Determination of the optimum level of fluoride for drinking water in different climatic zones of Sri Lanka based on the ambient temperature

Nirosha Ranasinghe, Estie Kruger, Marc Tennant

Abstract

Objectives: The study aimed to determine the optimal levels of fluoride (F) for drinking water in Sri Lanka in its different geographic regions.

Materials and Methods: The optimal level of F in drinking water was calculated by applying the equation of Galagan and Vermillion (Original and Modified), which permits the calculation of water intake as a function of temperature. The Annual Mean Maximum Temperatures (AMMT °C) recorded during 2011-2015 collected by the Department of Meteorology in 23 observation centers were used in the study.

Results: The optimal F concentration in drinking water from different geographic locations in Sri Lanka was calculated to be between 0.64 - 0.88 mg/L based on the original equation, while it was 0.36 – 0.49 mg/L with the modified equation.

Conclusions: The calculated optimum fluoride concentrations of drinking water in different climatic zones of Sri Lanka is much lower than the currently recommended water F levels to prevent dental caries (0.6-0.9 mg/L) and dental fluorosis (0.8 mg/L) in Sri Lanka. It is also lower than the water F levels recommended by the WHO and the US public health services.

Key words: Optimal fluoride level; Climate; Dental fluorosis; Dental caries

Introduction

Fluoride (F) in drinking water, in excess or at very low level is a major focus in dental public health for its positive (caries prevention) and negative impacts (dental fluorosis). Dental fluorosis occurs due to excessive daily intake of F during the critical period of permanent tooth development. Drinking water is typically the largest contributor to daily F intake particularly in fluorosis endemic regions. Even though the worldwide prevalence of dental caries has reported to have decreased significantly over the recent decades which may be associated with the widespread use of F [1], dental fluorosis still remains as an unresolved global public health issue, particularly among the less developed nations.

Historical research in dental public health in the 20th century revealed an inverse correlation between the F level in drinking water and caries experience [2, 3]. These studies were the baseline to estimate the optimal F level that would provide the maximum benefit of reduction in caries with the minimum risk of dental fluorosis. However, in 1957, Galagan and Vermillion reported the effect of temperature on the occurrence of varying degrees of fluorosis at the same fluoride level, in drinking water in the US population. The optimal level of F in drinking water is universally...
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calculated by applying the equation of Galagan and Vermillion, which permits the calculation of water intake as a function of temperature of the geographic location [4]. It has been calculated on the basis of annual mean maximum temperature (AMMT), and varied from 0.7 to 1.2 ppm depending on the climate of the country [5]. The equation was modified in later studies to be used in tropical and subtropical parts of Asia and Africa [6, 7]. In 2004, a Pakistani study applied this modified Galagan’s equation and determined the optimum F concentration to be 0.35 ppm [7].

A series of dental epidemiological research on groundwater F and fluorosis in Sri Lanka demonstrated varying degrees of prevalence of dental fluorosis in different parts of the country. According to a National Oral Health Survey report in 2002-2003, the prevalence of dental fluorosis in Sri Lanka among 12-year-old children ranged between 0-71% in the 22 districts covered. The highest reported districts were Anuradapura (71%), Matale (55%), Hambantota (38%), Polonnaruwa (32%), Kurunegala (27%), Vavuniya (26%), Moneragala (21%), Ampara (19%) and Rathnapura (18%). However, the maximum prevalence reported for aesthetically objectionable moderate and severe dental fluorosis was 22.5% from the district of Matale [8]. A study carried out in the Thambuttegama Medical Officer of Health area in the district of Anuradapura further reported a very high prevalence and severity of dental fluorosis among 12-15 year old children. Accordingly, 88.7% of the children had dental fluorosis as measured with Dean’s index. About 51% had moderate and severe dental fluorosis [9]. From these reports, it is evident that the problem of dental fluorosis in Sri Lanka, due to untreated ground water in the rural domestic water supplies, has been persistent for years without any sustainable health solutions. The relationship between F ingestion (during water consumption) and temperature has been evaluated in previous studies, and for countries with tropical arid and semi-arid climates, relatively low optimal F concentrations in drinking water are recommended. This is because inhabitants in tropical regions tend to consume more water than those from colder climates [4, 5, 6, 7]. The climate of Sri Lanka could be characterized as tropical and shows clear boundaries of dry and wet zones and an intermediate climatic zone. Regional differences in air temperature of the island is mainly due to altitude, and a largely homogenous temperature in lowlands (between 26.5°C to 28.5°C) quickly decreases as altitude increases, with the lowest in the highlands up to 16°C [10]. Dental fluorosis is highly prevalent in the dry zone with associated high F content in the groundwater. Dental caries prevalence shows no such clear variation (based on the climatic zone or water F level), and it may be attributed to the wide spread use of F toothpaste across the country in last two decades. According to the latest National Oral Health Survey report, the highest prevalence of dental caries in 12 year olds were reported in Trincomalee district (58%) while the lowest prevalence from the district of Kandy (27%) [8]. Another serious health problem with growing concern is the Chronic Kidney Disease of Unknown Aetiology (CKDu) among many people in the dry zone districts of Sri Lanka and its plausible association with ground water F [11, 12].

Against this backdrop, a clear knowledge of the optimal F content of potable water is needed to prevent excessive F intake, and assist in planning and implementation of rural water supply schemes to affected communities. Considering the variable climatic zones within the country, the present study aimed at determining the optimal concentrations of F for drinking water in Sri Lanka, using the air temperature of different provinces.

**Methodology**

The study used a cross sectional study design. The optimal concentration of F levels for drinking water in Sri Lanka was determined taking into account the regional differences in the ambient temperature across the island. Ethical clearance
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was not considered necessary for this study, as the data used was open access, and available online for public access.

Sources: The information on the Annual Mean Maximum Temperatures (AMMT) recorded during 2011-2015 was collected from the website of the Department of Meteorology in Sri Lanka. It was available for 23 observation centers in the country.

The optimal concentration of F for drinking water in Sri Lanka was calculated using both the original and the modified Galagan and Vermillion equation [4, 7].

The original equation developed by Galagan and Vermillion to calculate the optimal level of F in drinking water (mg/L) was:

\[
\text{Optimal F Concentration (mg/L)} = \frac{0.022}{0.0104 + 0.000724 \times \text{AMMT (°C)}}
\]

The original formula was developed based on the assumption that 44% of the fluid intake of US children was liquid cow’s milk, which contains almost negligible amounts of F. However, almost 100% of the fluid intake of Sri Lankan children is ground or tap water.

Therefore, the original equation was further modified with a correction factor of (1-0.44) to calculate the optimal level of F in for drinking water of Sri Lanka. The modified equation has been previously used in Pakistan, Chile, Sudan and the Republic of Macedonia in determining their optimal water F levels. It was assumed that the drinking habits of Sri Lankans are generally similar to the countries where it was applied earlier [6, 7, 13, 14].

\[
\text{Optimal F Concentration (mg/L)} = \frac{0.022 \times 0.56}{0.0104 + 0.000724 \times \text{AMMT (°C)}}
\]

Results and Discussion
The AMMT for the 23 meteorological sites of the country ranged between 20.25 – 33.30 °C. The hottest temperature was reported in Polonnaruwa, while the coldest temperature was from Nuwaraeliya (Table 1). The optimal F concentration in drinking water, calculated as based on the original equation, ranged between 0.64 - 0.88 mg /L, while it ranged between 0.36 – 0.49 mg/L with the modified equation. In the Sri Lankan dry zone, where dental fluorosis is a public health problem, 0.64 mg/L is the value obtained from the original formula, and 0.36 mg/L is obtained with the modified equation (Table 1, Figure 1, Figure 2).

Climate is one major factor which is closely related with the groundwater F issue. In tropical and subtropical climates, adverse health effects may occur even when following the World Health Organization (WHO) guideline value (1.5 mg/L) for drinking water quality. Water intake is usually greater in the countries of the hot tropical belt, compared to countries in the temperate zone. Therefore, temperature correction would be of value to minimize the health hazards due to accumulation of excessive quantities of F in the body acquired through drinking water.

The findings of this study are crucial to Sri Lanka in deciding the optimal F concentration in their potable water. However, the formulas are based on certain assumptions about drinking water habits and strong conclusions cannot be arrived at without conducting a large scale, good quality dose response study in the targeted community. Public health policy on the optimum F level at the population level should be based on ‘balancing caries against unacceptable dental fluorosis in populations’. These modified equations may also be needed in site specific cases based on the subsurface geological, geographical, hydrogeochemical and land-use conditions.
Table 1. Optimal amounts of F (Maximum Permissible Limit) according to Average Annual Maximum Air Temperature (AMMT °C), expressed in mgF/L

<table>
<thead>
<tr>
<th>Meteorological Station</th>
<th>AMMT (°C)</th>
<th>Op (mgF/L) Original</th>
<th>Op (mgF/L) Modified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anuradhapura</td>
<td>32.75</td>
<td>0.64</td>
<td>0.36</td>
</tr>
<tr>
<td>Badulla</td>
<td>28.23</td>
<td>0.71</td>
<td>0.40</td>
</tr>
<tr>
<td>Bandarawela</td>
<td>25.09</td>
<td>0.77</td>
<td>0.43</td>
</tr>
<tr>
<td>Batticaloa</td>
<td>31.56</td>
<td>0.66</td>
<td>0.37</td>
</tr>
<tr>
<td>Colombo</td>
<td>30.91</td>
<td>0.67</td>
<td>0.38</td>
</tr>
<tr>
<td>Galle</td>
<td>30.01</td>
<td>0.68</td>
<td>0.38</td>
</tr>
<tr>
<td>Hambantota</td>
<td>31.30</td>
<td>0.67</td>
<td>0.37</td>
</tr>
<tr>
<td>Jaffna</td>
<td>31.52</td>
<td>0.66</td>
<td>0.37</td>
</tr>
<tr>
<td>Katugastota</td>
<td>29.23</td>
<td>0.70</td>
<td>0.39</td>
</tr>
<tr>
<td>Katunayake</td>
<td>31.21</td>
<td>0.67</td>
<td>0.37</td>
</tr>
<tr>
<td>Kurunegala</td>
<td>32.25</td>
<td>0.65</td>
<td>0.37</td>
</tr>
<tr>
<td>Mahalilluppalama</td>
<td>32.09</td>
<td>0.65</td>
<td>0.37</td>
</tr>
<tr>
<td>Mannar</td>
<td>30.81</td>
<td>0.67</td>
<td>0.38</td>
</tr>
<tr>
<td>Mattala</td>
<td>32.89</td>
<td>0.64</td>
<td>0.36</td>
</tr>
<tr>
<td>Moneragala</td>
<td>32.52</td>
<td>0.65</td>
<td>0.36</td>
</tr>
<tr>
<td>Nuwara Eliya</td>
<td>20.25</td>
<td>0.88</td>
<td>0.49</td>
</tr>
<tr>
<td>Polonnaruwa</td>
<td>33.30</td>
<td>0.64</td>
<td>0.36</td>
</tr>
<tr>
<td>Putuvil</td>
<td>32.47</td>
<td>0.65</td>
<td>0.36</td>
</tr>
<tr>
<td>Puttalam</td>
<td>31.45</td>
<td>0.66</td>
<td>0.37</td>
</tr>
<tr>
<td>Ratmalana</td>
<td>31.72</td>
<td>0.66</td>
<td>0.37</td>
</tr>
<tr>
<td>Ratnapura</td>
<td>32.14</td>
<td>0.65</td>
<td>0.37</td>
</tr>
<tr>
<td>Trincomalee</td>
<td>32.66</td>
<td>0.65</td>
<td>0.36</td>
</tr>
<tr>
<td>Vavuniya</td>
<td>32.71</td>
<td>0.65</td>
<td>0.36</td>
</tr>
</tbody>
</table>

Figure 1. Map of Sri Lanka showing Optimal F levels (Original and modified values) in different meteorological locations across the country. The underlying color density of the map displays increases in level of groundwater F the darker the red. Note, that there was no underlying map for some areas in the north and east.

Note. Underlying map data derived from previous well specific data published in part by Chandrajith et al, 2012 [23].

The WHO standards recommended control limits ranged from 0.6 - 0.8 mg/L for countries with average annual temperatures of 26.3 - 32.6 °C [16].
In 1984, WHO guidelines suggested that in areas with a warmer climate, the optimal F concentration in drinking water should remain below 1.0 mg/L, while in cooler climates it could be up to 1.2 mg/L [15]. The differential levels were derived from the fact that perspiration is higher in hot weather than in the cold weather, and consequently water intake is even higher. This recommendation was further confirmed in 2004 when the WHO stated that dental fluorosis can occur at lower concentrations of water F in warmer areas due to greater consumption of drinking water [16]. However, the range of 0.5 – 1.0 mg/L is generally recommended by the WHO as the optimal concentration of F [5]. Even though the function of temperature has been given ample consideration in deciding the optimum F levels for drinking water in the past, the US public health service recently revised their temperature-based optimal F concentration (0.7-1.2 mg/L) in community water supplies to a fixed value of 0.7 mg/L [17, 18]. US public health reports claimed that recent data do not support a convincing relationship between water intake and outdoor air temperature and thus recommendations based on outdoor temperature are not relevant for their country. This was attributed to the wide use of air conditioning and the sedentary life style of the US community resulting [18].

According to WHO recommendations, it is imperative that each country calculates its own optimal level of F in drinking water based on its climatic conditions, water intake, dietary habits of the population and other possible F exposures like dental products [16]. The risk of fluorosis can be enhanced with regular consumption of some F containing food and beverages (Fish and Tea), and in accidental ingestion of F dentifrices [19]. In 1986, it was considered that drinking water is typically the single largest contributor for the daily F intake [20]. The reason explained was that the F in drinking water will be in the form of the free F ion and hence the absorption is relatively high compared to the other sources [20]. With relatively high F levels in groundwater in the rural dry zone in Sri Lanka, drinking-water has become increasingly important as a major source of F. Recent research further claimed the F leaching effect of Ceylon tea (0.32 - 1.69 mg/L) and informed its likely contribution in the development of dental fluorosis, if consumed by young children [21].

In 1992, Warnakulasuriya et al conducted a dose response study to find a better estimate of optimum levels of F in groundwater in Sri Lanka [22]. The value of 0.8 mg/L of F in drinking water was recommended as the upper limit for prevention of dental fluorosis and the range of 0.6 – 0.9 mg/L was recommended for the maximum caries protection. It was derived from the oral examination of a small sample of 380, 14-year-old children together with the chemical analysis of 380 water samples from their domestic source of drinking water in four geographic areas in the dry zone. The optimal concentration recommended for community water supplies in dry zone according to the Galagan modified formula, (which is 0.36 mg/L) was much lower than the optimal range of F levels recommended for maximum caries protection (0.6 – 0.9 mg/L), as concluded in the previous dose response study [22]. It complied with the value computed by the original equation, which was 0.64mg/L. However, a major part of the country’s dry zone is naturally fluoridated and the groundwater in many rural community water supplies contains F which is much higher than the recommended level. The wet zone has been spared by the F issue and the difference between the levels of groundwater F in wet and dry zones has been identified as a climatic feature by the geoscientists [23].

With the emergence of other sources of F (F dentifrice) contributing to the prevention of dental caries and susceptibility to dental fluorosis, the current situation should be studied in a well-planned large scale dose response study to find a better estimate of optimal F level for Sri Lanka. The hardness of groundwater is also an important consideration in ionic dissociation.
and the bioavailability of F. Literature suggested that the bioavailability of F increases if hardness of water exceeds 500 mg/L [24]. The reported super hardness in groundwater in some fluorosis endemic regions in Sri Lanka [11] may also be a plausible factor for the occurrence of fluorosis in areas with relatively low levels of F in groundwater.

The high prevalence of dental fluorosis in the dry zone in Sri Lanka still remains as an inherent psychosocial problem among the inhabitants. It has been afforded far less public health concern and priority compared to dental caries. The prevalence of unaesthetic dental fluorosis has been reported to be high in fluorosis endemic regions in dry zone, and as the affected community is mostly unaware, there are is low compliance with possible remedial measures available [9]. In contrast, Sri Lanka stands in the very low level category on the global dental caries scale, and it may be largely due to the widespread use of F toothpaste during the last 30 years [25]. It was based on the DMFT at 12 years of age (mean number of decayed, missing and filled teeth) which is the WHO recommended, most appropriate national indicator for dental caries [25]. With the increasing availability and promotion of non-F toothpastes in both endemic and non-endemic areas of the country, the great public health achievements in dental caries reduction is also now facing significant challenges.

In global context, a recent Cochrane review suggested fluoridated toothpaste as a significant risk factor for dental fluorosis [26]. A Dutch study also found the intake from F toothpaste to be as much as 0.2–0.3 mg/day, and it can further increase by the swallowing of toothpaste or F tablets up to 3.5 mg per day [27]. The dental mottling associated with accidental F ingestion, particularly in young ages, commonly manifests as mild or a very mild type of dental fluorosis. In Sri Lanka, such increasing trends of dental fluorosis in young children are not supported by the local literature. Therefore, this information does not support discouragement or banning of F tooth paste, or promotion of non-F alternatives (even in the F endemic areas). The reason is that anyone can develop dental caries at any age of life while the risk of dental fluorosis maximally last for 12 years until completion of a child’s permanent dentition. Finding solutions to endemic fluorosis by promoting non-F toothpaste is an inappropriate approach in dental public health, as this may place a double burden of both dental caries and dental fluorosis on these communities. Conversely, precautions should be taken when using F toothpaste for children less than 6 years to avoid unintentional ingestion, as their swallowing reflex has not completely developed, yet. Locally or internationally manufactured low F containing toothpastes (500-550 ppm), that can be used for young children, are not readily available in the local market. Therefore, the use of standard F toothpaste (1000-1500 ppm) in young children can be delayed until up to 2 years, and children less than 6 years of age, should be supervised by a responsible adult and an age appropriate amount of F toothpaste should be dispensed during tooth brushing [28].

The Galagan and Vermillion temperature correction has been used in deciding the optimum F concentration in drinking water to minimize the risk of F ingestion in tropical and subtropical climates. However, its use is challenged with the emergence of many ingestible forms of F. Hence, the ‘exposure dose’ is found to be today’s best estimate for assessing the risk of F ingestion and deciding the optimal F levels [29]. Fluoride toxicity is predicted by the exposure dose ((mg F/kg body weight/d) which is not only be applied to the F in drinking water, but all other forms of F exposure most commonly, dietary F (food and beverages like fish and tea) and accidental or unintentional ingestion of F dentifrices (F toothpaste). F exposure through drinking water can be computed for a given individual by using the generic equation, ED = C X WI BW. The ED stands for ‘Exposure Dose’ in mg/kg/d, C is
the concentration of F in mg/L, WI is the water intake in L/d, and BW is the body weight [29]. A recent review announced that precise ‘optimal’ oral intake of F for effective caries protection has not been determined [30]. However, in 1997, the US Institute of Medicine (IOM) estimated an Adequate Intake (AI) of 0.05 to 0.07 mg F/kg bw/d as the optimum amount of total daily intake of F and a Tolerable Upper Intake Level (UL) of 0.10 mg F/kg bw/d to prevent undesirable degrees of dental fluorosis [31]. Currently, these limits are under review with the argument that actual F intake exceed the UL without expected adverse effects of fluorosis [32]. However, based on these estimates, adverse effects of F seem to be best explained by exposure dose, exposure duration, and other factors such as age and dietary intake [29]. A recent study conducted in a city (with a tropical semi-arid climate and with optimally fluoridated water) to determine the total daily dose of F intake from diet (water, beverages and solid diet) and use of F toothpaste in Brazilian children, demonstrated that the children had a low F intake as measured by diet and F toothpaste, and drinking water was the main contributory factor for F ingestion [33]. Global research supports the addition of more F to the human system through drinking water and locally grown food in areas with high F in groundwater [34, 35]. However, the daily F exposure via surrounding vegetation in endemic areas and the associated diffusion effect of F in non-endemic areas has not been investigated in Sri Lanka. Further evidence of daily F exposure of children living in endemic fluorosis zones who are exposed to excessive F via ingestion such as drinking water, diet (crops grown in high F zone) and F dentifrices is not currently supported by the local literature and further research is recommended to fill the knowledge gap identified.

The total daily F exposure from drinking water in a temperate climate was determined to be 0.6 mg/adult/d in non-fluoridated communities and 2 mg/adult/d for the fluoridated communities [20]. These guideline values are only available for temperate climates, and its application to tropical countries (in combination with the temperature correction), is a high priority to minimize F hazards. If the F exposure is likely to approach levels greater than 6 mg/day, it has been recommended to consider setting a local/national standard at a concentration below the WHO guideline value of 1.5 mg/L for prevention of aesthetically unacceptable dental fluorosis [27]. Therefore, the optimal level of F in drinking water for endemic fluorosis regions dry zone should be decided methodically, using a dose response study in the targeted community and further measurements of daily F exposures.

Application of the pre-existing standard formulas of Galagan and Vermillion are important for countries with diverse climatic zones to calculate its own optimal level of F in drinking water based on the various water intake levels in different geographic regions. However, its use is challenged with the emergence of many ingestible forms of F and it should be considered together with other measures of F exposure.

**Conclusion**

According to the results of this study, the optimum fluoride concentration for drinking water in different climatic zones of Sri Lanka varies from 0.36-0.49 mg/L. It is much lower than the currently recommended water fluoride levels to prevent dental caries (0.6-0.9 mg/L) and dental fluorosis (0.8 mg/L) in Sri Lanka. It is also lower than the water fluoride levels recommended by the WHO and the US public health services. Considering the increased use of fluoride dentifrices in the country at the moment, and overall exposure to different ingestible forms of F, further dose response studies are warranted to estimate the optimum drinking water F levels for fluorosis endemic areas of Sri Lanka.

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Competing interest
None to declare

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