with poor diet and poor oral hygiene; it also reflects poor environment.

Keywords: environmental impact; drinking water quality; tooth decay.

Resumen

Existe una creciente preocupación por el estudio de los impactos ambientales en la salud humana. Los niños son particularmente vulnerables a las amenazas ambientales en cualquier parte del mundo.

Actualmente, en ciertas zonas de Indonesia, existen problemas con la calidad del agua, especialmente con el uso de aguas superficiales como fuente de agua potable para consumo humano. Hay evidencias de que ello contribuye a los procesos de aparición de caries dental. Por otra parte, los dientes proporcionan un excelente registro cronológico del estado nutricional y de la exposición a metales durante las etapas de desarrollo humano.
Este documento ofrece una visión general de los factores de riesgo de la caries y revisa cuatro estudios epidemiológicos y de laboratorio que han abordado estas cuestiones en Indonesia. En primer lugar, Winanto en 1993 mostró que la acidez y las altas concentraciones de estaño (Sn) en el agua potable están asociadas con la erosión de los dientes permanentes de los niños que viven cerca de una zona minera de estaño. En segundo lugar, Wulandari en 2009, utilizando espectrometría de absorción atómica en horno de grafito, mostró que los dientes temporales que contienen altas concentraciones de plomo (Pb) tienen un riesgo tres veces mayor de contraer caries. En tercer lugar, Satrio en 2010 comparó el estado dental de los niños que consumen agua procedente de la lluvia con los que utilizan otras fuentes de agua potable: esto reveló que el riesgo de aparición de caries dentales aumenta 19 veces con una baja concentración de flúor en el agua de bebida y 22 veces con un pH bajo en comparación con agua de pH neutro. En cuarto lugar, Musadad en 2009 llevó a cabo un estudio ecológico sobre el efecto de la calidad del agua potable en relación con la caries dental y reveló asociaciones significativas con la acidez, con la cantidad de consumo de agua, con el gasto de los hogares y con la distancia entre el domicilio y el proveedor de salud dental más cercano.
Por tanto, en Indonesia, la caries no solo se asocia con una mala alimentación y una higiene bucal deficiente, sino que también refleja las condiciones ambientales.

Palabras clave: impacto ambiental; calidad del agua potable; caries dental.

Resumo

Há uma crescente preocupação com o estudo dos impactos do ambiente na saúde humana. Entre a população do mundo, as crianças são particularmente vulneráveis às ameaças ambientais.
Atualmente, em algumas áreas da Indonésia, existem problemas significativos com a qualidade da água, especialmente devido ao uso de muitas águas superficiais para consumo humano. Há evidência de que isto contribui para o processo de cárie dentária. Além disso, os dentes fornecem um excelente registo cronológico do estado nutricional e indicação da exposição a metais durante o desenvolvimento humano.
Este artigo fornece uma visão geral dos fatores de risco para a cárie dentária e as revisões de quatro estudos epidemiológicos e laboratoriais que abordaram este assunto na Indonésia. Primeiro estudo: Winanto em 1993 mostrou que a acidez e concentrações elevadas de estanho (Sn) na água para consumo humano estão associadas com a erosão dos dentes permanentes em crianças que vivem perto de uma exploração mineira de estanho. Segundo estudo: Wulandari em 2009, recorrendo à espectrometria de absorção atômica com forno de grafite (GFAAS), mostrou que dentes decíduos que contenham uma alta concentração de chumbo (Pb) têm três vezes maior risco de contrair cárie. Terceiro estudo: Satrio em 2010, comparou o estado dos dentes entre as crianças que consumiam água da chuva e as crianças que consumiam água de outras origens. Este revelou que a baixa concentração de fluor na água contribui para aumentar 19 vezes o risco de cáries e que o consumo de água com pH baixo aumenta 22 vezes o risco de cárie quando comparado com o consumo de água com pH neutro. Quarto estudo: Musadad em 2009, realizou um estudo ecológico sobre o efeito da qualidade da água potável em relação à cárie dentária e revelou associação significativa com a acidez, a quantidade de água consumida, a despesa das famílias e a distância da residência a um serviço de medicina dentária.
Assim, na Indonésia, a cárie dentária não está associada apenas com a má alimentação e má higiene oral, mas também reflete a existência de más condições ambientais.

Palavras-chave: impacto ambiental; água para consumo humano; care dentária.

INTRODUCTION

Although a developing world provides many opportunities and challenges, many people face substantial barriers to their health, development and well-being in the form of environmental threats. Among the most vulnerable of the world's population are children, who are particularly susceptible to environmental hazards posed by air, water and ground pollution[1].

Water is essential to life, health and livelihood. Worldwide, there are still 884 million people in need of access to improved sources of drinking water. Expanding access to safe drinking water would drastically cut the loss of life from water-related illness and improve community health in developing countries[2].

In certain areas in Indonesia, people consume surface water for drinking and cooking, and the quality of this water is poor[3]. Contributing factors include the natural environmental phenomenon of acidic soil, high concentrations of potentially toxic minerals, combined with historically and culturally poor-hygiene practices. In addition, anthropogenic activities in peat swamp conversion, industrial pollution and unsustainable mining practices, also contribute to the poor state of the environment, especially regarding poor water quality.

The effect of poor quality drinking water on human health is often manifested in water-borne diseases such as bacterial diarrhoea and helminthic and other parasitic diseases. Across the whole population, dental decay is a sign of permanent damage to health. Moreover, teeth also provide an excellent record of nutritional status and environmental exposure throughout the life of a child[4].

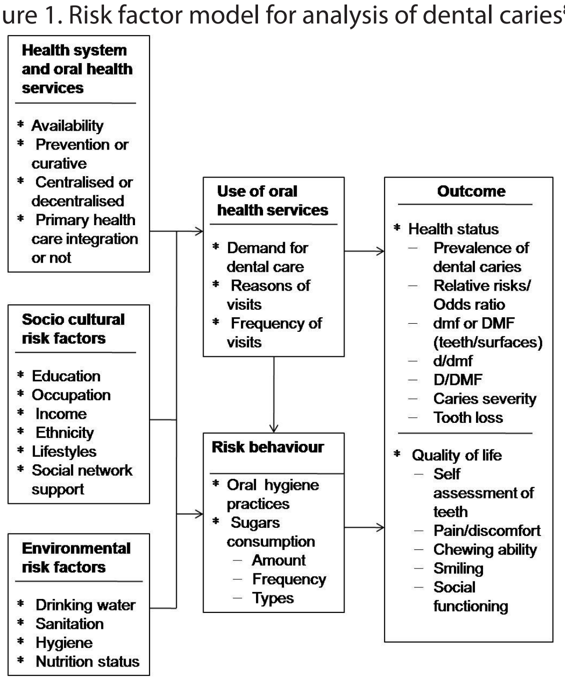
This paper analyses several studies of the high prevalence of both dental caries and dental erosion in regions of Indonesia, which have serious environmental problems.

a. Risk factors of tooth decay

The classical triad of epidemiology shows that disease results from the interaction between an agent and a susceptible host in an environment that supports transmission of the agent from a source to that host[5]. The same is true for the tooth decay.

Dental caries is a multi-factorial disease with four major aspects relating to susceptibility and resistance: namely host and tooth factors, the oral micro flora, dietary substrates- especially sucrose, and time[6]. Tooth structure and composition is strongly affected by the environment, especially during tooth development, *in utero* and during childhood: it is a reflection of disease, nutrition and overall body chemistry. Poor body chemistry can arise from disease, toxic food and drink, adverse effect of drugs, emotional stress and exposure to environmental pollutants[7].

Figure 1. Risk factor model for analysis of dental caries[8]



WHO strategies to reduce risk factors to oral health target environmental, economic, social and behavioural causes. Many epidemiological studies have revealed common risk factors related to socio-behavioural aspects, which connect oral health problems to other health issues, as can be seen in Figure 1[8].

The existing problems in oral health programs faced by many countries are limited resources, lack of political will and strong competition among other health priorities[9]. Hence, research priorities for Africa and Asia need to be focused on "policy initiatives in the holistic and community approach"[10].

b. Environmental risk factors for tooth decay

Research on the environmental cause of dental caries has been conducted for over a century. Cook, in 1914[11] postulated an inverse association between the prevalence of dental caries and water hardness. Dean in 1942[12] identified a significant inverse correlation between the concentration of fluoride in drinking water and tooth decay. High levels of fluoride (> 1.5 ppm), however, damage developing teeth causing fluorosis: protection against dental caries is absent under a level of < 0.5 ppm. This has led to the standard for the safety level of fluoride content to be between 0.6 and 1.0 ppm, depending on climatic conditions.

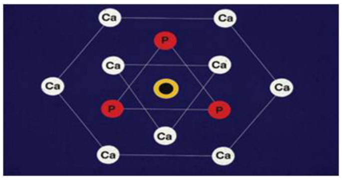
Fluoride in the environment comes from both natural and anthropogenic sources. Natural sources include rocks, such as granites and marine sediments, and emissions from geothermal or volcanic activity. Anthropogenic sources include industrial waste. All of these result in accumulation of fluoride in surface and groundwater reserves. In surface water, the fluoride level varies according to geographical location and proximity to emission sources. High concentrations are found in parts of East Africa, the Middle East, the Indian subcontinent, China, Western USA and Argentina[13].

High concentrations of fluoride in air are documented in communities in China that use high-fluoride coal for cooking[14]. Fluoride levels in fruits, vegetables and meats generally are very low except in tea and trona, the latter being a sedimentary salt added in cooking in Tanzania, which contributes to high fluoride ingestion and dental fluorosis[13]. Research regarding the potential adverse health effects of fluoride, notably to the skeleton and to any role in carcinogenesis is important, but no clear associations have been demonstrated with levels seen naturally around the world[13,15-19].

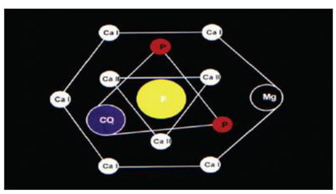
Laboratory studies have explained the mechanism of fluoride and other trace elements, along with calcium and phosphate ions, in strengthening the hydroxyapatite structure of dental enamel, as shown in Figure 2[20].

Figure 2 Unit cell of hydroxyapatite[20]

2a. Unit cell of hydroxyapatite showing central hydroxyl ion surrounded by triangles of calcium and phosphate, the whole surrounded by a hexagon of calcium ions



2b. Unit cell of hydroxyapatite showing central hydroxyl ion and possible location of substitute ions notably carbonate, magnesium and fluoride. Fluoride can replace the hydroxyl ion. Instead of destabilizing the crystal, its high electro negativity and symmetrical charge distribution result in a more stable crystal that is less soluble in acid



Investigation of water-borne trace metals other than fluoride, which might be associated with dental caries, began four decades ago in Colombia, South America. Children aged 8-14 years old in Heliconia village showed a low Decayed Missing Filled Teeth (DMFT) index: 6, meaning that in one person, there are 6 decayed, filled or missing teeth due to dental caries. In contrast, in Don Matias village the DMFT index is very high, 14. Diets were similar. Water samples were collected from individual homes in Heliconia and Don Matias, 41 and 50 respectively. Emission spectroscopy and measures of unbound fluoride, using a fluoride-sensitive electrode, showed the mean level of fluoride was very low < 0.1 ppm, in both villages. Further analyses revealed that concentrations of calcium, magnesium, molybdenum and vanadium were higher in the water samples from the village with a lower caries prevalence. On the other hand, concentrations of copper, iron and manganese were higher in the samples from the village with a higher caries prevalence[11].

c. Teeth as a biomarker of environmental exposure

Human teeth provide a nearly permanent and chronological record of an individual's nutritional status and trace metal exposure during development; it might provide an excellent bio-indicator of environmental exposure[21-23].

Elemental bio-imaging employing laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) can display the heterogeneity of trace elements throughout tooth structure, which correspond to specific structural life stages of tooth development, including each semester of prenatal development and early childhood[24,25].

Studies of lead concentrations in human teeth, using (LA-ICPMS), have shown that the spatial distribution of lead in dentine reflects blood levels at the time that specific layers of dentine are laid down[26]. Another study using Graphite Furnace Atomic Absorption Spectrometry (GFAAS) showed that lead accumulated in the surface enamel of deciduous teeth is linked to the environment in which people reside[27].

A study using Inductively Coupled Plasma Mass Spectrophotometry (ICP-MS) investigated the trace element content in teeth from children living in an area where endomyocardial fibrosis (EMF), a serious cardiac disease, is prevalent[28].

The value of teeth as substrates for toxicological analyses is greater than blood, bone or hair as biomarker of environmental exposure, because teeth cover a much longer lifespan[4,21,25,28].

METHODS

The overall aim of this paper is to report the environmental risk factors associated with dental disease in Indonesia. Cases of dental caries or tooth cavity, and surface erosion of teeth have been included. Tooth cavity is the result of demineralization of hard tissue due to acid from bacterial fermentation of debris. Tooth erosion is the loss of dental hard tissue, associated with acid that is not produced by bacteria.

The environmental state relates to both natural and anthropogenic factors. Of the study areas (Figure 3), two are rural (Bangka and Cilacap regency), one urban (Bandung city) and urban-rural areas in all regencies of Bangka Belitung. Three studies sampled school children and 1 study sampled households covering children > 12 years old, as well as adults.

Figure 3. Location of Study Areas

Modified from map of Indonesia[29]

All of the studies conducted interviews, examinations of the mouth, sampling of water and laboratory analysis. Questionnaires probed confounding factors of dietary habits, oral hygiene and access to dental health services. Oral health examinations were performed in accordance with WHO guidelines[30]. In 2 studies, one by Winanto and the other by Wulandari, the extraction of a permanent tooth[31] and an exfoliated deciduous tooth[32] was followed by further laboratory analysis of trace mineral concentrations.

Samples of drinking water were collected from individual sources to be analysed for physical and chemical parameters. Spectrophotometry was used in the laboratory analysis of the trace elements in teeth. Satrio[33] conducted microbiological tests to identity *Streptococcus mutans*. A summary of the methods used in these studies is shown in Table 1.

Table 1. Summary of the Method of the Studies

	Winanto[31] Bangka regency, Bangka- Belitung Province	Wulandari[32] Bandung city, West Java Province	Satrio[33] Cilacap, Central Java Province	Musadad[34] All regencies, Bangka Belitung Province
Aims	To investigate the association between the consumption of drinking acidic water containing tin (Sn) and dental erosion in children	To study the relationship between lead (Pb) and dental caries in deciduous teeth of primary school children	To investigate the influence of drinking behaviour on dental caries of the primary school students consuming rain water	To study the association between drinking water quality and dental caries in permanent teeth.
Dependent Variable	Dental Erosion in permanent teeth	Dental Caries in deciduous teeth	Dental Caries in permanent teeth	Dental Caries in permanent teeth
Independent Variables	Concentration of tin (Sn) and pH in drinking water	Concentration of lead (Pb) in exfoliated deciduous teeth	Concentration of Fluoride and pH in Rain Water as drinking water	Drinking water quality, household expenditure, access to health care
Study type	Case and Control	Cross Sectional	Cross Sectional	Cross Sectional
Population & Sample	School children aged 10-18 yrs, - 200 Cases (have teeth erosion) - 200 Controls	265 School children aged 6-8 yrs	School children aged $\geq$ 10 years - 60, rain water consumers - 60 controls	400 respondents, 12-65 years of age in 200 household
Data collection and analysis	- Oral examinations - Interview (questionnaires: socio-behaviour, oral hygiene, diet) Laboratory experiment: - Measurement of pH and tin - Test the solubility of enamel in a tin solution with different pH - Measurement of ion Calcium with AAS and Ion Phosphorus with Visible Light Spectrophotometry	- Oral examination - Extraction of incisor (persistence tooth) - Questionnaires (oral hygiene, diet) - Food recall for Ca intake. - Sample of drinking water to measure Pb Laboratory : - Measurement of Pb in teeth using GF-AAS, Ca in teeth with AAS - Concentration of Pb in drinking water	- Oral Examination - Interview (questionnaires) - Samples of drinking water: rain water and other sources - Specimen from dental caries for microbiology analysis Laboratory : - Water Analysis to measure pH and Fluor concentration using Alizarin method. - Microbiological analysis to detect *Streptococcus mutans*	- Oral Examination - Questionnaires (socio-behavior factor) - Sample of drinking water from each household Laboratory: - Drinking water quality; analysis of physical and chemical parameters

RESULTS

Two studies revealed the significant association between acidic drinking water and dental caries and one showed a similar association with tooth erosion. The different concentrations of trace mineral tin and lead were also correlated with tooth decay. Dietary habit and oral hygiene practice was shown to be significant in two studies. Significant findings of all studies are summarised in Table 2.

Table 2. Summary of significant findings

Winanto[31] Bangka regency, Bangka-Belitung Province	Wulandari[32] Bandung city, West Java Province	Satrio[33] Cilacap, Central Java Province	Musadad[34] All regencies, Bangka-Belitung Province
• The consumption of acidic drinking water containing tin increased the teeth erosion cases (odd ratio 13.78) coefficient contingency Cramer (C) 0.395 • The different percentage of OR Mantel-Haenszel and crude OR of variable 'storing drinking water' (39.89%) meaning that this confounding factor has effect compared to the research variables. • The increase of tin content and acidity level resulted in the increase of enamel solubility	• Calcium intake in this population is 288.72 mg/day below the standard of 600 mg/day • The average of Pb in teeth is 2.41 µg/g (CI 2.03-2.79). • The cut-off Pb point; the median of free caries teeth unit group is 1.55 µg/g • Individuals with teeth containing Pb>1.55 µg/g have 2.78 higher risk of having caries than those below 1.55 µg/g, after being controlled by oral hygiene	• The group with low Fluoride concentration in drinking water has 18.875 times higher risk of dental caries • Drinking acidic water has amounted to the risk of dental caries 21.916 higher than those who drink normal one. • All caries specimens positively contain Streptococcus mutans. • The students who drink rain water are more likely to suffer from dental caries 1.059 times greater than those who consumed well water • Consumption of high category of cariogenic diet contributes 8.696 times greater risk of caries than those in low categories	• Factors at individual levels showed a positive association between dental caries with oral hygiene and mouth rinsing habit. • Factors at household level showed that factors associated with dental caries are: water acidity (pH), sum of water consumption, household expenditure and the distance from residential to the dental health provider. • Multivariate analysis revealed that the role of compositional factor in individual level to the individual dental caries is 9.4 %, the rest, 90.6% is affected by the variation among contextual factors in the household level. Acidity and sum of water consumption have 17.2 % contribution to dental caries in individual.

DISCUSSION

When studying the spectrum from environmental hazard exposure to health effects, it can be observed that the organs and systems of the body may be adversely affected. This can vary from slight asymptomatic physiological and biochemical responses, to individual perceptions or symptoms of sickness, to clinically diagnosed disease and finally to death. Susceptibility is also influenced by the individual's characteristics such as age, race, behaviour, hygiene, dietary pattern and coexisting health conditions[35]. Quantification of the relationship between exposure and health effects also requires the assessment of confounders, because measurement error in confounders may also affect the health risk estimates[36,37].

All of the studies reviewed here commenced with interviews using questionnaires to investigate the possible confounding factors, which included the dietary habits, oral hygiene practice and access to oral health services.

Winanto[31] strengthened the limited causal-effect association through epidemiological survey with a laboratory experiment, which showed that the high concentration of tin is positively associated with tooth erosion. The difference in percentage between OR Mantel-Haenszel and crude OR of < 10-15 % indicates that the confounding factor has a relatively small effect compared to the research variables (age 4.65 %, local acidic food 3.27 %, *rujak suun* (pickles) 6.25 %, boiling drinking water 0.94 %). The value of 'storing drinking water' is 39.89 %, meaning that how respondents stored water from the abandoned tin mining hole, before they used it as drinking water, had an effect on the incidence of tooth erosion.

The Musadad[34] study, using a household as the sample unit, revealed that oral hygiene practice, household expenditure and the distance between a subject's residence to the nearest dental health centre, positively correlated with dental caries. However, his study showed that low pH in water had a significant association with dental caries, and this is consistent with the finding of Satrio[33].

Satrio[33] showed the well-known phenomenon that fluoride is essential in preventing dental caries. This study also revealed that children who consumed rainwater were more likely to have many more cavities that those who used well water as the source of drinking water.

Thus, three of the studies revealed the positive correlation between low pH in drinking water with both dental erosion and dental caries. These findings support the studies investigating the effect of acid drinking water on dental decay[38,39].

After controlling for oral hygiene index, Wulandari[32] showed that individuals whose teeth contained Pb $\geq$ 1.55 µg/g had about 3 times higher a risk of having caries than those with less than 1.55 µg/g. In line with Robinson's theory[20], lead ions can replace the calcium ions and result in destabilization of the hydroxyl apatite-crystal and a change in the tooth structure. This research supported other findings of lead related dental diseases[26,27].

Other epidemiological studies, in-vitro laboratory analysis and mapping endemic areas across the globe have revealed a variety of results regarding fluorosis and dental caries associated with trace elements in any source of drinking water including natural, treated and bottled water[40-51].

Winanto[31] and Satrio[33] highlighted the dental health problem faced by children lacking access to safe drinking water, which resulted from natural and anthropogenic environmental factors in rural areas. On the other hand, Wulandari[32] showed the impact of industrial and urban pollution on children's dental health. Musadad[34] showed that both lifestyle and environmental risk factors contributed to the incidence of tooth cavities.

Recommendation

Each piece of research led to recommendations specific for the particular research area. There were some issues common to all. Firstly, from a health perspective, dental health education needs to be intensified, particularly for school children, to improve oral health status. Secondly, it is necessary to engage related stakeholders, such as the department of environment, public works, mining and home affairs, to minimize health impacts of human activities.

CONCLUSION

Environmental risks to children vary from region to region. Children in some areas still face the major traditional environmental hazards, including unsafe water, lack of sanitation, contaminated food and exposure to a myriad of toxic heavy metals, chemicals and hazardous wastes that may be faced at home, at school or in the playground. In addition to these traditional environmental hazards, due to rapid changes in economic structures, technologies and demography, new or modern environmental hazards have appeared or been recognized, such as increasing industrialization and pollution in urban settings[52].

Interventions on children's health and environment should benefit and contribute to broader efforts aimed at reducing the environmental threats to health. Interventions need to address health and environmental problems, with a view to optimizing benefits in both sectors[53].

Field epidemiology and laboratory research in several areas of Indonesia have revealed that among this specific vulnerable group, tooth decay is not only associated with lifestyle and limited access to health services; it also reflects poor environmental conditions. Hence, there is a need to promote a comprehensive approach to overcoming environmentally related diseases.

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