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Community awareness on fluoride contaminant sources: a case study at Mount Meru slopes in Northern Tanzania

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Abstract

A study was conducted around the slopes of Mount Meru in Arumeru district of Arusha region at Ngarenanyuki ward, to update the awareness of the potential routes of human exposure to unacceptable levels of fluoride. Long term consumption of fluorine contaminated water and food, in addition to the use of fluoridated products, increases fluoride accumulation in the body. A cross-sectional, multi-phase sample design, in-depth structured questionnaires, informant interviews, and group discussions were carried out. Women aged between 15-45 years were involved. Participants identified water used for domestic purposes was the leading (68.63%) route of fluoride contaminant. Findings revealed that the majority (70.6%) of the participants were not aware of the potential sources of fluoride contaminants such as grown food crops/vegetables and fluoridated products. In addition, most (84.93%) of the respondents were using fluoridated toothpaste and children were not assisted or supervised as they use it which could lead to swallowing of the paste and increase the accumulation of fluoride in the body. Most (77 %) of the participants reported that their children had brown teeth enamel and use tap water as their primary source of domestic and drinking water. There were neither household's fluoride management methods nor alternative domestic water sources identified by participants at the household level. This study recommends an in-depth study to evaluate fluoride levels in all potential routes of contamination, to guide management of dental and skeletal fluorosis in the community. Interventions to reduce fluoride contamination in this endemic area are necessary to combat health risks associated with their exposure.

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Introduction

Fluorine, the 13th most abundant element, is the most electronegative element widely dispersed in nature (World Health Organization [WHO], 2014) although rarely found in its elementary state, it presents as inorganic fluoride (Firempong *et al.*, 2013). Most living organisms are potentially exposed as fluoride exists in soil, water, and air, (Mohammad *et al.*, 2017). Natural and anthropogenic activities are the main source of fluorine release in the environment, which are generally industries that emit both gas and particulate forms of fluoride, which can dissolve in the water surface, forming hydrogen fluoride (HF) or hydrofluoric acid.

Fluoride when absorbed by organism, it accumulates in mineralized tissues (bone and teeth) (Chen *et al.,* 2017; Ferreira *et al.,* 2018) wherever, it depends on the pH of the stomach contents (2.4% HF at pH 5; 96% HF at pH 2), the concentration meantime is 20-60 minutes after consumption, whereby, adults retain around 36% of fluoride, but children retain nearly 50% of fluoride and the remaining part of the absorbed fluoride is excreted through the kidneys into the urine (Gupta *et al.*, 2019). Fluoride, within optimum limits, is an important factor for dental health whilst, above a minimum concentration, has been demonstrated to be toxic (WHO, 2016).

Exposure to excessive fluoride through different fluoride contaminants sources such as, domestic water, fluoridated products like toothpaste, beverages, processed food and food crops which are grown in contaminated soil or irrigated with fluoride contaminated water can be the primary sources for the prevalence of dental and skeletal fluorosis (WHO, 2016). Nearly, all foodstuffs contain fluoride (WHO, 2014), the highest levels in field-grown vegetables are found in curly kale, however, other foods like tea, fish, meat, canned anchovies, fruits, cereals, chocolate milk, beverages, and some baby dietary supplements have been reported to have fluoride (Kanduti *et al.*, 2016; Ying *et al.*, 2018). High fluoride concentration in tea can be due to high concentration in tea plants or the use of additives during growth or fermentation (WHO, 2014). In areas where water with high fluoride concentration is used for tea preparation, the intake via tea can be greater and severe health effects.

In Africa, where most of the countries along with Rift Valley areas, reported with high fluoride concentration in its water sources and soil (Craig *et al.*, 2015**;** Malango *et al.*, 2017) community awareness about fluoride contaminant source is highly needed for the prevalence of dental fluorosis.

In Tanzania, the most fluoride endemic region includes; Arusha, Kilimanjaro, Mara, Manyara, Mwanza, Shinyanga, and Singida, while the moderately affected region includes Tabora, Kigoma, Dodoma, and Tanga (Malango *et al.,* 2017). In the Northern areas of the country, the Arusha region was identified with the highest concentration of fluoride in its water sources with an average fluoride concentration of 13.57 ± 64.16 mg/l. (Malango *et al.*, 2107) due to its geological nature. WHO, (2011) recommends fluoride intake through drinking water to be 1.5 mg/L. While, in Tanzania acceptable drinking water fluoride levels is 4.0 mg/L (Tanzania Bureau of Standards) (TBS, 2005). However, such recommendation is a significant variance from internationally recommendation levels, possibly leads to health effects overtime exposure.

Globally the main causes for the burden of dental caries are related to the high prolonged exposure to potential fluoride contaminate sources (WHO, 2015). The WHO, 2010) document entitled “Inadequate or excess fluoride: a major public health concern” describes the use of fluoride in a public health environment. Dental fluorosis is a developmental disturbance of enamel which occurs during enamel formation (WHO, 2016) and is strongly associated with cumulative fluoride intake during this critical time (Rango *et al.*, 2014; Ferreira *et al.*, 2018). The severity of the condition depends on the dose, duration, and timing of fluoride intake (Craig *et al.*, 2015; Slade *et al.*, 2018). The unmanaged initiation and utilization of fluoridated toothpaste increase fluoride concentration in the body especially for

children (Khan *et al*., 2015). Fluoride concentrations have been associated with intelligence quotient reduction (Bashash *et al.,* 2017; Valdez *et al*., 2017), as well as learning and memory deficits (Jetti, 2016). High fluoride exposure has been associated with adverse effects on fertility and the reproductive system, reflected in decreased birth rates and testicular disorders (Mesram, 2016). Arumeru District is known to be endemic in dental and skeletal fluorosis for a long time in Tanzania (Kaseva, 2006; Ghiglieri *et al*., 2010).

Though different de-fluoridation interventions have been reported in Tanzania, like coconut shells and activated carbon (Said *et al*., 2014), and regeneration of fluoride-saturated bone char (King *et al*., 2016). The bone char technique has been reported as successful for fluoride removal in drinking water in Tanzania; however, it is not available in most of the fluoride endemic areas.There are no systematic studies carried out in fluoride endemic areas in Tanzania on the community awareness of potential fluoride contaminant sources. Despite the extensive presence of high fluoride in water sources in most of Tanzania's Rift Valley areas and the seriousness of fluorosis in the Arumeru District, awareness of fluoride exposures through potential fluoride sources such as local food crops grown in contaminated soil and its health risk associated is insufficiently documented. Hence, the objective of the present study was to assess awareness of fluoride exposure through drinking water, locally grown foods, and other fluoride potential sources in the Arumeru District in Northern Tanzania. Ethical clearance was obtained from the National Institute for Medical Research (NIMR) and the permission to work in the geographic region was obtained from the Executive Director Arumeru District, who is the District Medical Officer (DMO). Simultaneously, permission to work in the villages was obtained from the Villages Health committees.

Materials and methods

Study area description

The survey was conducted in three villages of Ngarenanyuki ward focused at Ulkungwa' du, Uwiro, and Ngabobo in Arumeru District, one of six districts in the Arusha Region of northern Tanzania. It is located at 3.2923° S, 36.8250° E, along the Mount Meru slopes (Wikipedia Dec 2, 2018). As of the 2012 population census, Arumeru District had 268,144 people, with 136,880 females and 131,264 males (Tanzania National Bureau of Statistics, 2012). Ngarenanyuki ward was the second-most-populous ward in the region with 20,379 people. These areas are among the fluoride endemic areas in Tanzania characterized by the severity of dental fluorosis.

Data collection

The survey villages were purposively selected based on the report of dental fluorosis through previous study and personal observation during a field survey. In each village, participants were randomly selected for interviews from the sampling list obtained from Villages Health centers.Three hundred women of reproductive age from three villages (100 women from each village) were approached respecting information on their general awareness about fluoride exposure through consumption of locally grown food crops in contaminated soil and other potential sources. In Tanzanian communities, women control the family dietary intake; hence, their responses helped to identify fluoride exposure awareness in the surveyed communities.

The community residents across the villages ethnically are Maasai, Wameru, and waa Arusha, which traditionally positions them primarily as agriculturists and/or pastoralists. A survey was carried out from July to September 2018. A cross-sectional, multi-phase sample design, whereby in-depth structured questionnaires, informant interviews, and group discussions were carried out. Oral and written consent was obtained from the participants. Questionnaires were discussed during face to face interviews by individual participants. Women were asked to prioritize the fluoride potential contaminant sources, fluoride health effects, management for fluoride remedies in domestic or/drinking water.

Three health assistant officers were trained by the principal investigator (researcher) prior to the study being conducted. The questionnaire was piloted in a nearby village health center (Lutheran Dispensary Centre) at Ulkungwa'du village for its validity. The pre-testing was conducted among selected women in households in the surveyed areas. After verification of the validity of the questionnaire, the pre-testing was found to be useful for familiarising the participants and was distributed with the help of trained assistant health officers from each village. The information collected included: participant's socio-economic profile (e.g. age, education, income level, work status, and marital status), knowledge and perception of fluoride awareness in various variables. Women were interviewed in their local languages (Kiswahili) and Maasai with help of assistant officers.

Data analysis

Data obtained from the surveyed study were summarized and descriptive statistics were carried out through the Statistical Package for Social Sciences SPSS™ (, Inc., Chicago, IL, USA) Version 20. For each question, the percentage of participant's responses was calculated from each village. But those who didn't respond to certain questions were excluded from the calculation. Assessment of the differences of socio-demographic, knowledge of fluoride awareness perception on potential contaminant sources and any management methods for fluoride removal in drinking water at a household level, comparatives statistical tools were used (one-way analysis of variances, and Chi-square). The significance level was set at 0.05, which means the value was separated by Tukey's HSB (Honesty Significance differences).

Results

Socio-demographic profiles

Most of the respondents surveyed at Ulkung'wadu and Ngabobo villages were averagely aged between twenty and thirty years (26.73% and 23.1%). However, at Uwiro village the majority of women were aged between twenty years (33.7%). Similarly, more than half of women (66.5%) from all villages were qualified for primary education level, with the mean income level of less than 250000 (200$) TSH per annual (78.9%) of participants from Uwiro and Ngabobo villages. Meanwhile, at Ulkungwa'du village more than three-quarter (81.1%) of participants were earned less than 200 USD annually. While, an average of 24.3% of participants from all study villages were self-employed however, the majority of women were housewife (68.73%) (Table1).

Table 1. Participants demographic information in selected villages of Ngarenanyuki ward.

	Villages				
Variable	Ulkwangw'adu	Uwiro	Ngabobo	Mean	χ2
Age					
15-19	5.7	9.5	8.3	7.83	
20-24	9.5	20	12.5	14	
25-29	26.7	33.7	19.8	26.73	
30-34	28.6	14.7	26	23.1	
35-39	21	13.7	15.6	16.76	
40-44	7.6	7.4	16.7	10.56	
>45	1.0	1.1	1.0	1.03	98.507***
Education					
Never went to school	5.8	8.2	9.4	7.8	
Primary school/elementary	68.9	63.9	66.7	66.5	
Secondary school	24.3	27.8	24	25.36	
college/university	1.0			1	311.622***
Work status					
Non-government employee	2.0	2.1	3.2	2.43	
Self employed	22.5	24.5	23.2	23.4	
Home maker	67.6	69.1	69.5	68.73333	
Unemployed	7.8	4.3	4.2	5.433333	326.581***
Income					
< 250000	81.8	76.6	78.3	78.9	

Note: Statistically significant at *P < 0.05, **P < 0.01, ***P < 0.001; ns = not significant.

Women awareness and perception of fluoride contaminant sources

The present study found that the majority of respondents from Uwiro and Ngabobo villages heard about fluoride exposures (59.4%, 54.1% respectively). Whilst, more than half of participants from Ulkungw'adu they were not aware of it (55.7%). Approximately three-quarter (74.8%) of the respondents from Ngabobo village identified water as potential fluoride contaminant sources while only a few percents (12.8% 12.1% respectively) identified soil and other sources. Similarly more than half of women from Ulkungw'adu and Uwiro villages reported water as primary fluoride contaminated source (66.6%, 63.8%) while an average of 8.5 % of women from Ulkungw'adu identified soil as potential fluoride contaminant source and almost one-quarter (24.9%) reported other sources.

Table 2. Participant's perception of different variables from selected villages from Ngarenanyuki ward**.**

	Villages				
Variable	Ulkwang'adu	Uwiro	Ngabobo	Mean	χ2
	N=106	N=98	N=101		
Fluoride exposure					
Aware	44.3	54.1	59.4	52.0	78.346***
Not aware	55.7	45.9	40.6	48.0	
Fluoride contaminant sources					
Soil	8.5	21.4	12.8	13.99	
Water	66.55	63.8	74.8	68.63	
Other (s)	24.95	14.8	12.4	17.38	
Fluoride contaminant in food					33.059***
Aware	22.5	37.8	25.7	29.4	
Not aware	77.5	62.2	74.3	70.6	
Fluoride health effects					405.081***
Hard bended back	16	6.1	15.8	11.9	
Large heads	1.9	2	2.0	1.9	
Pits in a tooth in children	79.3	85.7	76.3	78.2	
Born fracture and pains	2.8	6.2	5.9	8.0	
Domestic water sources					537.068***
River	0.9	1.1	3.0	1.4	
Tap water	92.5	94.9	92.1	83.4	
Borehole	6.6	4.0	4.9	15.2	
Fluoride reduction methods (domestic water)					348.465***
Not available	100	98	98	97.7	
Available		2.0	2.0	2.3	
Toothpaste usage					
Fluoridated	83	83.7	88.1	84.93	
Non Fluoridated	17.0	16.3	11.9	15.07	

Note: Statistically significant at *P < 0.05, **P < 0.01, ***P < 0.001; ns = not significant.

More than three quarters (77.5%) of the participants at Ulkungwa'adu village were not aware of food exposure sources and/or potential contamination with fluoride. Similarly, more than half (62.2%, 74.3% respectively) of women from Uwiro and Ngabobo were unaware of fluoride contaminants in food.

More than 80% of the participants from Uwiro village reported that their children had red/brown tooth enamel, whilst more than three-quarter (79.3% and

76.3%) reported from Ulkungwa'du and Ngabobo villages respectively. However, majority of women were not aware of how high fluoride concentrations contribute to learning and memory impairment from all surveyed villages.

The current study found more than 80% of women were using fluoridated toothpaste however, no assistance or supervision was provided for children regarding the use of toothpaste. The current study found more than 90% of women used tap water as their primary source of domestic/drinking water. No participants described any existing fluoride removal management methods were available and no alternative domestic/drinking water sources (to lower fluoride concentrations) were reported (Table 2).

Discussion

The present study found that the surveyed community had insufficient awareness about potential fluoride contaminant sources, through locally grown food crops in contaminated soil or irrigated with fluoridated water and other sources like fluoridated products. Although, the majority of women they identified water as primary potential fluoride contaminant sources. This might be due to the taste of domestic water observed in both surveyed villages and the presence of red pits in the tooth for most of the participants. Participants declared that they had observed the presence of fluoride in domestic water since ancient times which locally referred to as '*Magadi*', they had been overused it without knowledge of its health effects for different purposes, such as feeding cows and in preparation of local food (*makukuru*). Wherever there are no existing management methods for fluoride removal in domestic/drinking water at household's level reported by participants.

According to, Kaseva *et al.*, (2006) and Das *et al.*, (2016), the use of *Magadi* can increase excessive fluorosis, risks of fluoride accumulation, as well as the severe health implications for children > 6 years of age when excessively ingested (Kanduti *et al.*, 2016). Fluoride exposure at 20 ppm (NaF) has been reported to cause loss of motor control, antioxidants (SOD), and oxidation of lipids in brain development (Reddy, 2015; Jetti 2016; Mersam *et al.,* 2017). It has been reported that fluoride inhibits iodine absorption which leads to decrease thyroid hormone causes learning and memory impairment (Yu *et al.*, 2015; Shalini *et al.,* 2015; Bashash *et al.*, 2017; Valdez *et al.*, 2017).

However, a study found that, participants from surveyed villages they had no knowledge about fluoride acceptable level in drinking water (National 4mg/L TBS 2005, International l.5mg/L WHO 2011). Education level might be a reason, in Tanzania (primary) education curriculum, fluoride known as an important factor for dental health rather than its side effects when excessive ingested particularly for children,resulting in insufficient knowledge of fluoride as potential contaminant sources when overexposed.

Also, participants mentioned economic status contributing to an inability to afford internal filter to reduce fluoride concentration level at households, and they had no possibility of using bottled water with minimum fluoride concentration even for children/infants food preparation. Conversely, insufficient awareness about potential fluoride contaminant sources like cereals crops/vegetables, dairy products, and fluoridated products might be causing excessive exposures to fluoride from other sources unknown through consumption of fluoride contaminated diverse diet.

Globally, groundwater fluoride contamination is a critical health challenge (Adekola *et al.*, 2015; Adimalla *et al.*, 2018). According to WHO, (2011 page 2) guidelines on safe water, "all people, whatever their stage of development and their social and economic conditions, have the right to have access to an adequate supply of safe drinking water." Due to water scarcity in the country and high fluoride concentration values of the ground and surfaces water sources in Tanzania (Makungu *et al.*, 2014; Malango *et al.,* 2017), difficulties are encountered in meeting

International permissible limit of 1.5 mg/L (WHO, 2011). Raising fluoride exposure awareness and appropriate interventions in nutrition will play important roles in dealing with the problem of fluorosis in fluoride endemic areas in Tanzania. Therefore, the provision of de-fluoridated drinking water and health education aimed at abating fluorosis in people is highly desirable in villages' areas of the Arumeru District in Northern Tanzania. The Government and relevant organizations should prepare suitable drinking water at the community levels by providing internal filters with affordable costs.

Fluoride level in different food crops has been reported in Africa and other fluoride endemic areas globally (Tegegne *et al.*, 2013; Mustofa *et al.*, 2014). Cereals crops are major food staples in most of African and Asian countries, and due to the geological nature of some Asian and African countries which are found along Rift Valleys areas (Eastern and Western Rift valleys). Most of food crops either grown in fluoride contaminated soils or irrigated by contaminated water which increases fluoride accumulation in plants and then an organism's body tissues after consumption. Prolong exposure to fluoride through diverse food consumption may lead to severe health effects.

The current study identified that crops that are grown during dry seasons irrigated through Ngarenanyuki River which identified with fluoride level up to 26mg/L (Ghiglieri *et al.*, 2010), meanwhile, an intense application of artificial fertilizers and pesticides were used. That might cause an accumulation of fluoride in the soil through leaching and leads to plant fluoride contamination. The application of phosphate fertilizers had been reported from some scientific study as causative sources of fluoride accumulation in the soil when frequently used (Sapbamrer 2018).The severity of the food insecurity could be high in the surveyed community due to fluoridated water used for crop irrigation, domestic water, and the application of phosphate fertilizers. In-depth innovative studies are highly needed in agricultural and nutrition at fluoride endemic areas to minimize dental and skeletal fluorosis in a community for future generations. Plants are the basis of diets for animals and human beings; therefore, increasing fluoride concentrations in plants may lead to a substantial intensification in humans due to contact with the food chain (Craig, 2015; Narsimha, 2018). Fluoride contamination may also affect rivers and soil thus extending to agriculture (Isah *et al.*, 2014), and resulting in a relevant issue for food security and ecosystems. Hence, the accumulation of fluoride by agricultural plants is a potential threat to human health.

Furthermore, the study revealed that participants were not aware of the possibility of fluoride exposure through fluoridated toothpaste, particularly for children, although the majority of them were using fluoridated toothpaste from all surveyed villages.

Also, they were not providing assistance for tooth brushing to their children which might lead to excessive swallowing of paste and most of them were having red/brown teeth. When fluoridated toothpaste is ingested above recommended level of 0.7 to 0.5 ppm (Sami *et al.*, 2016; Marin *et al.*, 2016), leads to risk for enamel fluorosis especially for children who begin using fluoride toothpaste at age < 2 years than children who began later or who do not use fluoride toothpaste (Asawa *et al.*, 2015; Rugg-Gunn *et al.*, 2018). Severe forms of this condition can occur when young children ingest excess fluoride, from any source, during critical periods of tooth development (Choi, 2015; Narsimha *et al.,* 2018). However, different findings have shown that the sixth year of life is the most important period for the development of dental fluorosis in late erupting permanent teeth, but the teeth are susceptible for an extended period from about 2 to 8 years (Bhagavatula *et al.*, 2016).

Apart from that, majority of women mentioned red/brown teeth as a fluoride health effects they were aware, nevertheless, commonly known acute health effects include death related to binding of fluorine

with serum calcium and magnesium, vomiting, nausea, chronic convulsion, necrosis of the mucosa of the digestive tract and heart failure (Ferreira *et al.,* 2018). An in-depth study is highly needed in a community to identify the severity of a problem in different age groups especially for children and adolescences for proper fluoride guidelines in endemic areas in Tanzania. However, evaluation of fluoride levels in commonly consumed vegetable and cereal crops to identify possible routes of fluoride in the human body is required.

As an emergency response, some studies since 1986 were carried out in Tanzania to investigate fluoride removal methods (Singano, 1991; Mcharo, 1986; Mjengera, 2001). According to Singano (1991) indicated that, by using calcinated magnesite (MgO) as filter media which results in the formation of hydroxyapatite, with fluoride removed as sodium fluoride. Also, Mjengera (2001) optimized bone char column media for defluoridation of drinking water at the household level.

Recently different technology has emerged, whereby governments in Tanzania with collaboration with different non–government organization introduced different projects to reduce fluoride level in domestic water in Arusha region (Ngurudoto) and other different scientific findings like Nano filter but, these technology doesn't exist in most of fluoride endemic areas not only in Arumeru district but also at other identified fluoride endemic areas in Tanzania, however, those technology it relied only in water rather than other potential fluoride contaminant sources like food crops. Following the severity of the condition at Ngarenanyuki ward of dental fluorosis, the community was supplied with public tap water by governments, for domestic purposes but the fluoride level in those public water has to be evaluated to identify its fluoride level and awareness to the community about its level has to be known. However, besides supplying public tap water, it is important to train community on the proper methods of pesticide and/or fertilizer application to reduce fluoride in the plant crops, soil, which can cause health risks and food insecurity through food value chain.

Conclusions

Results of the present study revealed that fluoride is a serious health problem, especially for children who are the future generation. Immediate measures are recommended to minimize the threat of fluoride at the household level and at the community level. A strategy such as nutrition interventions through proper diet with minimum fluoride exposure is recommended. Vegetables from non-fluoride areas can be prepared in powder form and distributed as a supplement to the children.

The community should be encouraged to use non-fluoridated water to grow vegetables for household consumption. Health education programs in relation to fluoride health effects for women of reproductive age are crucial in the community as well as for school children. Proper counseling for parents and caregivers regarding the use of fluoridated toothpaste for children aged <2 years is required. There is a crucial need for dental health programs in fluoride contaminated community areas in Tanzania to reduce the burden of dental diseases.

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