Received: 9 October 2022 | Revised: 22 February 2023 | Accepted: 26 February 2023

DOI: 10.1002/tqem.21982

HIGHLIGHT

WILEY

Fluoride removal and its impact on oral health in Sri Lanka's dry zone: Discussion and recommendation

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Abstract

Fifty percent of the dry zone areas in Sri Lanka have fluoride levels above 1 ppm. This paper discusses the ground conditions and recommends an appropriate range of fluoride in drinking water which can support preventive practices for improving the oral health of children 8-years old and younger. In efforts to address the Chronic Kidney Disease of Unknown etiology (CKDU), water treatment to reduce contaminant level in potable water has been implemented. Such treatment would also remove fluoride and has resulted in potable water with various fluoride levels, depending on concentrations in the raw water. While it is important to reduce fluoride levels, it is important to have appropriate residual levels for prevention of dental caries. It needs, however, to be noted fluoride in excess can cause dental fluorosis. In Sri Lanka's dry zone areas increasing prevalence of dental fluorosis with decreasing prevalence of dental caries has been noted. Consumption of tea and powdered milk could increase total intake of fluoride. Fluoridated toothpaste, when used properly, may, however, result in negligible intake of fluoride. Sri Lanka's hot tropical climate which results in substantial intake of fluids reinforces the need to consider reduction in water fluoride. Consideration of local studies and international standards indicate fluoride levels should be in the range of 0.225–0.500 ppm. In the range of 0.225–0.500 ppm, the prevalence of dental fluorosis and caries was only 14% and 8%, respectively, in an endemic district. When fluoride levels are above 0.500 ppm, the issue of dental fluorosis shall need to be addressed. When levels are below 0.225 ppm, oral health care services shall need to be directed at preventing dental caries.

KEYWORDS

chronic kidney disease, dental caries, dental fluorosis, fluorides, water purification

1 | INTRODUCTION

Fluoride is an essential part of good oral health (O'Mullane et al., 2016). However, excessive fluoride contributes to fluorosis and weakening of teeth while inadequate fluoride contributes to dental caries. Fluoride, naturally occurring in excess in drinking water, is a concern in many countries. In some parts of the world, low levels of fluoride in drinking water causes increased incidence of dental caries (Spencer et al., 2018). Sri Lanka, a low-income country off the southern tip of the Indian sub-continent, presents the case of a country with wide variation in naturally occurring fluoride levels in water, soil, and food.

Fluoride is an essential part of good oral health

Sri Lanka has a tropical climate with distinct wet, dry, and intermediate climatic zones depending on the rainfall distribution (Punyawardena, 2020). Weathering of the basement rock is the main reason for high levels of fluoride in the dry zone but such high levels can be further increased during the dry season following evaporative loss (Jayawardana et al., 2010). The wet climatic conditions coupled with geological variations result in low levels of fluoride in surface waters in the wet zone. To further complicate the fluoride situation, over the last three decades, Sri Lanka has experienced an epidemic of chronic kidney disease not associated with hypertension and diabetes (CKDu) (Wimalawansa, 2014). While no definitive etiology has been identified, scientific inquiry and the belief systems of residents have focused on contamination of water sources by agrochemicals. This has resulted in calls for water purification (Rajapakse et al., 2016). As a result, governmental and nongovernmental entities have invested heavily in water treatment units in rural, agricultural villages. These units typically use reverse osmosis (RO) with 5–10 m^3/day capacity and over 600 units have been deployed in agricultural villages in the dry zone. These RO units remove a range of dissolved contaminants including fluoride from the raw water. Recently nanofiltration (NF) has been deployed in place of RO (Cooray et al., 2019). As yet only eight NF units are operational with the government's commitment to replace RO with NF. The NF units remove less fluoride, and thus allowing for possibility of appropriate and beneficial residual levels (Jayawardana et al., 2010). Presently the RO product water can affect oral health because of the different levels of residual fluoride, depending on the extent of unguided blending. This is especially so for children below 8 years of age. Children below 8-years of age are particularly vulnerable to the negative impact of dental fluorosis and dental caries as they would be developing their permanent teeth (WHO, 2019).

Sri Lanka has a tropical climate with distinct wet, dry, and intermediate climatic zones depending on the rainfall distribution

Recently nanofiltration (NF) has been deployed in place of RO

This paper discusses (1) a possible optimum range for fluoride and need for such for use in Sri Lanka and (2) preventive practices for oral health care providers in managing the needs of children 8 years and below. The basis for such discussion will be the ongoing use of membrane systems (RO and NF) to treat water because of CKDu concerns. RO and NF (to a lesser extent) have an effect on residual fluoride in drinking water. Consumption of such filtered water has resulted in either increased prevalence of dental fluorosis or dental caries. The situation may have been complicated by other sources of fluoride such as toothpaste and beverages (tea and milk). This is in addition to drinking water consumption patterns in relation to high ambient temperatures.

2 | RECOMMENDATION

Based on recent epidemiological studies conducted in Sri Lanka (Ekanayake and van der Hoek, 2003; Jinadasa, 2019; Ranasinghe et al., 2018), the recommended optimal range for fluoride in water should be in the range of 0.225–0.500 ppm. This value should be taken into consideration when implementing water treatment units in the dry zone and especially when developing the blending protocol.

Preventive practices for oral health need to consider prevailing fluoride levels and the health sector needs to work collaboratively with water professionals so that the necessary adjustments can be made to the water treatment systems deployed and which shall be deployed.

3 | RATIONALE

3.1 | Fluoride and its impact on oral health

Recent findings (O'Mullane et al., 2016) suggest fluoride's action on prevention of dental caries is mainly topical. Fluorides delay demineralization and promote the remineralization of incipient enamel lesions. Fluorides also inhibit cariogenic bacteria's glycolysis pathway. Fluoridated water, salt, milk, fluoride toothpaste, and mouth rinses are cost-effective means of providing fluoride to the population. Professionally applied fluoride such as in varnish and gel contain a high concentration of fluoride and by applying them to enamel, a gradual release of fluorides to the oral cavity would occur (O'Mullane et al., 2016).

Excess fluoride can, however, have detrimental effects on oral health. Ingestion of excessive fluoride during the tooth developmental period lead to dental fluorosis. The severity of dental fluorosis depends on the dose, timing, age of the patient, and duration of exposure. The window of susceptibility is typically from birth to 8 years of age (DenBesten, 1999). Dental fluorosis develops due to excessive fluoride ingestion and absorption at the time teeth are forming. For the aesthetically important permanent teeth (maxillary incisors) the risk years are birth to 4 years; for later erupting permanent teeth, up to 8 years. Dental fluorosis does not develop after a tooth erupts but dental caries could develop at any age (Whelton et al., 2019). The mildest form of dental fluorosis appears as a white opaque striation on the enamel surface with increased porosity of the enamel. With a gradual increase in severity, the entire tooth surface becomes chalky white with a loss of translucency. When the condition is severe, there is pitting of the tooth surface on eruption (Cavalheiro et al., 2017).

The severity of dental fluorosis depends on the dose, timing, age of the patient, and duration of exposure

3.2 | Water treatment due to CKDu and its effect on fluoride in drinking water

Fluoride distribution in potable water in Sri Lanka has been mapped and wet zone areas of the country has fluoride concentrations less than 0.5 ppm. In contrast, about 50% of the dry zone have fluoride levels above 1 ppm. There are even pockets in the dry zone which have fluoride levels above 2 ppm. It has, however, been noted specific areas within the dry zone where there is opportunity to blend the groundwater with surface water, fluoride concentrations are low (Chandrajith et al., 2012).

Villagers in the dry zone have various water source options. Some continue to consume ground water from shallow or tube wells, which may or may not be contaminated with agrochemicals while others consume surface water drawn from reservoirs (tanks), rivers, and irrigation channels. Water from underground springs and rainwater harvests are also used with the belief these sources are uncontaminated. They may also use water from point-of-use treatment units in their homes, communal units at village level and water trucked in by commercial water suppliers and stored in tanks on the roofs of homes (National Water Supply and Drainage Board Sri Lanka, 2014). Treatment units use either the RO or NF method. Selection of water for drinking is dependent on preferences for taste and extent of concern over the CKDu risk. Most families do not use only one type of water but blend depending on preferences for taste, availability, and financial and time for acquisition constraints (Horbulyk et al., 2021).

Villagers in the dry zone have various water source options.

The RO method uses a semipermeable membrane (1 nm), which allows only very small molecules to pass through. The process results in a permeate and reject stream. Feed water is pumped under high pressure to force water against the natural osmotic gradient. The result produces water which is almost devoid of dissolved materials and hence fluoride concentration can be reduced substantially. The reduction level varies depending on the feed water fluoride concentration, the pressure applied, pretreatments, and maintenance of the RO systems (Solanki et al., 2022). This has not yet accounted for blending which may occur subsequently. A study conducted in the North Central province of Sri Lanka found fluoride concentrations below 1 ppm after RO treatment (Imbulana et al., 2020). RO units therefore have the potential of reducing fluoride to beneficial levels. In most areas in the dry zone of Sri Lanka the water fluoride concentrations are less than 1.5 ppm (Ranasinghe et al., 2019). RO units can, of course, reduce fluoride in water below beneficial levels if the source water had fluoride concentration much below 1.5 ppm.

NF membranes are partially permeable to fluorides and work well when the fluoride concentration of the feed water is low (Moran Ayala et al., 2018). At high fluoride levels the resultant water could have excessive residual fluoride. The NF system installed at Sirimapura in the Anuradhapura district in Sri Lanka has shown considerable removal of fluorides from water. When the natural fluoride level was 1.3 ppm, the product water had only 0.1 ppm, below the beneficial level (Cooray et al., 2019).

To further complicate matters, many RO and NF plants are not properly operated due to inadequate training of operators, insufficient monitoring, and maintenance. Lack of community involvement and supervision has led to the abandonment of many of these plants. Fouling of the membranes following use and lack of minerals in the product water, when new have been observed in the installed systems (Imbulana et al., 2020; Indika et al., 2021). The variability in output fluoride concentration has created difficulties for the development of oral health guidelines.

An approach which can be considered is to allow the RO and NF systems to generate product water with below optimum fluoride levels and then to add fluoride as a post-treatment. However, since the plants are generally poorly operated, this procedure of remineralization is rarely implemented and could be potentially dangerous due to poor supervision (Indika et al., 2021).

3.3 | Oral health of children in Sri Lanka

The prevalence of dental fluorosis is higher among 12-year-olds in the dry zone than the national prevalence according to a 2015–2016 national oral health survey report. In Anuradhapura district in the dry zone where fluoride is high, prevalence of dental fluorosis of aesthetic concern is 41% while 35% of 12-year-olds were affected in Vavuniya district. Dental fluorosis of aesthetic concern includes mild, moderate, and severe fluorosis but excludes questionable and very mild categories (Ministry of Health, Nutrition and Indigenous Medicine (Sri Lanka), 2018).

Prevalence of dental caries among Sri Lankan 12-year-olds had declined from 78%, 76.4%, 65.6% and to 30% in the periods of 1983–1984, 1994–1995, 2002–2003, and 2015—2016, respectively (Ministry of Health, Nutrition and Indigenous Medicine (Sri Lanka), 1983;

Ministry of Health, Nutrition and Indigenous Medicine (Sri Lanka), 1994; Ministry of Health, Nutrition and Indigenous Medicine (Sri Lanka), 2002; Ministry of Health, Nutrition and Indigenous Medicine (Sri Lanka), 2018). Prevalence of dental caries was therefore lower than the national value of 30% in areas with endemic dental fluorosis. The latter areas such as Anuradhapura, has only 16% dental caries while Vavuniya has around 20% according to the latest National Oral Health Survey (Ministry of Health, Nutrition and Indigenous Medicine (Sri Lanka), 2018).

Increasing trend of mild to moderate dental fluorosis coupled with decreasing incidence of dental caries poses oral health care professionals with the challenge of how fluoride can be used. The obvious conclusion is in areas with high fluoride levels, these levels need to be reduced for better oral health but not to the extent incidence of dental caries is increased. So, it is important that the population's oral health in the targeted areas be monitored and assessed in arriving at an optimum level of fluoride supplementation.

3.4 | Use of sources of fluoride other than water

Other than potable water, the majority of Sri Lankans would also have exposure to fluoridated toothpaste. According to the 1994–1995, 2002–2003, and 2015–2016 surveys, the use of fluoridated toothpaste among 12-year-olds was 80.9%, 85.5%, and 80% in the cohort (Ministry of Health, Nutrition and Indigenous Medicine (Sri Lanka), 1994; Ministry of Health, Nutrition and Indigenous Medicine (Sri Lanka), 2002; Ministry of Health, Nutrition and Indigenous Medicine (Sri Lanka), 2018). Fluoridated toothpastes were introduced to Sri Lanka in early 1980′s (Daily FT, 2012) with various herbal products used for cleaning teeth before. Non fluoridated toothpastes were introduced to the country in late 1980′s (1989) (The Sunday Times (Sri Lanka), 2019). It had been shown in a systematic review that toothpaste contributes to around 38% of total fluoride intake regardless of the age of children or fluoride concentration in drinking water (Saad et al., 2022). Recent research in Sri Lanka had, however, found fluoride toothpaste to be not primarily associated with dental fluorosis but fluoride level in drinking water to be the main cause (Jinadasa, 2019). Use of fluoridated toothpaste is useful for reducing incidence of dental caries (FDI World Dental Federation, 2019).

Fluorides is also ingested via tea (National Institute of Health, 2022). Dietary intake of fluoride via tea for Sri Lankan adults had been studied and it was found to be around 2.68 mg per liter per person per day. When the fluoride content in groundwater in certain regions is high, the total dietary fluoride intake becomes further enhanced (Chandrajith et al., 2021). This goes above the daily adequate level recommended for adults by National Institute of Health which is 4 mg (National Institute of Health, 2022). Although values were not determined for Sri Lankan children below 8 years of age, there is empirical evidence that tea consumption is a risk factor for dental fluorosis in children as well (Van Der Hoek et al., 2003). As tea consumption is a traditional practice in many Sri Lankan households, it could be taken as another source of fluoride intake among Sri Lankans. The National Institute of Health has determined the fluoride content in other foods such as fruits, vegetables, and cheese to be negligible. Breast milk and cow's milk were also found to have negligible amounts of fluorides, but powdered milk differs as it requires addition of water containing fluorides (National Institute of Health, 2022). As Sri Lankan children drink powdered milk with added water there is risk of aggravating dental fluorosis through the former's consumption. It has also been shown that meat and fish contain higher amounts of fluoride when skeletal parts are included (O'Mullane et al., 2016).

3.5 | Fluoride metabolism

According to recently published evidence, 90% of the ingested fluoride is absorbed in the alimentary tract. Of the amount absorbed, approximately 55% is retained in the body of children and around 36% in adults while the remaining portion of the absorbed fluoride is excreted with urine (O'Mullane et al., 2016).

3.6 | Ambient temperature and water consumption in the dry zone

The ambient temperature over the last 50 years has increased by around 1°C. The temperature can be as high as 33°C in June, July, and August (World bank group, 2021). In countries in the tropical region the amount of water consumed is higher compared to temperate countries. Though the proposed concentration of fluoride in water is low, the amount of fluoride ingested could nonetheless be higher. What is absorbed to the plasma (55% of the total absorbed) is important to maintain a low fluoride level throughout the day and this acts to prevent caries.

4 | PROCESS

4.1 | Proposing a fluoride standard for Sri Lanka

The upper limit of the drinking water standard established by WHO for fluoride is 1.5 ppm. Where there is fluoridation, the recommended range is 0.5–1.0 ppm (World Health Organization, 2019). The current standard in Sri Lanka for fluorides is 1 mg/L (Sri Lanka Standards Institute, 2013). Countries that practice community water fluoridation had adjusted fluoride levels in potable water downwards. For example, in the US, drinking water fluoride levels have been reduced from 0.7–1.2 to 0.7 ppm. The USA had considered the prevalence of dental fluorosis among 12—15-year-olds in the 1986–1987 and 1999–2004 periods and had observed an increase in prevalence of mild to moderate dental fluorosis (Beltrán-Aguilar & Dye, 2010). After considering factors such as other sources of fluoride and prevalence of dental caries and ambient temperature and water consumption, a new guideline for fluoride in drinking water was proposed (U.S. Public Health Service, 2015).

EXHIBIT 1 Proposed reference values for oral health care for children under 8 years of age

Level of natural fluoride in the water before membrane separation	Availability of water filtration (RO or NF unit)	Approaches to prevention	Needed oral health care services
Above 0.5	No	Use an alternative water source such as rainwater or bottled water to prevent dental fluorosis	Needs to focus treatments on dental fluorosis that may be already present
Above 0.5	Yes	If water contains optimum level after treatment, can be used for drinking, if not use an alternative water source such as rainwater or bottled water	Needs to focus treatments on dental fluorosis that may be already present
Between 0.2 and 0.5	No	Optimum level for drinking	—-
Between 0.2 and 0.5	Yes	Water is good for drinking. Membrane in filter used could be changed to a different one with a different pore size to keep fluorides to maximum. Post treatment/remineralization of the effluent water to increase fluoride levels with proper training of staff and monitoring	Needs additional topical fluoride applications such as varnish or gel for prevention of caries among those having a moderate to high caries risk
Below 0.2	No	Water is good for drinking	Needs additional topical fluoride applications such as varnish or gel for prevention of caries among those having a moderate to high caries risk
Below 0.2	Yes	Water is good for drinking. Membrane in filter could be changed to a different one with a different pore size to keep fluorides to maximum. Posttreatment/remineralization of the effluent water to increase fluoride levels according to manufacturer guidelines.	Needs additional topical fluoride applications such as varnish or gel for prevention of caries among those having a moderate to high caries risk

Abbreviations: NF, nanofiltration; RO, reverse osmosis.

It had been shown that at 0.7 ppm of fluoride around 12% of participants would have fluorosis of aesthetical concern (Iheozor-Ejiofor et al., 2015). Another study, reanalyzing Deans data had shown that at each increase in fluoride level there is a reduction in DMFT (decayed missed and filled teeth) as well as percentage without dental caries. At very low fluoride levels the prevalence of dental fluorosis is also very low, and prevalence of fluorosis only increased with increasing fluoride level in drinking water (Whelton et al., 2019).

Malaysia, which is a tropical country had adjusted the fluoride level in drinking water from 0.7 to 0.5 ppm and had since observed prevalence of dental fluorosis decreasing from 38% to 31%. It was determined at 0.5 ppm fluoride, caries preventive effects is maintained (Mohd Nor et al., 2018).

In Australia community water fluoridation is at 0.6–1.1 ppm (Australian Government, 2017). Hong Kong fluoridates its drinking water at 0.5 ppm (Department of Health, Government of Hongkong Special administrative Region, 2022) while Singapore does so at 0.5 ppm in its community water supply (Chong & Tseng, 2011). In South Korea community water fluoridation occurs at 0.8 ppm in the public water supply (Kim et al., 2017).

In Sri Lanka, a study by Warnakulasooriya et al. had concluded that the optimum fluoride level to be maintained in drinking water sources should be 0.8 ppm at a time when fluoridated toothpaste was not widely in use among Sri Lankans (Warnakulasuriya et al., 1992). A similar assessment, conducted by Ekanayake and van der Hoek concluded that 0.3 ppm level of fluoride in drinking water would maximize caries preventive effects and minimize the risk of dental fluorosis in the dry zone at a time when fluoridated toothpaste was used maximally (Ekanayake & van der Hoek, 2003). However, these studies had not considered the water consumption pattern with ambient temperature variations. The Galagan and Vermillion formula uses the ambient temperature and the fluid intake pattern to determine the optimum fluoride level in drinking water (Galagan & Vermillion, 1957). This formula was used by Ranasinghe et al. who had concluded that the standard for Sri Lanka should be 0.36–0.49 mg/L (Ranasinghe et al., 2018). Although ambient temperature values for this study were taken from Sri Lanka, water consumption pattern was from elsewhere. A study conducted in the intermediate zone comprising dry and wet zone areas (Kurunegala district in the Northwestern Province) in 2019 examined the prevalence of dental fluorosis with varying fluoride levels. By using a receiver operating characteristic (ROC) curve, a statistical method that identifies the threshold level of fluorides looking at the binary outcome or presence or absence of fluorosis, proposed 0.225 ppm as the optimum fluoride level. The fluoride level of 0.225 ppm had a sensitivity and specificity of 0.576 and 0.681, respectively. In the range of 0.225–0.500 ppm, the prevalence of dental fluorosis and caries was only 14% and 8%, respectively (Jinadasa, 2019). This study also looked at prevalence of dental fluorosis and dental caries at a time when other sources of fluorides are common. As none of these recommendations were used in the water systems in Sri Lanka, their effects could not be assessed for effectiveness. However, the introduction of membrane-based water treatment in the CKDu affected areas has offered an opportunity for reviewing the appropriate level of fluoride. As discussed above the water fluoride level needs to be below 0.5 ppm and above 0.225 ppm to protect against fluorosis and caries.

4.2 | Develop preventive practices for oral diseases relative to fluoride

Dental caries could be prevented by promoting water fluoridation, fluoridated toothpaste, fluoride applications, fissure sealant applications, and dietary counselling (Department of Scientific Information, Evidence Synthesis & Translation Research, ADA Science & Research Institute, LLC, 2021).

Dental fluorosis also could be easily prevented by drinking appropriately fluoridated water (Sherwood, 2010).

As there is a significant correlation between fluoride levels and oral health, development of preventive practices for dental caries and dental fluorosis management is dependent on three major factors: (1) the level of naturally occurring fluoride in the local environment; (2) the availability and use of water from RO or NF units; and (3) access to dental health services.

Information on fluoride level in drinking water, availability, and use of water filtration units should be collected in each area and with these data in hand the following practices could be implemented to improve oral health of children under the age 8 (Exhibit 1).

As shown in Exhibit 1, when the fluoride level is above 0.5 ppm measures need to be taken to prevent dental fluorosis such as introduction of alternative sources of water but when it is below 0.225 ppm there is a need to reorient oral health care services to prevent dental caries. Proper monitoring of water purification systems and the quality of the product water is an important aspect in preventing these two conditions.

Fluoride toothpaste as well as fluoride in the drinking water has a part to play in prevention of dental caries (Wright et al., 2014). Fluoridated toothpaste has a topical action. Children below 3 years need to be given a smear layer and from 3 to 8 years need a pea sized amount (FDI World Dental Federation, 2019). Guidance on the proper use of fluoride toothpaste in the community should be conducted by Dental Surgeons (DS) and School Dental Therapists (SDT) during the prenatal period for mothers and by conducting education sessions in schools for the children.

4.3 | Lessons learnt and way forward

The current guidelines for fluoride in drinking water in Sri Lanka are WHO based (Sri Lanka Standards Institute, 2013) and do not address the local ecological, sociocultural, behavioral, water contamination and filtration systems and prevalence of dental caries and fluorosis situation. The water authority maintains a value below 1 ppm in urban water supplies and there are no actions taken when it is very low. Most of the people in the rural areas depend on wells, rivers, tanks, or community water treatment units for their requirements. The fluoride values of drinking water vary for the dry and wet zones. With the guideline range proposed, preventive and treatment measures can be introduced for better oral health. As there is no centralized supply of water at the locations considered raw and product water shall need to be monitored at intervals. The range proposed in this paper is 0.225–0.5 ppm is provisional and is based on still limited observations. It is, however, likely an appropriate starting point from which a refined range can be subsequently determined as more data becomes available. More research is needed to assess the amount of fluoride ingested by children and adults in endemic areas.

At present the performance of the RO and NF systems is not adequately monitored and has resulted in inappropriate levels of fluoride. A protocol needs to be developed such that these systems can come under the purview of the country's water authority.

If a district has raw water with fluoride levels which a RO or NF system cannot adequately address, the current practice of the Sri Lanka water authority is to locate an alternative source with a suitable fluoride level. This approach is called well screening and it should be encouraged in all the affected areas.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing not applicable—no new data generated.

REFERENCES

Australian Government, National Health, & Medical Research Council. (2017). *Water fluoridation and human health in Australia: Questions and answers*. Australian Government, Department of Health and ageing.

Beltrán-Aguilar, E. D., & Dye, B. A. (2010). Prevalence and severity of dental fluorosis in the United States, 1999–2004. *Center for Disease Control and Prevention, US Department of Health and Human Services*, *53*, 8.

Cavalheiro, J. P., Bussaneli, D., Restrepo, M., Fragelli, C., Cordeiro, R., Rojas, A., & Jeremias, F. (2017). Clinical aspects of dental fluorosis according to histological features: A Thylstrup Fejerskov Index review. https://doi.org/10.21615/CESODON.30.1.4

Chandrajith, R., Bhagya, S., Diyabalanage, S., Wimalasiri, S., Ranatunga, M. A., & Barth, J. A. C. (2021). Exposure assessment of fluoride intake through commercially available black tea (Camellia sinensis L.) from areas with high incidences of chronic kidney disease with undetermined origin (CKDu) in Sri Lanka. *Biological Trace Element Research*, *200*(2), 526–534. https://doi.org/10.1007/s12011-021-02694-2

Chandrajith, R., Padmasiri, J. P., Dissanayake, C. B., & Prematilaka, K. M. (2012). Spatial distribution of fluoride in groundwater of Sri Lanka. *Journal of the National Science Foundation of Sri Lanka*, *40*(4), 303–309. https://doi.org/10.4038/jnsfsr.v40i4.5044

Chong, G., & Tseng, P. (2011). A review of the uses of fluoride and outcomes of dental caries control in Singapore. *Singapore Dental Journal*, *32*, 14–18. https://doi.org/10.1016/S0377-5291(12)70011-1

Cooray, T., Wei, Y., Zhong, H., Zheng, L., Weragoda, S. K., & Weerasooriya, R. (2019). Assessment of groundwater quality in CKDu affected areas of Sri Lanka: Implications for drinking water treatment. *International Journal of Environmental Research and Public Health*, *16*(10), 1698. https://doi.org/10.3390/ijerph16101698

DailyFT. (2012). Signal celebrates five decades of caring for oral hygiene in Sri Lanka | Daily FT. Retrieved from https://www.ft.lk/healthcare/signal-celebrates-five-decades-of-caring-for-oral-hygiene-in-sri-lanka/45-92361

DenBesten, P. K. (1999). Biological mechanisms of dental fluorosis relevant to the use of fluoride supplements. *Community Dentistry and Oral Epidemiology*, *27*(1), 41–47. https://doi.org/10.1111/j.1600-0528.1999.tb01990.x

Department of Health, Government of Hongkong Special administrative Region, O H. E. D. (2022). *Oral care tips—Oral health care zone for grown-ups*. Retrieved December 30, 2022, from Oral care tips website: https://www.toothclub.gov.hk/en/en_adu_01_02_06.html

Department of Scientific Information, Evidence Synthesis & Translation Research, ADA Science & Research Institute, LLC. (2021). *Caries risk assessment and management*. Retrieved March 25, 2022, from https://www.ada.org/resources/research/science-and-research-institute/oral-health-topics/caries-risk-assessment-and-management

Ekanayake, L., & van der Hoek, W. (2003). Prevalence and distribution of enamel defects and dental caries in a region with different concentrations of fluoride in drinking water in Sri Lanka. *International Dental Journal*, *53*(4), 243–248. https://doi.org/10.1111/j.1875-595x.2003.tb00752.x

FDI World Dental Federation. (2019). Promoting oral health through fluoride toothpaste. *International Dental Journal*, *69*(1), 17–18. https://doi.org/10.1111/idj.12469

Galagan, D. J., & Vermillion, J. R. (1957). Determining optimum fluoride concentrations. *Public Health Reports (1896-1970)*, *72*(6), 491–493. https://doi.org/10.2307/4589807

Horbulyk, T., Kafle, K., & Balasubramanya, S. (2021). Community response to the provision of alternative water supplies: A focus on chronic kidney disease of unknown aetiology (CKDu) in rural Sri Lanka. *Water International*, *46*(1), 37–58. https://doi.org/10.1080/02508060.2020.1868124

Iheozor-Ejiofor, Z., Worthington, H. V., Walsh, T., O'Malley, L., Clarkson, J. E., Macey, R., & Glenny, A. M. (2015). Water fluoridation for the prevention of dental caries. *The Cochrane Database of Systematic Reviews*, *2015*(6), CD010856. https://doi.org/10.1002/14651858.CD010856.pub2

Imbulana, S., Oguma, K., & Takizawa, S. (2020). Evaluation of groundwater quality and reverse osmosis water treatment plants in the endemic areas of Chronic Kidney Disease of Unknown Etiology (CKDu) in Sri Lanka. *The Science of the Total Environment*, *745*, 140716. https://doi.org/10.1016/j.scitotenv.2020.140716

Indika, S., Wei, Y., Hu, D., Ketharani, J., Ritigala, T., Cooray, T., … Weerasooriya, R. (2021). Evaluation of performance of existing RO drinking water stations in the North Central Province, Sri Lanka. *Membranes*, *11*(6), 383. https://doi.org/10.3390/membranes11060383

Jayawardana, D. T., Pitawala, H. M. T. G. A., & Ishiga, H. (2010). Groundwater quality in different climatic zones of Sri Lanka: Focus on the occurrence of fluoride. *International Journal of Environmental Science and Development*, *2*, 244–250. https://doi.org/10.7763/IJESD.2010.V1.47

Jinadasa, B. K. G. T. (2019). Dental fluorosis among 15-year-old school children in Kurunegala district; risk factors and its association with dental caries and oral health related quality of life [Thesis, Postgraduate Institute of Medicine]. Postgraduate Institute of Medicine. Retrieved from http://librepository.pgim.cmb.ac.lk/handle/1/3127

Kim, H. N., Kim, J. H., Kim, S. Y., & Kim, J. B. (2017). Associations of community water fluoridation with caries prevalence and oral health inequality in children. *International Journal of Environmental Research and Public Health*, *14*(6). https://doi.org/10.3390/ijerph14060631

Ministry of Health, Nutrition and Indigenous Medicine (Sri Lanka) (1983). National Oral Health Survey Sri Lanka 1983–84. Colombo.

Ministry of Health, Nutrition and Indigenous Medicine (Sri Lanka) (1994). National Oral Health Survey Sri Lanka 1994–95. Colombo.

Ministry of Health, Nutrition and Indigenous Medicine (Sri Lanka) (2002). National Oral Health Survey Sri Lanka 2002–03. Colombo.

Ministry of Health, Nutrition and Indigenous Medicine (Sri Lanka) (2018). National oral health survey Sri Lanka 2015–2016 (p. 118). Retrieved from http://www.health.gov.lk/moh_final/english/public/elfinder/files/publications/2019/NOHS2015-2016.pdf

Mohd Nor, N. A., Chadwick, B. L., Farnell, D. J. J., & Chestnutt, I. G. (2018). The impact of a reduction in fluoride concentration in the Malaysian water supply on the prevalence of fluorosis and dental caries. *Community Dentistry and Oral Epidemiology*, *46*(5), 492–499. https://doi.org/10.1111/cdoe.12407

Moran Ayala, L. I., Paquet, M., Janowska, K., Jamard, P., Quist Jensen, C. A., Bosio, G. N., … Boffa, V. (2018). Water defluoridation: Nanofiltration vs membrane distillation. *Industrial & Engineering Chemistry Research*, *57*(43), 14740–14748. https://doi.org/10.1021/acs.iecr.8b03620

National Institute of Health. (2022). *Fluoride fact sheet for health professionals [Health Information*]. Retrieved April 15, 2022, from US Department of Health and Human Services website: https://ods.od.nih.gov/factsheets/Fluoride-HealthProfessional/

National Water Supply and Drainage Board Sri Lanka. (2014). *Annual report 2013. National water supply and drainage board*. Retrieved from http://www.waterboard.lk/web/images/annual_reports_2013/annual_rep_en_thirteen.pdf

O'Mullane, D. M., Baez, R. J., Jones, S., Lennon, M. A., Petersen, P. E., Rugg-Gunn, A. J., & Whitford, G. M. (2016). Fluoride and Oral Health. *Community Dental Health*, *33*(2), 69–99.

Punyawardena, B. V. R. (2020). Climate. In R. B. Mapa (Ed.), *The soils of Sri Lanka* (pp. 13–22). Springer International Publishing. https://doi.org/10.1007/978-3-030-44144-9_2

Rajapakse, S., Shivanthan, M. C., & Selvarajah, M. (2016). Chronic kidney disease of unknown etiology in Sri Lanka. *International Journal of Occupational and Environmental Health*, *22*(3), 259–264. https://doi.org/10.1080/10773525.2016.1203097

Ranasinghe, N., Kruger, E., & Tennant, M. (2018). Determination of the optimum level of fluoride for drinking water in different climatic zones of Sri Lanka based on the ambient temperature. *Fluoride Research*, *48*(02), 78–87.

Ranasinghe, N., Kruger, E., & Tennant, M. (2019). Spatial distribution of groundwater fluoride levels and population at risk for dental caries and dental fluorosis in Sri Lanka. *International Dental Journal*, *69*(4), 295–302. https://doi.org/10.1111/idj.12476

Saad, H., Escoube, R., Babajko, S., & Houari, S. (2022). Fluoride intake through dental care products: A systematic review. *Frontiers in Oral Health*, *3*, 916372. https://doi.org/10.3389/froh.2022.916372

Sherwood, A. (2010). Fluorosis varied treatment options. *Journal of Conservative Dentistry: JCD*, *13*, 47–53. https://doi.org/10.4103/0972-0707.62631

Solanki, Y. S., Agarwal, M., Gupta, A. B., Gupta, S., & Shukla, P. (2022). Fluoride occurrences, health problems, detection, and remediation methods for drinking water: A comprehensive review. *The Science of the Total Environment*, *807*(Pt 1), 150601. https://doi.org/10.1016/j.scitotenv.2021.150601

Spencer, A. J., Do, L. G., Mueller, U., Baines, J., Foley, M., & Peres, M. A. (2018). Understanding optimum fluoride intake from population-level evidence. *Advances in Dental Research*, *29*(2), 144–156. https://doi.org/10.1177/0022034517750592

Sri Lanka Standards Institute. (2013). *Sri Lanka standard 614: 2013 UDC 663.6 specification for potable water (First Revision)*. Retrieved from https://pdfcoffee.com/sls-614-pdf-free.html

The Sunday Times (Sri Lanka). (2019). Siddhalepa to expand India operations. *The Sunday Times* Sri Lanka. Retrieved from http://www.sundaytimes.lk/190106/business-times/siddhalepa-to-expand-india-operations-328567.html

U.S. Public Health Service. (2015). Recommendation for fluoride concentration in drinking water for the prevention of dental caries. *Public Health Reports*, *130*(4), 318–331. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4547570/

Van Der Hoek, W., Ekanayake, L., Rajasooriyar, L., & Karunaratne, R. (2003). Source of drinking water and other risk factors for dental fluorosis in Sri Lanka. *International Journal of Environmental Health Research*, *13*(3), 285–293. https://doi.org/10.1080/0960312031000122433

Warnakulasuriya, K. A., Balasuriya, S., Perera, P. A., & Peiris, L. C. (1992). Determining optimal levels of fluoride in drinking water for hot, dry climates—A case study in Sri Lanka. *Community Dentistry and Oral Epidemiology*, *20*(6), 364–367. https://doi.org/10.1111/j.1600-0528.1992.tb00700.x

Whelton, H. P., Spencer, A. J., Do, L. G., & Rugg-Gunn, A. J. (2019). Fluoride revolution and dental caries: Evolution of policies for global use. *Journal of Dental Research*, *98*(8), 837–846. https://doi.org/10.1177/0022034519843495

WHO (Ed.) (2019). Inadequate or excess fluoride: A major public health concern. World Health Organization. Retrieved from https://www.who.int/publications-detail-redirect/WHO-CED-PHE-EPE-19.4.5

Wimalawansa, S. J. (2014). Escalating chronic kidney diseases of multi-factorial origin in Sri Lanka: Causes, solutions, and recommendations. *Environmental Health and Preventive Medicine*, *19*(6), 375–394. https://doi.org/10.1007/s12199-014-0395-5

World bank group. (2021). *World Bank climate change knowledge portal*. Retrieved July 22, 2022, from https://climateknowledgeportal.worldbank.org/

World Health Organization (2019). *Preventing disease through healthy environments Inadequate or excess fluoride: A major public health concern*. World Health Organization. Retrieved from https://apps.who.int/iris/handle/10665/329484

Wright, J. T., Hanson, N., Ristic, H., Whall, C. W., Estrich, C. G., & Zentz, R. R. (2014). Fluoride toothpaste efficacy and safety in children younger than 6 years. *The Journal of the American Dental Association*, *145*(2), 182–189. https://doi.org/10.14219/jada.2013.37

How to cite this article: Thilakarathne, B. K. G., Schensul, S., Weeragoda, S. K., Weerasooriya, R., & Jern, Ng. W. (2023). Fluoride removal and its impact on oral health in Sri Lanka's dry zone: Discussion and recommendation. *Environmental Quality Management*, 1–8. https://doi.org/10.1002/tqem.21982