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Spatial distribution of groundwater fluoride levels and population at risk for dental caries and dental fluorosis in Sri Lanka

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Objectives: To investigate the distribution of groundwater fluoride levels in Sri Lanka in relation to its population distribution to determine the population at risk for dental caries or dental fluorosis. **Methods:** The study used the most upgraded spatial distribution map of groundwater fluoride levels in Sri Lanka, and it was overlaid with a census of population data of the country. **Results:** The results indicated that 12% of children aged <12 years were at risk for dental fluorosis, while 81.4% of those who lived in low-fluoride zones were vulnerable for development of dental decay. Overall, 82.4% of the country's population lived in low-fluoride zones and 11.2% were at risk of potential health hazards posed by ingestion of excessive fluoride. **Conclusion:** The spatial approach provides a useful decision-support tool for developing an oral health strategy of safe fluoride use based on predicted oral health risks in communities.

Key words: *Groundwater, dental fluorosis, dental caries, spatial distribution*

INTRODUCTION

Dental caries and dental fluorosis – two major, but preventable, oral diseases and public oral health problems – share the two extremes of a common environmental risk factor, namely the fluoride level in natural groundwater sources. Fluoride ions in drinking water are well known for having both beneficial and detrimental effects on oral and general health[1]. Fluoride has been recognised as a 'double-edged sword' because of its beneficial effect in small amounts but its toxicity when safe limits are exceeded[2]. Very low concentrations of fluoride in drinking water are associated with a higher risk for dental caries, while a very high fluoride concentration can cause dental and skeletal fluorosis and many other systemic health issues.

Studies carried out in the USA and Europe in the 1950s demonstrated a link between improved dental health and increased fluoride levels in drinking water and this is considered to be one of the greatest accomplishments in 20th century dental public health[3]. Furthermore, studies conducted using naturally fluoridated water supplies showed that at a fluoride concentration of 0.5–1.5 mg/L there was a reduction in caries, with no associated dental fluorosis or only questionable mottling of the teeth if the fluoride concentration exceeded 1 mg/L. However, when the fluoride concentration exceeds 1.5 mg/L in drinking water, it can cause dental mottling and discoloration, commonly known as dental fluorosis[4]. Skeletal deformities have also been reported in known fluoride belts in range of countries following ingestion of 4–10mg/L of fluoride via drinking water[5]. Therefore, both geoscientists and dental public health specialists have an important role in assessing the environmental risk of fluoride. This involves the identification and amelioration of problems in areas where people are at risk for dental caries because of exposure to no or only a low level of fluoride, or are at risk for dental fluorosis and other potential systemic health hazards as a result of ingestion of high concentrations of fluoride.

Safe fluoride use is the single most effective public health measure for reducing dental caries across populations, with its most pronounced effects occurring in those who are most at risk[6,7]. Hence, fluoride was added to public water supply schemes in many countries in order to raise the concentration of fluoride ions to a level that effectively prevents caries, and this was the most successful approach for dealing with wide inequalities in access to oral health care across the population[7]. However, the most important action of fluoride is topical, through direct contact of fluoride with the tooth surface by use of fluoride toothpaste and other topical fluoride modalities. Scientific evidence for the topical action of fluoride in preventing demineralisation and promoting remineralisation, and its antibacterial efficacy, have been strongly established and it has been noted that, for fluorides to have a lifelong effect, they must be used regularly throughout life[8].

Sri Lanka is an island with a total population of 20.3 million, and the climate is tropical. The southwest region of the country, including the inland, receives 2500 mm/a average rainfall, while the remaining north, north-central and eastern parts remain dry around 7 months period of the year (May–September)[9]. The climate in lowlands of Sri Lanka is arid and semi-arid, and mean annual temperature in the lowlands stands at 27.5 °C[10]. In Sri Lanka, groundwater resources that exceed the World Health Organization (WHO) water quality guideline of 1.5 mg of fluoride (F) /L are widespread in the dry zone and referred to as areas of 'endemic fluorosis'. Fluorosis has been prevalent for a long time among the population in most parts of the dry zone as a result of consumption of naturally occurring groundwater containing a high level of fluoride[11,12]. Nearly 80% of children living in the dry zones of Sri Lanka are affected with mild to severe forms of clinically detectable fluorosis on their teeth; most present with milder forms[13,14]. Moreover, fluoride in groundwater has also been reported as a contributory factor in the aetiology of chronic kidney disease in arid regions in tropical countries, including Sri Lanka[15]. Chronic kidney disease is the most widely spread systemic health condition in some districts in the dry zone of Sri Lanka; however, identifying a definitive cause is still challenging and therefore this condition is referred to as chronic kidney disease of unknown aetiology (CKDu)[16].

Similarly, dental caries also remain as a major public health problem worldwide, including Sri Lanka, causing widespread pain, discomfort and dysfunction in all age groups[17]. Dental caries is also one of the most costly diet-related diseases in the world: untreated caries in permanent teeth accounts for the highest proportion of productivity loss in South Asian countries[18]. Despite a significant reduction in dental caries in the last 20–30 years, particularly in children, only some of this improvement has carried through to adulthood, with high levels of dental caries persisting in the Sri Lankan population[19,20]. According to the last Sri Lankan National Oral Health Survey in 2002–2003, caries experience in the primary dentition of children was high, and the prevalence of early childhood caries in 5-year-old children was reported as 65%. On average, each child in this age group experienced more than three decayed teeth. The reported prevalence of dental decay among 12- and 15-year-old schoolchildren was 39% and 52%, respectively[20]. Dental caries was the most prevalent health problem to be identified and reported in annual school medical inspections among schoolchildren in Sri Lanka[21].

The fluoride dosages ingested may differ in different countries or areas based on climatic conditions, as people in hot, humid countries will drink a larger volume of water than people in countries with cooler temperatures. Based on these assumptions, Galagan and Vermillion[22] developed a method for controlling the level of fluoride ingested that took into consideration the annual mean maximum temperatures, and 0.7 mg/L was recommended for temperate countries with average temperatures of 31–34 °C. The WHO standards recommended control limits ranging from 0.6 to 0.8 mg/L for temperatures of 26.3–32.6 °C[23]. The WHO further emphasised that climatic conditions, volume of water intake and intake of fluoride from other sources should be considered when setting national standards for fluoride levels in drinking water[23]. In 1992, the optimal level of fluoride recommended in drinking water in Sri Lanka was 0.6–0.9 mg/L for caries protection, and 0.8 mg/L of fluoride was suggested as an appropriate upper limit for the control of dental fluorosis[24]. These values were determined after examination of only 380, 14-year-old children, together with 380 water samples from their domestic source of drinking water, in four geographical areas of the country[24]. With the emerging evidence of fluoride as a contributory factor for CKDu in the dry zone of Sri Lanka[15], the control limits for fluoride are currently under review. In Sri Lanka, nationally accepted control limits for fluoride have not yet been established and further research with a sufficiently large sample size is required for setting up national standards. The 1986 hydrogeological map of groundwater fluoride in Sri Lanka[25] was upgraded in 2011 to take into account the drastic changes in water quality in recent years following development of various irrigation schemes[12].

The aim of this study was to provide a detailed estimate of the distribution of populations at risk for dental fluorosis and dental caries in Sri Lanka based on the upgraded F map, using Geographic Information System (GIS) technology. GIS is a promising technology used for detailed analysis of fluoride levels in groundwater sources in many localities worldwide[26,27]. The maps generated have been used by relevant planners and policy makers for making appropriate recommendations and interventions at community level for preventing dental caries, while minimising dental fluorosis and other systemic health hazards.

The findings of this study could inform the development of strategies to ensure sustainable oral health improvements in Sri Lanka. It could also contribute to make informed decisions to address the problem of unsafe fluoride levels in drinking water and thereby prevent associated health issues.

MATERIALS AND METHODS

The study used a cross-sectional study design. It describes the spatial distribution of fluoride levels in natural groundwater sources relative to socio-demographic characteristics of the Sri Lankan population. Ethical clearance was not considered as necessary for this study as the data used were open access and available online for public access.

Sources

The information on groundwater fluoride levels was obtained from the latest upgraded contour map showing the spatial distribution of groundwater fluoride levels in Sri Lanka[12]. It was based on groundwater fluoride data from 14,500 primary and secondary natural water sources. Population data were obtained from the most recent population census in 2012, retrieved from the Census and Statistics website of Sri Lanka[9].

Population

The population census data were available at high resolution that divided the country into provinces, districts and 'Grama Niladari' areas (GN), where GN is the smallest level of administration unit in Sri Lanka[9]. The population census data at GN levels were used, and centroids were added to each of the GNs for population location. First, the age category of <12 years was used to analyses the population at risk for dental fluorosis as this age range covers the entire developmental period of the permanent dentition except third molars. Second, the total population was used to analyse the population at risk for dental caries and systemic health hazards.

Cut-off levels for fluoride

The groundwater fluoride level was categorised into five basic levels in the F map, namely <0.5, 0.5–1, 1–1.5, 1.5–2 and >2 mg/L. The WHO water quality guideline values and the Sri Lankan standards, based on available literature and expert opinion, were used in the analysis. The dental caries risk was estimated based on exposure to a groundwater fluoride content of <0.5 mg/L. The Sri Lankan evidence available for maximum caries protection (0.6–0.9 mg/L) was approximated to 0.5–1 mg/L as this was the closest match with the classification used in the F map[24]. The dental fluorosis risk was estimated based on exposure to a groundwater fluoride content of >1 mg/L as this was the value with the closest match to the upper limit (0.8 mg/L) for control of fluoride, as agreed by Sri Lankan research[24] and the WHO standards for tropical climates[23].

Geocoding approach

The existing water fluoride map[12] was digitised by hand and integrated with the population data using QGIS 2.14.1. All data were transformed into Coordinate Reference System WGS84 for analysis. The GN shapefiles were integrated with the hand-digitised map and centroids of each GN used to determine the fluoride 'zone' that each GN was included. This method is consistent with many previous studies in the field. It was noted that 2.4% (489,000) of the total population and 3.5% (159,000) of the child population were not recorded as they were not appropriately linked to a specific GN. Thus, 19.6 million (more than 96%) of the 20.3 million total population in the 2012 census were included in the analysis.

RESULTS

The fluoride intake associated with dental fluorosis occurs especially in childhood, whilst that of importance to prevent dental caries and some systemic health hazards occurs along the whole life course. Hence, it was important to interpret the data separately for children (12 years and younger) and the total population.

Children exposed to different groundwater fluoride levels

The total number of children under the age of 12 years in Sri Lanka, in 2012, was 4.39 million. The results of the present study indicated that 12% of children aged <12 years (0.52 million) were exposed to water fluoride levels of > 1.0 mg/L and therefore could be considered to be at higher risk for fluorosis. Based on the WHO cut-off of 1.5 mg/L of fluoride, however, the number of children at risk for fluorosis decreases to only 2.4% (0.1 million). If the cut-off was lowered to 0.5 mg/L of fluoride, the at-risk child population increases to 18.6% (0.82 million).

In the present study, we found that 81.4% (3.57 million) of children lived in low-fluoride zones, where groundwater fluoride levels were <0.5 mg/L. These very low levels of fluoride might indicate higher risk of dental caries in children, especially in the absence of exposure to other sources of fluoride, such as toothpaste. The maximum degree of natural caries protection according to national standards (i.e. groundwater fluoride levels of 0.5–1 mg/L) was available only for 6.6% (0.28 million) of the child population. With respect to the WHO recommendations of 0.5–1.5 mg/L, however, this number increases to 30.6% of children (*Table 1* and *Figure 1*).

Groundwater resources with fluoride levels of >2 mg/L were located in the districts of Anuradhapura and Kurunegala. In the Anuradhapura district, 17% (0.03 million) of children were at high risk (>2 mg/L) while almost 90% (0.18 million) were at risk of consuming water containing fluoride levels of >1 mg/L. In Kurunegala, only 1% of children were at high risk (>2 mg/L) and 21% were at risk of ingestion of fluoride levels >1 mg/L. In the Polonnaruwa district, almost 86% (0.07 million) of children fell into the risk group exposed to water fluoride levels of >1 mg/L. Hambantota, Ampara, Matale, Monaragala, Vavuniya and Trincomalee districts also emerged as having high fluoride levels, therefore posing varying degrees of risk of fluorosis to the child inhabitants.

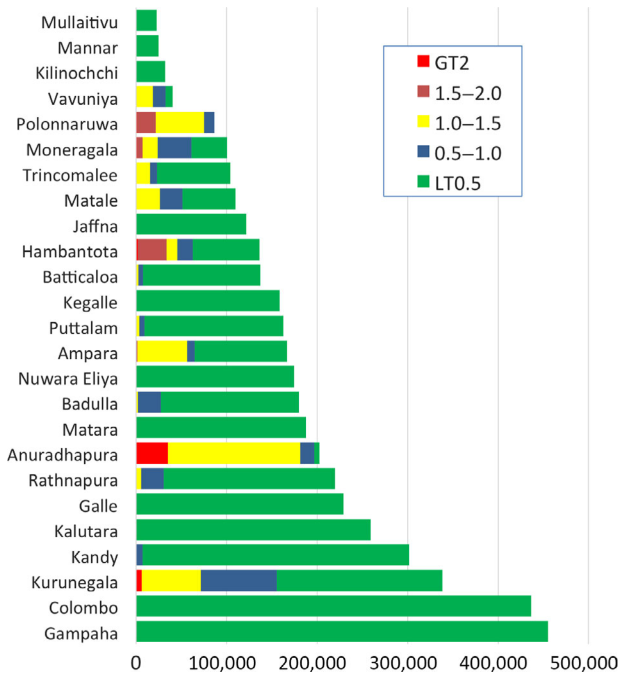

Figure 1. Number of children <12 years of age exposed to different groundwater fluoride levels in different districts in Sri Lanka. Note: fluoride content in groundwater: >2.0 mg/L (GT2), 1.5–2.0 mg/L, 1.0–1.5 mg/L, 0.5–1.0 mg/L, <0.5 mg/L (LT0.5).

Total population exposed to different groundwater fluoride levels

Further analysis of the total population of the country found that 11.2% (2.2 million) of all people were exposed to water containing more than 1 mg/L of fluoride. This number decreased only to 2.3% (0.45 million) if analysed based on WHO cut-off levels of 1.5 mg/L. If the cut-off of 0.5 mg/L of fluoride was used, the population at risk for dental fluorosis was 17.6% (3.5 million).

The majority of the population (82.4%, 16.1 million) lived in low-fluoride zones, where levels of fluoride in water were <0.5 mg/L, and they might be at higher risk for dental caries in the absence of fluoride exposure from other sources. Maximum natural caries protection was ensured only for 6.4% (1.2 million) of the population according to the national standards (0.5–1 mg/L). However, it was ensured for 15.3% (3 million) with respect to the WHO recommendations of 0.5–1.5 mg/L (*Table 2* and *Figure 2*).

The distribution pattern of the at-risk population of all ages showed a similar pattern to that of children aged <12 years (*Figure 1*). In the Anuradhapura district, 17% (0.14 million) inhabitants were included in the high-risk category (>2 mg/L), while almost 90% (0.7 million) were exposed to groundwater fluoride levels of >1 mg/L. In the Kurunegala district, only 1.7% of people (0.02 million) were severely at risk and 20% were exposed to fluoride levels of >1 mg/L. In the Polonnaruwa district, almost 86% (0.3 million) of people fell into the risk group of exposure to fluoride levels of >1 mg/L. Similarly, people in Hambantota, Ampara, Matale, Monaragala, Vavuniya and Trincomalee districts are all at substantial risk, showing varying degrees of exposure to high fluoride.

DISCUSSION

Oral diseases and disorders affect almost all members of the Sri Lankan community. This study provided reasonable estimates on population at risk for two major public oral health problems – dental fluorosis and dental caries. These conditions remain prevalent in Sri Lanka despite advancements in clinical dentistry and the countrywide community-based oral health-

Table 1 Exposure of children <12 years of age to different groundwater fluoride levels in Sri Lanka

	Fluoride level (mg F/L)					
Variable	<0.5	0.5–1.0	1.0–1.5	1.5–2.0	>2.0	Total
Number exposed	3,572,794	289,939	421,275	60,166	45,583	4,389,759
Percentage exposed	81.4	6.6	9.6	1.4	1	100

Table 2 Exposure of the population in Sri Lanka to different groundwater fluoride levels

	Fluoride level (mg F/L)					
Variable	<0.5	0.5–1.0	1.0–1.5	1.5–2.0	>2.0	Total
Number exposed	16,172,383	1,247,215	1,751,315	251,368	196,734	19,619,015
Percentage exposed	82.4	6.4	8.9	1.3	1.0	100

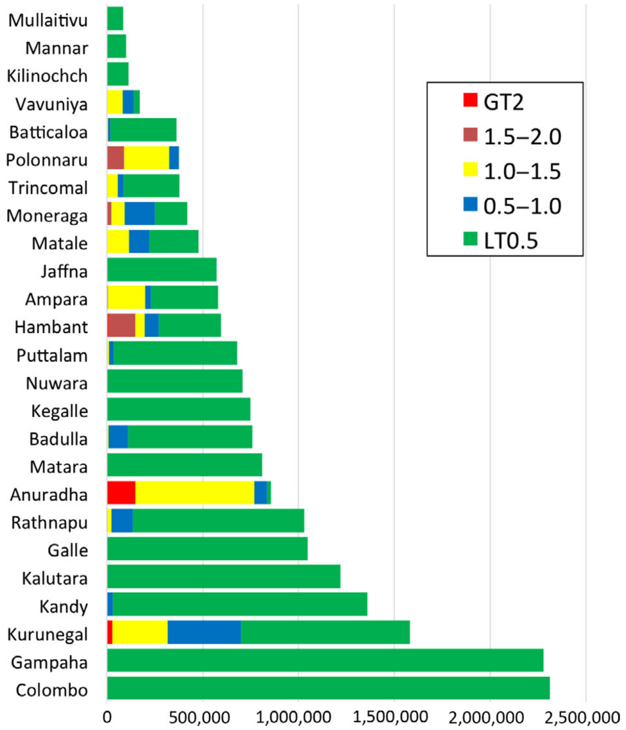

Figure 2. Number of inhabitants exposed to different groundwater fluoride levels in different districts in Sri Lanka. Note: fluoride content in groundwater: >2.0 mg/L (GT2), 1.5–2.0 mg/L, 1.0–1.5 mg/L, 0.5–1.0 mg/L, <0.5 mg/L (LT0.5).

promotion programmes. The findings of this study could contribute to the development of practical solutions to the problem of endemic fluorosis in developing countries, as well as consensus on safe fluoride use in areas where fluoride is endemic.

The findings of this study indicated that dental fluorosis is likely to be prevalent in the island's dry zone, and 0.53 million (12%) children younger than 12 years of age are at risk of dental fluorosis when the fluoride level exceeds 1 mg/L. It should be noted that the risk of dental fluorosis can be underestimated by using a fluoride cut-off of 1 mg/L, as the upper limit recommended for tropical countries is 0.8 mg/L. Similarly, 11.2% (2.2 million) of the total population remained exposed to high fluoride levels in groundwater across the life span when fluoride level exceeds 1.0 mg/L. If the cut-off was set as low as 0.5 mg/L, considering the tropical climatic condition of the country the at-risk population would increase to 17.6% (3.5 million). The extent of the risk revealed in the present study is not as high as previously reported[12]. These estimates are important for providing safe water in higher-fluoride zones and highlight the need for targeting water-treatment technologies and appropriately managed public water supply schemes.

Groundwater sources that exceed the WHO limits (1.5 mg/L) were located in the districts of Anuradhapura, Kurunegala, Hambantota, Polonnaruwa and Monaragala. There is a potential high risk of dental fluorosis in these areas, and the most vulnerable groups are children. The fluoride levels need to be reduced in these regions to decrease endemic fluorosis. Despite having a long history of defluoridation programmes in several high-risk districts in Sri Lanka, endemic fluorosis still remains a major public health issue. This could, in part, be a result of problems with the sustainability of defluoridation programmes and poor public compliance with the household filtration methods introduced. Removal of fluoride from water is a difficult process that mostly includes activated carbon filtration, reverse osmosis, and ion exchange or distillation techniques. However, none of these methods has been found to be sufficiently feasible, cost-effective or safe for implementing widely in Sri Lanka[28]. A study conducted in Inginimitiya village of the Puttalam district in Sri Lanka concluded that rainwater harvesting has widespread community acceptance and appears to be effective in preventing dental fluorosis[29].

It is of concern that the use of non-fluoridated herbal toothpastes is being actively promoted in both fluoride-endemic and fluoride-non-endemic areas in Sri Lanka based on only two previous studies[30–32]. It should be noted that dental caries increased, even in the presence of simultaneous severity of dental fluorosis, in areas with moderate and high levels of fluoride in drinking water, and a positive relationship was observed between dental caries and dental fluorosis[33]. Hence, the most effective action will be to provide safe water to affected communities rather than promote non-fluoridated herbal toothpaste. This is supported by a recent review of existing evidence related to caries and fluorosis risks, which recommends low-fluoride toothpaste (500–550 ppm) for low-caries-risk young children (<3 years) living in fluoridated communities and a toothpaste containing, at minimum, 1,000 ppm fluoride in all other cases[34]. Further research is needed to fill the research gap regarding whether to use fluoride-free toothpaste or toothpaste containing low (500–550 ppm) or standard (1,000 ppm) amounts of fluoride, for maximal caries protection but minimal dental fluorosis in areas where fluoride is endemic. It is acknowledged that fluoride toothpaste use should maintain a balance between preventing caries and minimising dental fluorosis, especially in young children[35]. The highest risk of developing dental fluorosis of the anterior permanent teeth as a result of ingestion of a high concentration of fluoride is during the first 2 years of life[36]. Current guidelines for fluoride intake in the population recommend 0.05–0.07 mg of F/kg body weight/d[37]. These guidelines are under review at the moment and further recommend prospective epidemiological studies with sufficiently large representative samples of children to establish a relationship between exposure to fluoride at an early age and the development of fluorosis[38].

The results of the present study show that 81.4% (3.57 million) of children aged <12 years, and 82.4% (16.1 million) of the country's total population live in low-fluoride zones where groundwater fluoride levels are <0.5 mg/L. In Sri Lanka, there is no authorisation for any 'water fluoridation schemes' to facilitate common public water supplies to reach the majority of the population. Furthermore, substantial capital expenditure would be necessary for plant installation, equipment, replacement and upgrading of such facilities, as well as ongoing running costs. Despite being a lower-middle-income developing country, only 55% of the Sri Lankan population has a pipe-borne water supply, and island-wide implementation of water-fluoridation schemes is not feasible. Fluoride toothpastes have been available in Sri Lanka for the last 30 years and seem to be effective. The three National Oral Health Surveys undertaken across the island in 1983–1984, 1994–1995 and 2002–2003 clearly show the reduction achieved in dental caries experience, especially in children, with the introduction of fluoride toothpaste. The dental caries experiences of 12-year-old children, denoted by the mean decayed, missing, filled teeth index, were 1.9, 1.4 and 0.9 in the last consecutive surveys[19,20]. According to the National Oral Health Survey data, dental fluorosis is highly prevalent in children living in areas with associated high-fluoride groundwater. Prevalence and severity data of dental caries available at the district level fail to show such a strong relationship with groundwater fluoride level. This can be explained by the dilution and diffusion effects of fluorides. The decreasing trend of dental caries seems to be mainly attributed to the widespread use of fluoride toothpaste across the country in the last two decades[19,20].

The WHO technical report series on 'Fluoride and Oral Health' (1994) clearly states, 'One of the WHO's policies is to support the widespread use of affordable fluoridated toothpaste in developing countries'[39]. There has been much debate over the last few years on whether the fluoride toothpastes being used in Sri Lanka contain free fluoride at levels that will prevent caries, whilst also safe for usage in areas where fluorosis is endemic[40]. Hence, Sri Lanka now grapples with contemporary dilemmas and controversies regarding the prevention and control of dental caries at one end of the spectrum and mitigating the detrimental effects of endemic fluorosis within the context of rising promotion of non-fluoride herbal toothpastes at the other end.

The study selected the age category of <12 years in children to estimate the population at risk for dental fluorosis. However, children are at actual risk of enamel fluorosis only up to 8 years of age because enamel is no longer susceptible to fluorosis once its pre-eruptive maturation is complete. Nevertheless, the age of 12 years is a good age to study the prevalence of dental fluorosis, as most permanent teeth have usually erupted by this age, including premolars (which are quite often affected by enamel mottling). Hence, the data presented in this study, based on the selected age category, could be a good base for future epidemiological studies.

The limitations of this study include the assumption that the risk of fluorosis is mainly through the ingestion of fluoride from natural drinking water. However, there are some other sources of fluoride ingestion that should also be taken into account during risk assessment. The most common sources of effective daily intake for Sri Lankans are beverages (such as tea) or foods (such as fish) and other fluoride ingestion mechanisms such as use of fluoridated toothpaste (especially unsupervised tooth brushing of young children using fluoride toothpaste). However, the amounts of fluoride ingested from these sources are relatively low compared with the amount of fluoride ingested by consumption of drinking water. Furthermore, this analysis treats all severities of dental fluorosis as one common phenomenon, whereas the current consideration is that majority of the population experiences no ill effects from mild fluorosis. Population-based research on aesthetic perceptions of quality of life of children concluded that milder forms of dental fluorosis have lesser impact on daily life[41].

Similarly, dental caries is also a multifactorial disease, with different associated factors, including dietary sugars, dental biofilm and the oral environment, and therefore the protective mechanisms of fluoride against caries development are but one factor. This implies that not all dental caries risk will be minimised when consuming water with a fluoride content of 0.5–1.5 mg/L or will always be higher risk when water contains a fluoride content of <0.5 mg/L. The risk for dental caries will obviously depend also on many individual-level factors. Current evidence suggests that, although there appear to be some benefits of systemically ingested fluoride, the most pronounced effect of fluoride is topical, through the regular usage of fluoride toothpaste, and these facts should be considered when interpreting the results. It should also be taken into account that not all inhabitants are exposed to groundwater because central water supplies do exist in some urban areas of Sri Lanka. It is noted that the majority of the country's urban population have access to safe water via piped water systems, while groundwater is the preferred source of water for most rural communities.

It was concluded that 12% (0.53 million) of children aged <12 years lived in high-fluoride zones (1 mg/L) and are at risk of dental fluorosis, and 81.4% (3.57 million) of children aged <12 years lived in low-fluoride zones (<0.5 mg/L) and are at risk for dental decay. The high fluoride (>1 mg/L) level in drinking water is a significant problem among 11.2% (2.2 million) of Sri Lankans; conversely, 82.4% (16.1 million) have low levels of fluoride (<0.5 mg/L) in their water. Against this backdrop, this study provides a scientific platform to initiate discussions and further research to inform general dentists, specialist dentists, physicians, public health specialists, geoscientists and all dental and non-dental primary health-care categories on whether fluoride use is effective and safe in the Sri Lankan population and its implications for future oral and general health of the next generation. A national consensus on fluoride use is needed in Sri Lanka to prevent dental caries and minimise dental fluorosis, as well as other adverse health problems associated with exposure to excessive levels of fluoride, in the population.

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Conflict of interest

None to declare.

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