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Research paper

Insights to promote safe drinking water behavioural changes in zones affected by fluorosis in the East-African Rift Valley

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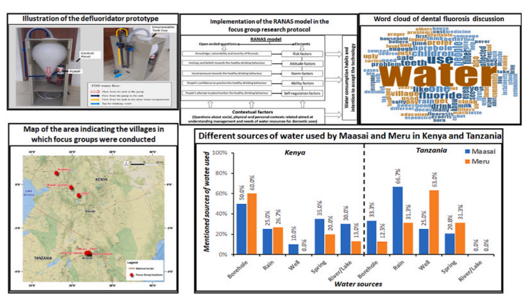
HIGHLIGHTS

- A new defluoridator was tested in local rural communities of Kenya and Tanzania.
- Factors affecting drinking behaviour were explored using the RANAS model.
- Lack of trust towards foreign companies negatively influences purchasing behaviour.
- Information about wrong beliefs regarding fluorosis can improve risk knowledge.
- Visual cues can nudge people towards the adoption of healthy drinking behaviour.

GRAPHICAL ABSTRACT



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ABSTRACT

The presence of fluoride in drinking water can have beneficial effects in reducing the incidence of dental caries when its concentration lies in the optimal range of 0.5–0.7 mg/L. However, fluoride intake below and above this range can have negative effects on tooth enamel and skeletal fluorosis in case of prolonged exposure to high concentrations. Unfortunately, in some areas of the world, such as rural communities of the East-African Rift Valley (EARV), water is dramatically contaminated by fluoride which may cause dental and skeletal fluorosis because its concentration is often well above the maximum threshold of 1.5 mg/L recommended by the World Health Organisation.

To tackle this problem experts and policy makers have attempted to introduce defluoridation techniques that, as well as being cost-effective, allow end users to drastically reduce the level of fluoride below the above-mentioned threshold. However, the adoption of these techniques remains quite low because behavioural factors influencing people's safer water consumption in these areas of the world is poorly understood. To fill such a gap in this study we explore how these factors can influence the adoption of a new defluoridator in Kenyan and Tanzanian rural communities of the EARV. To achieve this objective 75 people belonging to Maasai and Meru ethnic groups were interviewed running nine focus groups where these factors were investigated using the RANAS (Risk, Attitude, Norm, Ability, Self-Regulation) model.

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Results show that the drinking behaviour of people living in the EARV is dramatically affected by contextual factors and exacerbated by the high level of fluoride naturally contained in drinking and cooking water. Behavioural insights into how policy makers and marketers could reverse this unhealthy drinking behaviour introducing technological devices that can cut the quantity of fluoride contained naturally are discussed arguing in favour of the possibility of using different behaviour changing techniques.

1. Introduction and background

Excessive fluoride in drinking water affects living conditions and health status of approximately 200 million people worldwide, especially in countries such as India, China, Argentina and Mexico. In Africa, high fluoride groundwater levels have been reported mostly in the East African Rift Valley (EARV) that originates in Eritrea and extends through Ethiopia, Kenya and Tanzania and to Malawi (Ijumulana et al., 2020). This problem is accelerated by young volcanic activities, occurrence of thermal waters, especially those with high pH, gases emitted from earth's crust, granitic and gneissic rocks (Ijumulana et al., 2020, 2021).

In Kenya and Tanzania, health problems caused by dental and skeletal fluorosis are associated with high fluoride content contained naturally in surface and groundwater and this correlation has been documented since 1944 (Grech and Latham, 1964). In Kenia, the population exposed to high fluoride intake is estimated at 7 million (Coetsiers et al., 2008), while in Tanzania ten million people suffer from the same problem as highlighted by the Tanzanian Ministry of Water and Irrigation (Hawkins, 2010). The Central Kenya Rift and Arusha district in Tanzania, where this study was conducted, are the regions of the EARV most affected by this problem. In Kenya, the highest levels of fluoride in groundwater are found in the volcanic areas of the EARV, with Nairobi and Central Provinces reporting the highest value of fluoride as 1,640 mg/L and 2,800 mg/L, respectively in Lakes Elmentaita and Nakuru (Malago et al., 2017). In Arusha, in the area surrounded by Mount Meru, this problem is determined by the relationship between its geology and hydrogeology as described by Ghiglieri et al. (2010). Hydrogeological units host aquifers with different qualities of groundwater where high values of fluoride (up to 68 mg/L) were recorded (Ghiglieri et al., 2010, 2012; Tomašek et al., 2022). Studies conducted in this region show that the occurrence of fluoride is space dependent and the presence of many sources with high and few with low fluoride concentrations is one of the challenges affecting the blending technology adopted by Arusha Urban Water Supply Authority (Ijumulana et al., 2020, 2021).

As groundwater is the main water resource for human and agricultural needs, the geological and hydrogeological conformation of the geographical areas described above seriously challenge the health of people living in rural communities e.g. about 25% of the Tanzanian population depends entirely on groundwater for drinking (Ligate et al., 2021; Ijumulana et al., 2022). According to the World Health Organisation (WHO), epidemiological evidence suggests that systemic fluoride intake of drinking and cooking water above 1.5 mg/L can carry an increased risk of dental fluorosis, while progressively higher concentrations lead to risks of skeletal fluorosis (Ward et al., 2009). Therefore, where the fluoride concentration of groundwater for human consumption might be over beyond 40 mg/L, dental and skeletal fluorosis dramatically affect the life of Kenyan and Tanzanian rural communities (Tekle-Haimanot et al., 2006; Ghiglieri et al., 2012; Njuguna et al., 2020). About 90% of people living in these areas are affected by dental fluorosis at different stages of severity, and dental and skeletal fluorosis are recognized health problems (Vuhahula et al., 2009).

The difficulty to reduce very high levels of fluoride contained in surface and groundwater forced policy makers to set a higher standard of fluoride concentration than that established by the WHO (1.5 mg/L) because the latter cannot be guaranteed with the available technology and current socio-economic conditions of these rural communities (Malago et al., 2017). For example, the standard water fluoride concentration recommended by the Tanzania Bureau of Standards was fixed at 4 mg/L due to lack of reliable defluoridation technologies, especially in the semiarid rural area (Mbabaye et al., 2018). However, recently the standard water fluoride concentration recommended by Water Supply and Sanitation Authority of the Tanzanian government has been reduced from 4 mg/L to the WHO recommended level of 1.5 mg/L (EWURA, 2020).

Strategies to solve groundwater fluoride contamination are based on an in-depth knowledge of the hydrogeology of an area that can help local and government agencies to build wells that intercept good quality water and development of defluoridation methods. Several defluoridation methods have been extensively studied exploiting different technologies (Yadav et al., 2018) such as reverse osmosis, membrane and nanofiltration, electrodialysis or various adsorbent and ion-exchanger material (e.g. LDH, bauxite, red soil, bio-sorbent and bone char), and coagulation and precipitation methods (e.g. Nalgonda technique, calcium-based material).

Although a few studies indicate that these different defluoridation technologies effectively remove fluoride from water, an applicable and reliable method has not yet been developed due to various contraindications regarding the technical viability and economic feasibility, especially for their use in rural areas (Ayoob et al., 2008). Usually, these technologies are simple and have a relatively low costs of adoption, but the reasons behind their poor acceptance and lack of sustainability appear to be complex. Peal, Evans & van der Voorden (2010) argue that poor technology acceptance and use of water quality interventions is affected by the hygiene and sanitation tools of the hardware (e.g. defluoridation devices) and by the use of software. For example, hardware constraints prevent a large-scale use of the bone char method, especially in rural areas (Albertus et al., 2000). Software used to manage these defluoridation devices requires interaction of human beings in a cultural and social sensitive environment that makes it difficult to promote health drinking behaviour through the adoption of new technologies (Makutsa et al., 2001; Peal, Evans and van der Voorden, 2010). Furthermore, as fluoride concentration in water is not constant, the monitoring of defluoridation performance is a mandatory activity. This activity is fundamental to identify when the sorbent material of defluoridation devices runs out and needs to be changed. Specific equipment and trained personnel are necessary to perform laboratory analyses necessary to identify the fluoride concentration at which these devices start their removal action (Mbabaye et al., 2017). Huber et al. (2012, 2013, 2014) also found that the adoption of new defluoridation devices reducing fluoride in drinking water imply the uptake of new behaviour. Their studies emphasize the importance of acquiring a good knowledge of social and psychological factors behind the use of defluoridation devices. This knowledge allows policy makers to plan behavioural change interventions that can encourage the population to adopt innovative technologies and consume drinking water containing acceptable levels of fluoride.

In order to fill such a gap, this study aims at exploring what contextual and behavioural factors can influence the adoption of a new filter system helping Kenyan and Tanzanian rural communities to switch from untreated drinking water to safe defluoridated water. To discover how this device could be accepted and introduced, the following research questions were explored: What are the water consumption habits and needs of people living in rural communities of the EARV? What are the difficulties that they face to satisfy their water needs? How do people perceive water quality and its relationship with their health?

What are the behavioural factors that can influence the adoption of new device and healthy drinking behaviour? What strategies or policies could be used to nudge rural communities towards healthy drinking behavioural changes?

The remainder of this paper is organised as follows. Section two will explain the methodological approach employed in this study to explore the acceptance of the new device. Section three will discuss results of focus groups conducted with rural communities of Kenya and Tanzania. Section four will discuss key findings of contextual and behavioural factors providing insights about policies that government and donors could implement to help these rural communities to adopt healthy drinking behaviour. Section five will conclude the study.

2. Methods

The objective of this study was to explore via focus group discussion how contextual factors influence unhealthy drinking habits of these rural communities and how insights from behavioural factors affecting the acceptance of the new filter system described below can help rural communities of the EARV to switch towards the consumption of fluoride-safe water.

2.1. Characteristics of the new defluoridator

An innovative filter system, consisting of a new defluoridator device used in conjunction with the sorbent octacalcium phosphate as a means of fluoride removal, was developed in the framework of the EU Horizon2020 "FLOWERED" project by Idini et al. (2019) .[1] This filter system, called Flowered Defluoridator Device, was conceived with the scope of replicating the natural mechanism of fluoride absorption occurring in the human body and of being highly efficient in rural contexts.

Fig. 1 shows that this prototype works with a pump that can be powered by a car battery or a small solar panel system and in case of electricity black-out can also work manually. The application of the new device shows that a single sorbent dose of 80g can purify 20 L of waters reducing the fluoride contamination below the acceptable drinkable threshold even if the initial concentration of fluoride reaches 21 mg/L. It can also decrease its contamination by about 50% for extreme rich-fluoride water, without negative effects on the overall water quality (Idini et al., 2019, 2020). The filter uses a fixed amount of sorbent for every defluoridation cycle and at the end of the process, a simple filter system removes the sorbent from the water. This process was also tested in situ and results showed that this new device can defluoride water with 22 mg/L of fluoride concentration well below the WHO suggested limit of 1.5 mg/L in 2 h (Idini et al., 2020). The functioning of this prototype was illustrated to focus group participants showing them Fig. 1.

2.2. The RANAS model and the focus group research protocol

The adoption of this new defluoridator and the consumption of fluoride-safe water can be influenced by many factors such as drinking habits, risks connected with perceived vulnerability to illnesses, severity and factual knowledge of dental and skeletal fluorosis diseases, commitments to healthy drinking behaviour, perceived personal capacity to use the devices in terms of daily routine (Huber & Mosler, 2013; Mulopo et al. (2020). As the RANAS (Risks, Attitudes, Norms, Abilities and Self-regulations) model fits the exploration of these factors well, we developed a focus group research protocol where open-ended questions were framed around the elements of this conceptual framework. The RANAS model was developed by Mosler (2012) and has been applied in several studies evaluating people's behaviour in developing in relation to the consumption of fluoride-safe water (Huber et al., 2012; Huber and Mosler, 2013; Huber et al., 2014; Entele and Lee, 2020) and arsenic safe water (Inauen et al., 2013,2014), handwashing (Contzen et al., 2015; Lilje & Mosler,2018), cleaning of water storage containers (Stocker and Mosler, 2015) and access to and use of hygienic shared sanitation facilities (Tumwebaze and Mosler, 2014, 2015; Harter et al., 2018; Nunbogu et al., 2019).

The RANAS model can be used in several steps of water sanitation and hygiene intervention programmes where researchers first use qualitative methods to identify possible behavioural factors and then quantitative tools to measure these factors in order to identify behavioural techniques and strategies to nudge people towards behavioural changes (Contzen and Mosler, 2015). Insights about perceptions and preferences concerning drinking water quality have also been captured in several qualitative studies (Jones et al., 2005, 2007; Ward et al., 2009), but in this study key aspects of open-ended questions were developed to collect information about the elements of the RANAS model as illustrated in Fig. 2.

The focus group research protocol was divided into three sections. The first sections had the scope of warming up the discussion introducing the project, the research theme and to collect information about gender, age, education and family size of participants. Participants also received explanations of the role undertaken by the facilitator and that audio recordings would have only been used for the purpose of this study without disclosing their identity. They were told to express their opinions freely because their opinions matter and that there were no right or wrong answers.

Sections two and three contained open ended questions related to the RANAS model that the moderator asked to participants of selected Kenyan and Tanzanian rural communities of the EARV. Section two aimed at eliciting information related to contextual factors characterised by social, physical and personal contexts influencing water needs, management and drinking habits. The moderator triggered the discussion around questions exploring sources and availability of water in their villages, management and consumption of these resources, and the price that they pay for safe and unsafe water.

Section three opened informing interviewees that according to the WHO, more than 200 million of individuals in the world were affected by elevated levels of fluoride in drinking water and that in their living area this impacts negatively on their health. To trigger the discussion around the behavioural elements of the RANAS model, this information was coupled with pictures of people affected by dental and skeletal fluorosis. This allowed the moderator to explore participants' knowledge of these diseases, beliefs and perceived risk of their families when drinking unsafe water. After having explored knowledge and risk, the moderator explained how this new filter system works showing them Fig. 1 and highlighting that this device would be available to them both for domestic and community use (villages and schools). They were also informed that the domestic filter can produce 20 L of fluoride-safe-water each cycle, while the community filter produces 1000 L of fluoride-safe water each time. The moderator concluded this short presentation stressing that the action of using the defluoridator must be part of the participants daily routine. This explanation allowed the moderator to explore their attitudes towards unsafe and safe water obtained with the new device, the approval of their communities for domestic and community filters, their confidence in using the device and commitment towards the production of fluoride-safe water.

2.3. Sampling and data analysis

Fig. 3 shows the geographical area in which nine focus groups were conducted in October 2018. Of the nine focus groups, five were conducted interviewing Maasai (two in Kenya and three in Tanzania) and four Meru (two in both countries). Participants of these two ethnic groups were located around Nakuru in Kenya and Mount Meru in Tanzania, zones highly affected by fluorosis. In fact, these villages were affected by a concentration of fluoride in surface and groundwater ranging between 2 and 18 mg/L, and thus well above the recommended

[1] For more information about the Flowered project see http://www.floweredproject.org.

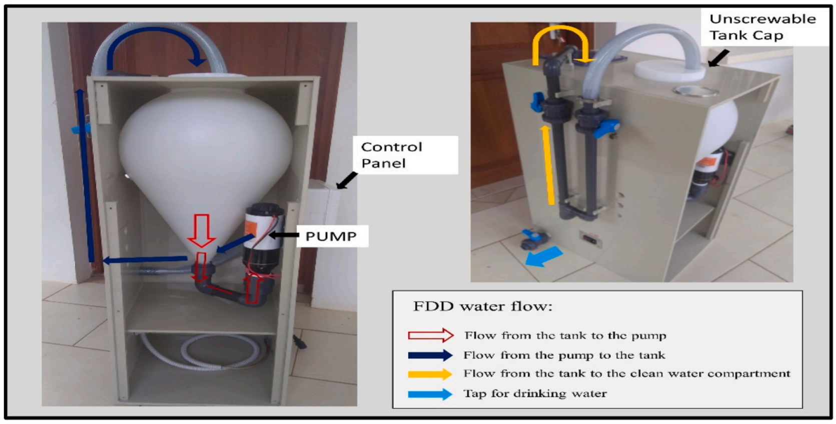

Fig. 1. Illustration of the defluoridator prototype.

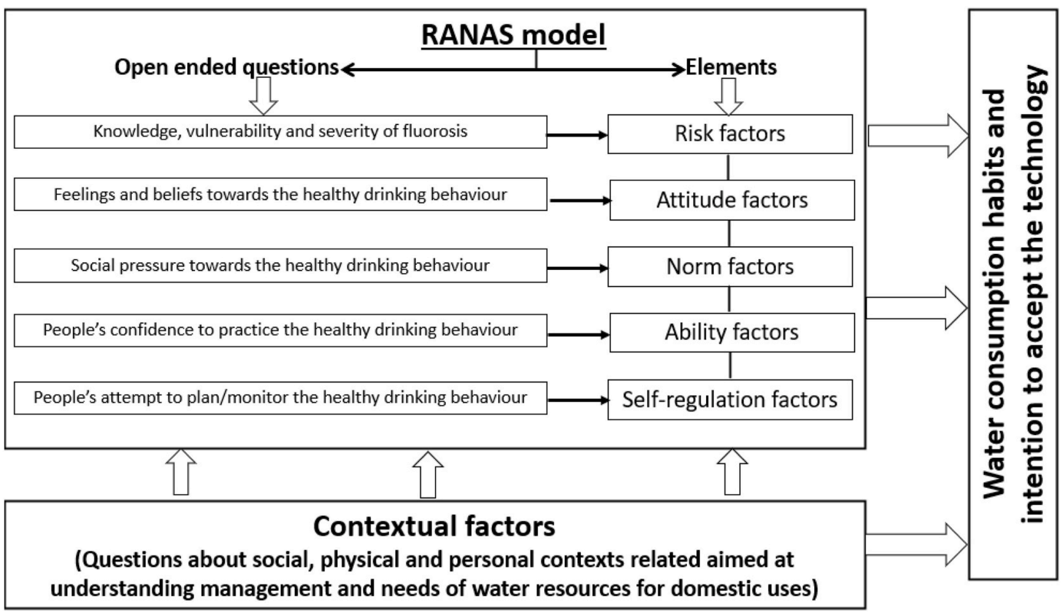

Fig. 2. Implementation of the RANAS model in the focus group research protocol.

limit of 1.5 mg/L suggested by Ward et al. (2009).

Moreover, four focus groups were conducted in three Kenyan villages (Gilgil, Kipkenyo, Kambi ya moto) and five focus groups in four Tanzanian villages (Uwiro, Oldonyo Sambu, Mkuru, Ngare Nanyuki). In each country, two focus groups were conducted in the same village and participants were recruited with the help of researchers involved with H2020 Flowered project and working for the University of Eldoret in Kenya, and Nelson Mandela University and the NGO OYKOS in Tanzania. The recruitment started in July 2018 contacting the heads of these seven villages who in turn selected focus group participants. To be eligible interviewees were required not to have had any experience with focus group discussions, to be involved with decisions regarding drinking water for their families and to give their consent to participation and audio recording.

The interviews were conducted in Swahili and Maa (Maasai) dialect by one of the authors and by researchers from the institutions mentioned above who took notes on the discussions and group interactions. The audio-recorded tapes were then translated into English and checked for accuracy by the research team. To analyse this data, we followed strategies provided by the literature on qualitative data i.e. reducing data into a manageable size in order to allow fundamental identification of themes and following the theoretical aspects of the proposed conceptual framework (Bazeley, 2013; Jackson and Bazeley, 2019). Thus, the interviewee's responses were coded into themes related to the RANAS model and entered in NVIVO 12. The most interesting aspects of these discussions will be reported in italics in the results chapter. Furthermore, because of the relatively high total number of participants, where possible some answers where coded and imported into IBMSPPS to explore mean differences and correlations between Maasai and Meru performing independent sample t-tests and χ^2 square tests.

3. Results

Seventy-five Maasai and Meru were interviewed in total and their socio-demographic characteristics by focus group can be observed in Table 1. The total number of participants was more or less equally distributed by gender (52% male) and by country (53% Tanzania), while for ethnicity more Maasai (59%) were interviewed because the village leader of focus group three recruited more participants than other leaders. Furthermore, many participants were aged between 31 and 50 (59%), educated at primary and secondary school (46%) and had a family size of between two and five people (41%).

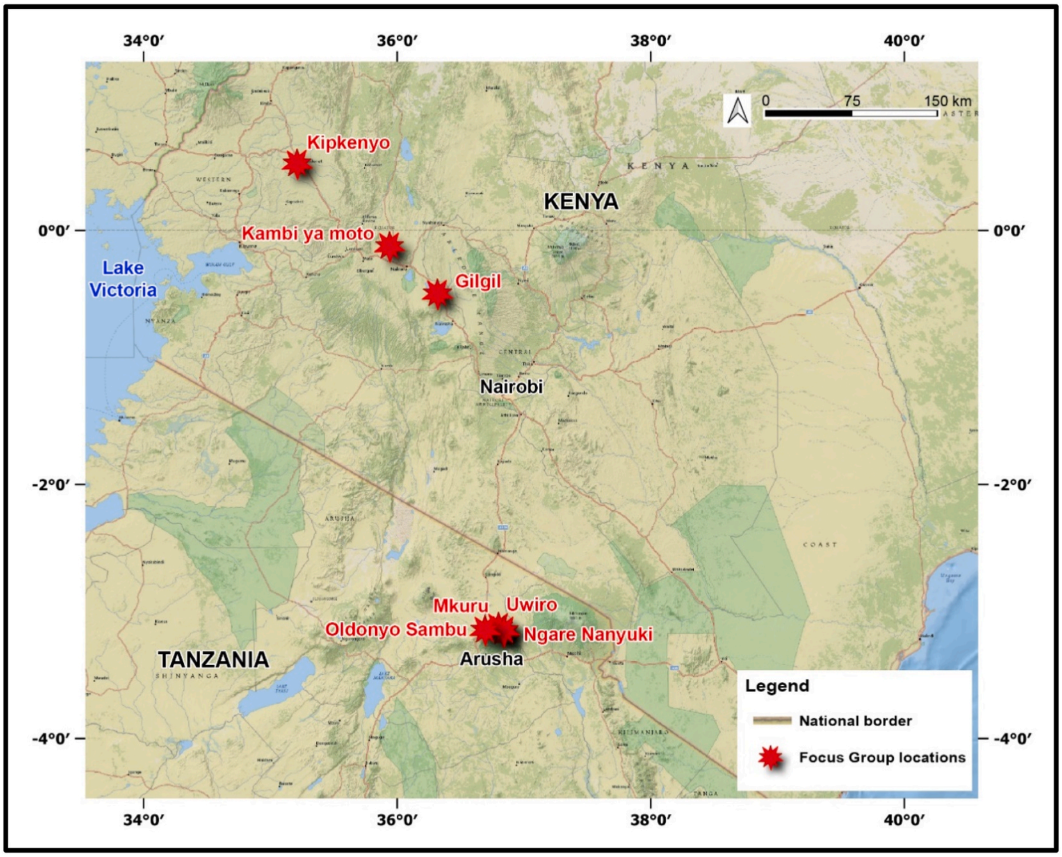

Fig. 3. Map of the area indicating the villages in which focus groups were conducted.

Table 1
Socio-demographic characteristics of participants by focus group.

Socio-demographic characteristics		Focus group number									
		FG1 ($N=$ 8)	FG2 ($N=$ 8)	FG3 ($N=$ 12)	FG4 ($N=$ 7)	FG5 ($N=$ 8)<	FG6 ($N=$ 8)	FG7 ($N=$ 8)	FG8 ($N=$ 8)	FG9 ($N=$ 8)	Total ($N=$ 75)
Gender	*Male*	4	3	6	5	4	5	4	3	5	39
	Female	4	5	6	2	4	3	4	5	3	36
Age	*Younger than 30*	2	0	2	0	6	2	0	3	3	18
	From 31 to 50	5	6	7	3	2	6	5	5	5	44
	Older than 50	1	2	3	4	0	0	3	0	0	13
Education	*Primary*	1	1	3	3	5	4	1	0	4	22
	Middle	3	4	5	1	1	4	7	6	4	35
	Secondary/ higher	4	3	4	3	2	0	0	2	0	18
Family size	*From 2 to 5*	5	5	5	1	3	3	2	5	2	31
	From 6 to 8	2	2	3	4	4	2	2	3	3	25
	From 9 to 14	1	1	4	2	1	3	4	0	3	19
Ethnicity	*Maasai*	8	0	12	0	8	8	0	0	8	44
	Meru	0	8	0	7	0	0	8	8	0	31
Country	*Kenya*	8	8	12	7	0	0	0	0	0	35
	Tanzania	0	0	0	0	8	8	8	8	8	40

3.1. Understanding management and needs of water resources for domestic uses

As regards water collection and administration, 86% of participants stated that generally females are responsible for these activities, while men in some cases help women with fetching water. The total daily average of water collected and used by participants was 100.36 ($s=43.16$) and 81.89 ($s=38.72$) Litres in Kenya and Tanzania respectively and this difference was not significant to the independent sample *t*-test ($t=1.81$; $d.f.=63$; $p=0.07$). We also explored these differences between Maasai and Meru in both countries. In Kenya, for Maasai the daily average stated water consumption was higher than that indicated by Meru, but these differences were not significant to the independent sample *t*-test.[2]

[2] In Kenya, Maasai's and Meru's daily average water consumption were 106 ($s=31.12$) and 93.85 (s-54.55) Litres respectively ($t=0.74$; $d.f.=26$; $p=0.47$), while in Tanzania they were 72.61 ($s=24.90$) and 97.14 ($s=51.95$) Litres respectively ($t=1.94$; $d.f.=35$; $p=0.06$).

This was also the case for drinking and cooking water where a daily average of 20 L was observed. However, half the participants seemed to be concerned about water availability because it is not enough to satisfy their families' needs and to serve an increasing population especially in relation to the quantity of safe drinking and cooking water. Maasai participants emphasized the use of water for pastoral purposes because they need to wash cows with medicine that kills insects and therefore, sometimes they must use the water they fetch or buy to spray their animals. Quantity is also reduced both by animals that destroy water supply when they pass through the water channelling and by dirt which impedes people from collecting water. Some participants appeared to be so concerned about water scarcity that they were planning to migrate especially during the drought season.

I don't get my 200 L and it is problematic water because you can go for a whole day and pick up six buckets from the morning when you get up till ten o'clock.

Our water source satisfies us but sometimes with difficulty because animals destroy the source when they pass through the water channelling and thus, they can delay two days the supply of water.

The population has increased so water is not enough especially during droughts.

Distances and time in water collection appeared to be very important factors for water management. According to United Nations Human Settlements Programme Staff (2003), a distance of 200 m is considered appropriate to fetch water every day for family needs. However, only 41.3% of participants fetched water within the recommended WHO distance with Maasai walking longer distances than Meru. On the average, in order to fetch water Masai walk 2,233 m while Meru 784 m and this difference was significant to the independent sample *t*-test ($t = 2.48$; $d.f. = 73$; $p = 0.01$). Thus, many housewives must spend a disproportionate part of the day in fetching water for the family's needs as confirmed in other studies (Bartram and Howard, 2003; Graham et al., 2016). Furthermore, water collection appears to be very demanding especially for some Maasai participants.

It is within my neighbourhood and it is able to meet my needs, but it serves people as far as 4 km.

It is roughly 10 km. My wife could go using donkeys. She takes the donkeys near the stream where the water is sold. After she buys the three or four gallons, she puts them on donkeys and then takes them home.

Furthermore, to cope with scarcity and the demanding time needed to fetch water, during focus group interviews Maasai and Meru participants mentioned the use of different sources of water 260 and 255 times, respectively. Fig. 4 shows that in Kenya boreholes were the most mentioned sources of water used by Maasai (50%) and Meru (60%). In Tanzania, rain was stated 66.7% by Maasai and wells 63% by Meru, but in Kenya the latter never reported wells. Furthermore, water from rivers and lakes was never mentioned among participants of Tanzanian rural communities, while water gathered from rivers and lakes appeared to be more important for Kenyan participants especially Maasai (30%). Even though Kenyan and Tanzanian participants stated that they had to access and manage different sources of water, they underlined again that this was a scarce resource that often is not enough to satisfy the needs of their households' members and farm animals.

They used borehole water during the dry season while harvested and stored rainwater from March to May using strategies like an iron sheet roof or plastic containers. Boreholes were used more during the dry season because solar pump panels were not efficient during the rainy season.

During rainy season we get water from the river, but in the dry season, we use the borehole water.

The current water borehole does not supply enough because it is solar pumped and in some periods there is not enough sun to pump it. The water source depends on solar hence it doesn't pump during the rainy season. A long time ago, the water was enough, but the number of people has increased plus animals, so it is not enough these days.

Sometimes, participants reduced the distance of fetching water taking advantage of gravity pipeline systems placed usually at the top of hills.

We use gravity since the hot spring water is at the top of the hill.

We fetch water from the borehole and piped water from Koinaike. Piped water is available once a week.

For about 22% of participants, the management of water resources is free because they stated that they do not pay anything for the water they fetch. However, other participants pay for untreated water either for each fetched bucket of water (20 L) or a monthly flat fee system payment. The latter payment was mentioned by two groups of Maasai participants in Tanzania where the flat fee covered the price of water and the maintenance of the boreholes. For Kenyan participants, the price of one bucket of water ranged from KESsh 2 (US$ 0.02) to KESsh 150 (US $ 1.48) with an average price of KESsh 15 (US$ 0.15). In Tanzania, for the same bucket of water, ranged from TZSsh25 to Tsh 500 with an average price of TZSsh 226 (US$ 0.098). The observed difference between the average prices of a bucket of water in Kenya and Tanzania was relevant and significant to the independent sample *t*-test ($t = 2.23$; $p = 0.03$).

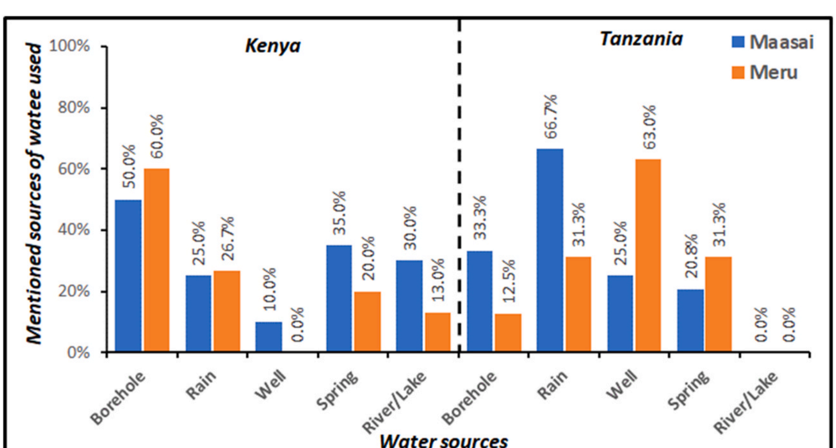

Fig. 4. Different sources of water used by Maasai and Meru in Kenya and Tanzania.

3.2. Perceived risks of drinking water and knowledge and beliefs of fluorosis

Concern over the quality of water was amplified by perceived participants' risk for safe drinking and cooking water. In both countries, only about 30% of Maasai and Meru participants perceived the water that they consume was safe. In some cases, their perception was backed up by the opinion of experts, non-governmental agencies and water companies supplying water. For other participants, the perceived quality of water was just backed up by their beliefs. For example, they believed that water is safe because they use it without any treatment or because they see that it does not alter the colour of the food they consume.

We believe that the water is good because it is from underground and experts said it is good.

The water I buy is clean water because it comes from a water supply company that get water from Welewa.

I just believe that water is safe because we have been using it without treating it.

However, the majority of Maasai and Meru participants perceived that water was of bad quality and unsafe because they were exposed to health risks caused by dirtiness and high levels of fluoride. Water is polluted and contaminated by worms and bacteria and sometimes they must share water with wild animals.

The tap water is dirty. This will be a problem especially due to how we live our lives.

At times, the water I use is evidently not clean. It might be as a result of varying rates of contaminations and pollutions as it flows downstream.

The water for the people and the cattle should be purified from the source of the river.

They expressed concern over high levels of fluoride in drinking water for themselves, future generations, but also for livestock and agriculture because fluoride is transferred to food and will affect their health. Many Maasai and Meru were also worried about their children when they go to school and thus advise them to take a bottle of safe water from home. Some participants stated that drinking water has a bad taste and is too salty and they defined this type of water that they drink as 'isokot'.

The water has a lot of salts such that when left to settle in containers, it leaves crystal behind.

Consumed water also has magadi. Maasai do not understand fluoride. It is only these days we know from experts but as Maasais we say "isokot' meaning water with bad taste. Water with 'magadi' tastes bad and then we understand that water is not good.

The future generation is at risk of so many health-related problems if they will continue to use this water without treating it. Most of them will have no teeth with crippled legs.

Discussion triggered by pictures of dental and skeletal fluorosis showed that these two diseases were well-known across participants and that, other than three participants, they were aware that the cause was water or food contaminated by fluoride.

The problem of teeth comes from water and our ancestors told us that the water has a problem making the teeth to look like this.

Because where I was born, in Makuyuni, there are no such disorders, when I came and saw the children here, I knew it was the water.

It is also in the foods we eat because the fluoride water is also used to irrigate vegetables so even in foods fluoride is located.

I do not know, I am not sure if it is the water we consume. Initially, we thought the problem in children was as a result of consuming sweets and sugar foodstuffs, but later we realized it was not the cause. Our kids do not eat sweets and yet they are affected.

Prevalence of dental fluorosis appeared to be higher than skeletal fluorosis with nearly 67% of participants' households affected by dental fluorosis and only about 17% by skeletal fluorosis. In each country no significant differences were observed between Maasai and Meru participants,[3] but country comparison shows that dental fluorosis was more prevalent across Kenyan households and this difference was significant to the χ^2 test ($\chi^2 = 7.74$; $d.f. = 1$; $p = 0.005$) as shown in Fig. 5. This result was likely to be influenced by participants of the Mukuru village (focus group 5) who stated that their village was not affected neither by dental nor by skeletal fluorosis even if they were aware of the consequences of these diseases in other villages included in this study.

I have not seen such problems here in our village, but in other areas like Oldonyo, Sambu and Ngabobo regions.

The link between the cause and consequences of dental fluorosis emerged clearly during focus group discussions. This pattern is evident from the word cloud in Fig. 6 which depicts the most frequently occurring words emerging from focus group discussions. Water use were the most recurrent words and they were linked to the management of this resource and to problems caused by fluoride water to their health. Fig. 6 seems to indicate that participants retrieved information following a network of semantic nodes (Vogel and Wanke, 2016) where central words (more frequent with larger font) could represent nodes activated by pictures from their memory, while more distant words were activated later (less frequent word with smaller fonts). Thus, the most recurrent words (water, problem, fluorosis, teeth etc.) activated concern because it was brown coloured, tooth decay and loss of teeth that affect their children, families, and neighbours. Participants highlighted that this problem starts in their childhood and inflicts pain and psychological discomfort because sometime people take joke about them and as a result they feel ugly.

I took two children to Nairobi to stay far and use better water. I feel bad because these people were not born like these conditions. I am one of those affected and my children are affected.

My teeth were brown like these one and I do not like them at all. It started from my childhood. We have cases in my family, but they are at the early stages of dental fluorosis.

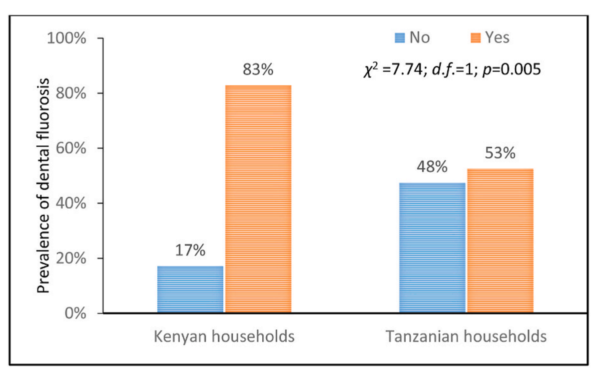

Fig. 5. Households' prevalence of dental fluorosis by country.

[3] In Kenya, 75% of Maasai and 93.3% of Meru stated that they had dental fluorosis in their families ($\chi^2 = 2.03$; $d.f. = 1$; $p = 0.15$) while in Tanzania only 58.3% of Maasai and 43.8% of Meru declared to have this health problem ($\chi^2 = 0.82$; $d.f. = 1$; $p = 0.37$).

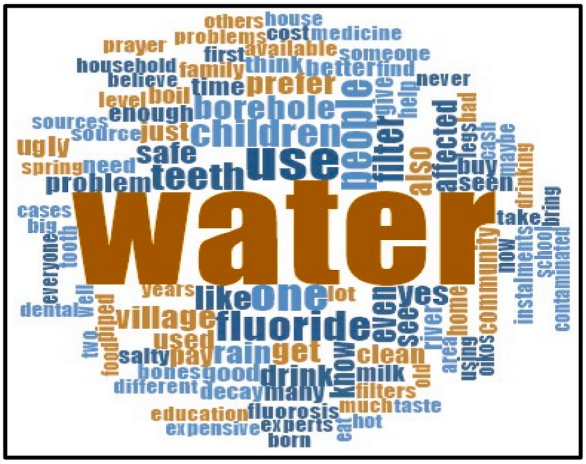

Fig. 6. Word cloud of dental fluorosis discussion.

I am the one affected and future generations are at risk of so many health problems if they will continue to use this water without treating it.

Yes, children are at the initial stages of fluorosis while adults have reached the advanced levels, and some have already lost their teeth.

Initially their teeth were white, but the more they use they use this water the more their teeth turn brown and then started to break. Besides, I am also a victim, 10 of my teeth have started to crack.

In these two photos, I see myself. I am sure the water is toxic. My teeth are bad, and people even joke that I smoke cigarettes and I cannot refuse them. How can I refuse that my teeth are coloured?

Even if skeletal fluorosis was less prevalent than dental fluorosis, the description of its negative health effects was severely described by many Maasai and Meru participants. Women were hit more than men and they were sad and concerned about ageing because this process will affect them earlier and more suddenly than in a situation where human beings have enough economic resources to access clean and safe water. Children were described as having big heads and the occurrence of bowlegs in adults dramatically affect their well-being inflicting physical and psychological suffering. Their knees are weak, bodies cannot stand straight, and they find it difficult to stand up straight way but only after having walked for a while. Walking is painful, working is hard, and people feel a sense of tiredness and show signs of resignation to fight against fluorosis because of poverty. Poverty does not offer them many water alternatives and they are forced to choose just between lethal and survival health choices i.e. dying from typhoid or getting fluorosis.

It is not just bowlegs. The body cannot stand straight. You cannot also turn the neck.

Very harmful to the bones, the body is tired. People cannot run and if a person falls slightly, they get broken very easily. Experts say that it also reduces the ability of the brain, the brain system lowers down, and this is because people use fluoride water without filter.

We have bowed like them. The other day I was passing through the south part of the village I was really sad. A lady is old but because of the water, the knees are weak, and the back bowed. I see people hide and I would cry, because when I see that my conscious is disturbed. Children are suffering, they have big heads. The schools are far, so they fail because of the way they are affected. Until now the problem has no solution.

I fear a lot this is disability brought by water and when we reach 50 years old we cannot walk completely. You can see a woman today and tomorrow she is old. Long time ago old people had too much energy, but nowadays at 40 years men cannot do any labour jobs. Many women after a few births cannot even leave the house. The legs are bowed and then the man is also disabled. We cannot even have more children.

Women are affected more. If we are invited to a meeting and asked to sit down, that is the day you will laugh at people in this area. When a woman wants to stand up, she will kneel down and start to stand up like an aeroplane taking off in the runway. She will stand straight in about 50 m from here.

Poverty is the only reason why we constantly consume this water. Before using boreholes, river Rongai used to be the main source of drinking water. However, the major problem with river was typhoid because it killed so many people. As a result, it is better to drink fluoride water than dying from typhoid.

A sense of powerlessness in fighting these diseases was also evident by the fact that the majority of participants think that there are no methods to prevent fluorosis other than using painkillers or procedures based on beliefs that circulate within their rural communities. These procedures are used especially for keeping their teeth white and their discussions showed how much they care for their children. For example, they brush teeth with soil or herbs, boil water with a medicine that protects them from bacteria, or drink a lot of milk also as adults, while their children only drink milk until they are two or three years old.

I used soil to brush my teeth till they become white. I do not think this solves the problem because my teeth became too light and weak, and continuing with soil brushing they could have cracked.

I use herbs known us "Sununi" or "Loisuki" to brush my teeth, but we do not know if they prevent tooth decay.

Mostly I drink soups or fats from the cow and so I mix it with herbs but I cannot mix it with water only because it might have side effects.

We only give children water once or twice a day with boiled medicine called Endemelua (specific for children). It also protects from fluoride in water including bacteria. You just boil together with the water.

We use exclusive milk for children until they are 2, 3 years old. We give children very little water. We use milk here and Maasai say that if they drink milk, they will have white teeth. They only drink a lot of milk and porridge.

We don't start to feed/eat our children earlier. Children only eat goat oil and mothers' milk until they are one year. After that they start with animal's milk.

Maasai use milk even when they are adults. Some Maasai in Lemanda are badly affected by fluoride because nowadays they have less cattle or their animals do not give birth regularly affecting their milk production.

We do not have traditional cure. We only buy painkillers from shops to relieve the pain. The ultimate remedy whenever we have tooth ache because of decay is removing it.

3.3. Attitudes towards the use of filtered water and perceived costs of defluoridators

Attitudes towards defluoridated water was challenging to investigate in terms of perceived benefits as only about 30% of respondents had consumed or consume it. These participants showed positive attitudes towards defluoridated water because they could experience benefits in terms of taste and impact on their health. They stated that defluoridated water tastes sweet, and that they felt different because in the morning their bones were lighter than when they drank unfiltered water.

Yes, we pick water from our borehole and take it to catholic Dioceses of Nakuru for treatment. The treated water is very sweet and cool.

When we were supplied with the buckets I used them for about five months, when I used defluoridated water it felt different when I woke up in *the morning I felt my bones lighter, and you do not fill thirsty a lot of times.*

I used filtered water and it was different.

Despite these positive evaluations, participants' attitudes towards filtered water was also influenced by perceived costs of the defluoridator shown to them. Some participants stated that they were willing to make a financial sacrifice to get clean and safe water and perceived the defluoridator as a means to save money getting rid of the high price that they must pay for treated water.

Water is life, and we can also sacrifice to ensure that we have it clean and safe.

Yes, because the purification containers from Catholic are very expensive. They are being sold at Ksh 12,000.

However, other participants, while accepting its usefulness, questioned the affordability of the proposed defluoridator. Poverty appeared to affect the opportunity cost incurred by the adoption of the new device dramatically. Maasai and Meru participants perceived the proposed filtered device to be expensive also when the facilitator explained that the cost of this defluoridator (220 US$) and its cost of maintenance (OCP about 0.02 US$ per litre of treated water) could be obtained with a discount of about 35% of in case of mass production. Many participants declared that they would not be able to afford to pay for it in cash but that they would be able to pay in instalments.

I will be one to use filters, but the biggest problem is its cost. Just consider the cost and make it affordable to us. This is a lot of money and I can't afford in to raise once and pay cash.

My first request is to make [the defluoridator] cheaper and affordable by the majority. Then, I will prefer the instalment mode of payment.

Furthermore, interviewees disentangled the cost of the device from that of its maintenance basing their judgements on previous experience. Some of them were concerned that buying the device without having the financial resources to replace filters would not help them to get rid of fluorosis. Thus, health benefits were traded off especially against hidden costs of the defluoridator determined by the cost that they should sustain to maintain the device efficiently in the long run. This issue was also amplified by the lack of trust towards companies that had tried to introduce other defluoridators in their rural communities without disclosing the high hidden costs of these devices. Lack of transparency towards these companies clearly seemed to undermine attitudes towards the acceptance of the new device. Some participants called for help on behalf of donors who should recognise this bundling problem and subsidise maintenance costs.

Using it will not be a burden, maybe the cost of maintaining it.

There was a company that tried to intervene by constructing a tank and a treating plant at the borehole, but the investor hiked the price of the treated water without consulting the community. As a result, the community resolved to use the borehole water in its untreated form.

Now, it also has a challenge after buying, they wanted that every six months to pay you TSh 30,000 fees for them to come to you and to change the bones and the filter. So, if you miss it so much and you keep using that water, you do not know whether the water is safe or not.

The cost of buying is very expensive and yet every month they will need money to change it. Thus, you can find someone who fails to afford it and decide to use water with fluoride.

We only used the filter for 3 months and then they stopped filtering. This company needs us to pay Tsh 10,000 which we cannot afford.

The only hindrance might be the cost of buying these filters. It is my wish that you find a means of subsidising it through donor support so that it is affordable. The biggest problem is the poverty levels of most of the residents of this area.

3.4. Norms, ability and self-regulation towards the adoption of the new device

The acceptance of the proposed defluoridator was influenced very much by the social pressure of Maasai and Meru rural communities. Most participants stated that people who are important to them would have approved the adoption of this device because it can help to solve health problems caused by unfiltered water. However, the strong influence of norms was clearer when participants were asked to choose between domestic and community defluoridators. Only ten participants exclusively preferred the domestic filter because it allowed them to bypass the long decisional process required by the installation of the community defluoridator, to have control over household water demand personally with more responsibility and to manage lack of electricity more efficiently than community filters.

It is easier to use and to manage water demand in comparison to community filters and each person takes personal responsibility to take care of his/her own filter.

It is better because community filters will take a long time for us to agree on many issues. Community filters will need free land to construct the filtering point and you see that will be a long process.

The household filter is good for now even with the manual operation while solar or electricity is being designed. We need a filter and the one ready we will use. We do not have access to electricity in our region. For this reason, the hand manual household filter is the best of us.

Another 13 participants also opted for the domestic device but in this case their choice could only be accepted if the private filter would have been available to all or alternatively if a community filter would have also been available to the most vulnerable members of their communities. For these participants, the choice of the domestic defluoridator appears to be conditional to the improvement of the health status of the whole rural community. This behaviour shows altruism and a strong sense of identity and protection towards the most vulnerable people in their communities i.e. the poor and children away from home for many hours of the day when at school.

I would prefer the household level filter, only if everybody can have one.

We need the household one, but we must be consulted as a community first.

I like if we get the small filter in every household because it is not very expensive, but with the big filter we can put it in every village, and this will be applicable to all people.

I would like all the people to get in the system, because I see there is a problem in the society and I cannot be happy about it, you just pray that the fluoride problem leaves us.

I like both. The household level filter for my use and the community filter because some families cannot afford and some will not be able to manage the filter. The community filter can be centrally managed, and this is much better.

I would prefer the smaller one for my household use but propose the larger one for our schools where our children spend most of the time.

This sense of identity was even more evident for about 70% of Maasai and Meru who opted for the community filter. Preferences for the new device appeared to be dominated by a sense of belonging and a latent feeling of perceived disapproval towards the choice of the private filter. To comply with social norms participants were willing to sacrifice their private health benefits for both altruism and solidarity towards the most vulnerable people and a better collective health status of their rural communities. If the community could adopt this new filter system, they themselves and many neighbours would feel happy to use fluoride filter water.

I prefer the filter for the whole village as opposed to the individual one. Everyone will benefit from clean water. Some people cannot afford the private filter, their maintenance may be difficult and so its use.

I would like all the people to get in the system, because I see there is a problem in the society and I cannot be happy about it, you just pray that the fluoride problem leaves us.

I like the village filter so all of us can use it. It is not being fair to have mine alone.

The community filter can be better because of poverty.

For some participants, preferences for the community defluoridator were also influenced by its superiority to satisfy high demand of clean and safe water.

In terms of ability, while some participants appeared to be sure regarding the implementation of the new defluoridator, the majority of them were concerned about how to use it without having received adequate training because this is a very different way of managing water resources. They expressed lack of ability in handling the defluoridator and adding powder, but also lack of confidence to continue healthy drinking behaviour. Some participants stated that even if many things are delivered to them, they fail to take advantage because without education they do not have confidence to perform the behaviour correctly. The government and experts should invest in training programmes and education before introducing device because they represent authority, are trusted and the benefits of the new device will be accepted.

I don't have problem to filter water and none will oppose its usage in my home. I am going to talk to others to adopt it because if experts have confirmed that it is good for us we will appreciate it.

We do not know how to filter water. We only put it in containers for storage.

The only thing is that we can educate people on proper utilization of water and how they can use that machine, because the things that are brought to us should be approved by the government through the chief. The chief should educate people because he is the chief and if he says this has a benefit we will accept because he is the leader.

I can say that we need education before these filters arrive. We receive many things and no education, and they always fail after a short time. I am requesting for sustainable education that can last so that we can have long term help. It would be bad if we receive the filters and we end up not achieving anything.

You experts should give us education how to use the filters in a safe way. You can help us with seminars so that we can help each other to avoid more this fluoride problem. This will allow us to us the filter and the water in a safer manner.

I encourage you to continue training us on the importance of filters so that we can embrace and accept this device. Continuous training will solve the many negative cultural believes and myths about deflouridation filters.

Finally, with regard to self-regulation all participants expressed commitment towards the use of the filter and the time necessary to produce filtered water for their families will not affect their planned daily activities.

It doesn't waste time for me to filter water. I am very sure that I will use the filters because it can help me.

I see I will use it, I will not care for two hours to save my life even years and years.

Every morning I will first filter water and I will make sure my family has enough safe drinking water.

I will be committed, and I do not see any constraints also from my family because it is a solution to our problem.

We shall use it continuously. I have liked the prototype equipment and I will use it because it has a solution to our water problems.

4. Discussion

4.1. Influence of contextual factors

The healthy drinking behaviour of people is dramatically affected by contextual factors and exacerbated by scarcity of water and high level of fluoride naturally contained in drinking and cooking water. Scarcity of water was also aggravated by its intermittence and high level of contamination. To meet their needs of drinking, cooking, washing and watering animals, participants must use multiple sources of surface water and groundwater during the dry season, and harvest rainwater through iron sheet roof or plastic containers in the rainy season. Some Maasai had to travel several kilometres to fulfil their needs, expressing concerns over the location of water sources, which was well above the of 200 m distance considered appropriate to ensure households' daily water needs (Bartram and Howard, 2003; Howard et al., 2020). Thus, despite the effort and the different strategies that Maasai and Meru put in place to cope with quantity and quality water supply issues, pedo-climatic conditions, high content of fluoride, poverty, and lack of infrastructure seriously challenge and threaten the life of people in the EARV. Considering that several studies show a large scale of variability in space of fluoride in ground water (Ijumulana et al., 2020, 2021, 2022) more attention should be paid to monitoring practices of this resource in terms of quantity and quality (Ligate et al., 2021). To limit the impact of these contextual factors and to ensure the future sustainability of groundwater resources in EARV, regional groundwater databases containing all-important water quality parameters could be established and updated with the collaboration of private and public sector (Ligate et al., 2021).

Our findings also corroborate the enormous time and effort that women in these rural communities spend to manage water resources and to prevent water and sanitation related diseases (AFB, 2015). The dynamic of these rural communities appears to be complex and strongly influenced by Hofstede's cultural dimensions such as masculinity, collectivism and long-term orientation (Hofstede, 1987; Van Der Voorn, 2008). Thus, it is important that these socio-cultural dimensions are recognized by donors, marketers and policy makers (Minasyan, 2016) because lack of such knowledge may lead to cross-cultural miscommunication and deficiencies in the participatory process required to nudge people toward the acceptance and implementation of these new defluoridator (Van Der Voorn, 2008). Cultural dimensions and hidden values such as the role of women in EARV communities and cooperation across of families (Van Der Voorn, 2008) could be integrated in the RANAS model to further understand people's behaviour and nudge them towards the adoption of the healthy drinking behaviour.

4.2. Behavioural insights for policy makers and other stakeholders

The results of the RANAS model offer insights to think about how policy makers and marketers could reverse unhealthy drinking behaviour introducing technological devices that can cut the quantity of fluoride that is naturally contained in water. Nevertheless, the majority of Maasai and Meru were aware of the link between fluorosis diseases and drinking water, yet many believe that the water is safe. Thus, to enhance risk knowledge in these rural communities, policy makers could disseminate information about wrong beliefs and the relationship between unhealthy drinking behaviour and fluorosis diseases. Local authorities could visit these rural communities and stress that it is not possible to cure dental fluorosis using herbs or drinking milk but showing how everyday unhealthy drinking behaviour will lead to these diseases.

Policy makers could also think about changing the unhealthy drinking habits of Maasai and Meru using behavioural techniques based on visual cues that have been adopted successfully in other contexts like coloured bins helping people to recycle rather than just throwing everything in the same container (Keramitsoglou and Tsagarakis, 2018; Sörme at al., 2019) or traffic light labels placed on food packaging to allow consumers to make more informed healthy choices (Sonnenberg et al., 2013; Thorndike et al., 2014). For example, the sites where Maasai and Meru collect water could be provided with signposts in different colours in relation to the severity of fluoride contained in water. Visual cues could alert Maasai and Meru about this relationship and push them to switch to more healthy drinking behaviour. These signposts can help people living in these rural communities first to become aware of their ingrained unhealthy drinking habits and then to raise them to a conscious level because exposure to this information and reflection can help them to consider the merits of defluoridated water. The mapping of visual cues in places at high levels of fluoride could be facilitated by the use of integrated geostatistical techniques, spatial statistical methods and GIS mapping tools (Ijumulana et al., 2020, 2021, 2022). The integration of these techniques as well as providing information about water quality can allow EARV rural communities and government to invest in the proposed filter systems in a more efficient way.

Furthermore, information campaigns conducted by governmental authorities and NGOs, as well as stressing the severity of the relationship between water and fluorosis diseases, could emphasize key aspects of these findings in relation to attitudes, norms and ability. For example, these messages could highlight the importance of drinking defluoritated water for adults and for children in particular because from focus group discussions concern for future generations emerged clearly. As the majority of Maasai and Meru had never tried fluoride-safe water, communication campaigns could include witnesses of the few Masaai and Meru who have had the opportunity to consume and appreciate the benefits of the healthy drinking behaviour in terms of health and taste. Participants' attitudes towards the adoption of healthy drinking behaviour were also strongly influenced by the cost of the new defluoridator. Costs were perceived as a barrier and several participants complained about bad experience with foreign companies that had tried to introduce similar technologies without disclosing hidden costs. Thus, marketers who want to introduce this new device must first of all regain confidence towards Maasai and Meru and then be clear about the costs that must be incurred to buy the device and to filter water daily. Further research could explore how the elements of the RANAS model could influence willingness to pay both for the defluoridator and for the powder necessary to filter water. Therefore, as the costs of the new device appear to influence its adoption in a strong way, further studies should not only evaluate the private benefits of defluoritated water, but also the public benefits derived from saving money for the reduced prevalence of dental and skeletal fluorosis in these areas of the EARV. Such information can help policy makers and donors to assess the net benefits of the adoption of the new technology and thus to decide what water policies could be implemented based on evidence. Considering the poverty of these rural communities, these studies could help local governments and donors to understand to what extent the adoption of the new device could be introduced with or without subsidises.

The results of the RANAS model, also show that although people appear to be committed to the use and daily production of fluoride-safe water, foreign companies who wish to enter these markets should collaborate more with local authorities and invest in promotion and training programmes of the new defluoridator. They should convey know-how helping people to enact correct drinking behaviour and help rural communities to set up infrastructure. Norms towards the adoption of the proposed highlight strong sense of belonging and solidarity towards the most vulnerable members of these rural communities and thus support for infrastructure should be oriented towards filters used by the community more than for the adoption by single households.

5. Conclusion

Access to fluoride-safe water is a fundamental human need and, therefore, a basic human right. However, in areas of the EARV the consumption of contaminated water jeopardizes both the physical and social health of all people creating a sense of powerlessness and sadness in fighting dental and skeletal fluorosis. This situation is an affront to human dignity which must be solved urgently to meet United Nations sustainable development goals three and six. To meet such goals more collaboration and investments are necessary on behalf of governments, international organisations and donors to fund large projects involving multidisciplinary research teams and private companies that can identify the best contextual solutions, behavioural changing techniques and policies that can help rural communities of the EARV to change their unhealthy drinking habits.

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Declaration of competing interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gsd.2022.100809.

References

AFB, 2015. Water Supply & Sanitation in Africa: Findings, Lessons and Good Practices to Improve Delivery. African Development Bank. Retrieved from. https://www.pseau.org/outils/ouvrages/bad_water_supply_sanitation_in_africa_findings_lessons_and_good_practices_to_improve_delivery_2015.pdf. (Accessed 27 June 2021). Accessed.

Albertus, J., Bregnhøj, H., Kongpun, M., 2000. Bone char quality and defluoridation capacity in contact precipitation. In: *3rd International Workshop On Fluorosis Prevention And Defluoridation*. of Water, pp. 61–72.

Ayoob, S., Gupta, A.K., Bhat, V.T., 2008. A conceptual overview on sustainable technologies for the defluoridation of drinking water. Crit. Rev. Environ. Sci. Technol. 38 (6), 401–470. https://doi.org/10.1080/10643380701413310.

Bartram, J., Howard, G., 2003. Drinking-water standards for the developing world. Handbook W. Wastew. Microbiol 221–240.

Bazeley, P., 2013. Qualitative Data Analysis: Practical Strategies. Sage.

Coetsiers, M., Kilonzo, F., Walraevens, K., 2008. Hydrochemistry and source of high fluoride in groundwater of the Nairobi area, Kenya/Hydrochimie et origine des fortes concentrations en fluorure dans l'eau souterraine de la région de Nairobi, au Kenya. Hydrol. Sci. J. 53 (6), 1230–1240. https://doi.org/10.1623/hysj.53.6.1230.

Contzen, N., Mosler, H.J., 2015. The RANAS approach to systematic behavior change. Methodol. Fact Sheet 1–6.

Contzen, N., Meili, I.H., Mosler, H.J., 2015. Changing handwashing behaviour in southern Ethiopia: a longitudinal study on infrastructural and commitment interventions. Soc. Sci. Med. 124, 103–114. https://doi.org/10.1016/j.socscimed.2014.11.006.

Entele, B.R., Lee, J., 2020. Estimation of household willingness to pay for fluoride-free water connection in the Rift Valley Region of Ethiopia: a model study. Groundw. Sustain. Dev. 10, 100329 https://doi.org/10.1016/j.gsd.2019.100329.

EWURA, 2020. Water and Wastewater Quality Monitoring Guidelines for Water Supply and Sanitation Authorities, second ed. Energy and Water Utilities Regulatory Authority Tanzania, Dodoma.

Ghiglieri, G., Balia, R., Oggiano, G., Pittalis, D., 2010. Prospecting for safe (low fluoride) groundwater in the eastern African Rift: the arumeru district (northern Tanzania). Hydrol. Earth Syst. Sci. 14 (6), 1081–1091. https://doi.org/10.5194/hess-14-1081-2010.

Ghiglieri, G., Pittalis, D., Cerri, G., Oggiano, G., 2012. Hydrogeology and hydrogeochemistry of an alkaline volcanic area: the NE Mt. Meru slope (East African Rift–Northern Tanzania). Hydrol. Earth Syst. Sci. 16 (2), 529–541. https://doi.org/10.5194/hess-16-529-2012.

Graham, J.P., Hirai, M., Kim, S.S., 2016. An analysis of water collection labor among women and children in 24 sub-Saharan African countries. PLoS One 11 (6), e0155981. https://doi.org/10.1371/journal.pone.0155981.

Grech, P., Latham, M.C., 1964. Fluorosis in the northern region of Tanganyika. Trans. R. Soc. Trop. Med. Hyg. 58 (6), 566–574.

Harter, M., Mosch, S., Mosler, H.J., 2018. How does Community-Led Total Sanitation (CLTS) affect latrine ownership? A quantitative case study from Mozambique. BMC Publ. Health 18 (1), 1–10. https://doi.org/10.1186/s12889-018-5287-y.

Hawkins, P., 2010. National Water Quality Management and Pollution Control Strategy. Tanzania Ministry of Water and Irrigation. Retrieved from. http://extwprlegs1.fao.org/docs/pdf/tan169533.pdf. (Accessed 28 June 2021). Accessed.

Hofstede, G., 1987. The cultural context of accounting. Account. culture 1–11.

Howard, G., Bartram, J., Williams, A., Overbo, A., Geere, J.A., World Health Organization, 2020. Domestic Water Quantity, Service Level and Health. World Health Organization.

Huber, A.C., Mosler, H.J., 2013. Determining behavioral factors for interventions to increase safe water consumption: a cross-sectional field study in rural Ethiopia. Int. J. Environ. Health Res. 23 (2), 96–107. https://doi.org/10.1080/09603123.2012.699032.

Huber, A.C., Bhend, S., Mosler, H.J., 2012. Determinants of exclusive consumption of fluoride-free water: a cross-sectional household study in rural Ethiopia. J. Pub. Health 20 (3), 269–278. https://doi.org/10.1007/s10389-011-0445-z.

Huber, A.C., Tobias, R., Mosler, H.J., 2014. Evidence-based tailoring of behavior-change campaigns: increasing fluoride-free water consumption in rural Ethiopia with persuasion. Appl. Psychol.: Health Well-Being 6 (1), 96–118. https://doi.org/10.1111/aphw.12018.

Idini, A., Dore, E., Fancello, D., Ghiglieri, G., Frau, F., 2019. Dissolved fluoride removal by OCP, a precursor of apatite. E3S Web of Conferences 98 (Water-Rock Interaction Controlling Water Quality and Human Health Issues). https://doi.org/10.1051/e3sconf/20199809012.

Idini, A., Frau, F., Gutierrez, L., Dore, E., Nocella, G., Ghiglieri, G., 2020. Application of octacalcium phosphate with an innovative household-scale defluoridator prototype and behavioral determinants of its adoption in rural communities of the East African Rift Valley. Integrated Environ. Assess. Manag. 16 (6), 856–870. https://doi.org/10.1002/ieam.4262.

Ijumulana, J., Ligate, F., Bhattacharya, P., Mtalo, F., Zhang, C., 2020. Spatial analysis and GIS mapping of regional hotspots and potential health risk of fluoride concentrations in groundwater of northern Tanzania. Sci. Total Environ. 735, 139584.

Ijumulana, J., Ligate, F., Irunde, R., Bhattacharya, P., Maity, J.P., Ahmad, A., Mtalo, F., 2021. Spatial uncertainties in fluoride levels and health risks in endemic fluorotic regions of northern Tanzania. Groundw. Sustain. Dev. 14, 100618.

Ijumulana, J., Ligate, F., Irunde, R., Bhattacharya, P., Ahmad, A., Tomašek, I., et al., 2022. Spatial variability of the sources and distribution of fluoride in groundwater of the Sanya alluvial plain aquifers in northern Tanzania. Sci. Total Environ. 810, 152153.

Inauen, J., Hossain, M.M., Johnston, R.B., Mosler, H.J., 2013. Acceptance and use of eight arsenic-safe drinking water options in Bangladesh. PLoS One 8 (1), e53640. https://doi.org/10.1371/journal.pone.0053640.

Jackson, K., Bazeley, P., 2019. Qualitative Data Analysis with NVivo. Sage.

Jones, A.Q., Dewey, C.E., Doré, K., Majowicz, S.E., McEwen, S.A., Waltner-Toews, D., et al., 2005. Public perception of drinking water from private water supplies: focus group analyses. BMC Publ. Health 5 (1), 1–12. https://doi.org/10.1186/1471-2458-5-129.

Jones, A.Q., Dewey, C.E., Doré, K., Majowicz, S.E., McEwen, S.A., Waltner-Toews, D., et al., 2007. A qualitative exploration of the public perception of municipal drinking water. Water Pol. 9 (4), 425–438. https://doi.org/10.2166/wp.2007.019.

Keramitsoglou, K.M., Tsagarakis, K.P., 2018. Public participation in designing the recycling bins to encourage recycling. Sustainability 10 (4), 1240. https://doi.org/10.3390/su10041240.

Ligate, F., Ijumulana, J., Ahmad, A., Kimambo, V., Irunde, R., Mtamba, J.O., et al., 2021. Groundwater resources in the East African Rift Valley: understanding the geogenic contamination and water quality challenges in Tanzania. Sci. Afr. 13, e00831.

Makutsa, P., Nzaku, K., Ogutu, P., Barasa, P., Ombeki, S., Mwaki, A., Quick, R.E., 2001. Challenges in implementing a point-of-use water quality intervention in rural Kenya. Am. J. Pub. Health 91 (10), 1571–1573. https://doi.org/10.2105/AJPH.91.10.1571.

Malago, J., Makoba, E., Muzuka, A.N., 2017. Fluoride levels in surface and groundwater in Africa: a review. Am. J. W. Sci. Eng. 3 (1), 1–17. https://doi.org/10.11648/j.ajwse.20170301.11.

Mbabaye, G.K., Mtalo, F., Minja, R.J., Legonda, I., 2017. Standardizing defluoridation of community waters using bone char. J. Water Supply Res. Technol. - Aqua 66 (2), 131–139. https://doi.org/10.2166/aqua.2017.056.

Mbabaye, G., Minja, R., Mtalo, F., Legonda, I., Mkongo, G., 2018. Fluoride occurrence in domestic water supply sources in Tanzania: a case of Meru district Arusha region. Tanzan. J. Sci. 44 (3), 72–92.

Minasyan, A., 2016. Your development or mine? Effects of donor–recipient cultural differences on the aid-growth nexus. J. Comp. Econ. 44 (2), 309–325.

Mosler, H.J., 2012. A systematic approach to behavior change interventions for the water and sanitation sector in developing countries: a conceptual model, a review, and a guideline. Int. J. Environ. Health Res. 22 (5), 431–449. https://doi.org/10.1080/09603123.2011.650156.

Mulopo, C., Kalinda, C., Chimbari, M.J., 2020. Contextual and psychosocial factors influencing the use of safe water sources: a case of madeya village, uMkhanyakude district, South Africa. Int. J. Environ. Res. Publ. Health 17 (4), 1349. https://doi.org/10.3390/ijerph17041349.

Njuguna, S.M., Onyango, J.A., Githaiga, K.B., Gituru, R.W., Yan, X., 2020. Application of multivariate statistical analysis and water quality index in health risk assessment by domestic use of river water. Case study of Tana River in Kenya. Process Saf. Environ. Protect. 133, 149–158. https://doi.org/10.1016/j.psep.2019.11.006.

Nunbogu, A.M., Harter, M., Mosler, H.J., 2019. Factors associated with levels of latrine completion and consequent latrine use in northern Ghana. Int. J. Environ. Res. Publ. Health 16 (6), 920. https://doi.org/10.3390/ijerph16060920.

Peal, A.J., Evans, B.E., van der Voorden, C., 2010. Hygiene and Sanitation Software: an Overview of Approaches. Water Supply & Sanitation Collaborative Council, Geneva (Switzerland).

Sonnenberg, L., Gelsomin, E., Levy, D.E., Riis, J., Barraclough, S., Thorndike, A.N., 2013. A traffic light food labeling intervention increases consumer awareness of health and healthy choices at the point-of-purchase. Prev. Med. 57 (4), 253–257. https://doi.org/10.1016/j.ypmed.2013.07.001.

Sörme, L., Voxberg, E., Rosenlund, J., Jensen, S., Augustsson, A., 2019. Coloured plastic bags for kerbside collection of waste from households—to improve waste recycling. Recycling 4 (2), 20. https://doi.org/10.3390/recycling4020020.

Stocker, A., Mosler, H.J., 2015. Contextual and sociopsychological factors in predicting habitual cleaning of water storage containers in rural Benin. Water Resour. Res. 51 (4), 2000–2008. https://doi.org/10.1002/2014WR016005.

Tekle-Haimanot, R., Melaku, Z., Kloos, H., Reimann, C., Fantaye, W., Zerihun, L., Bjorvatn, K., 2006. The geographic distribution of fluoride in surface and groundwater in Ethiopia with an emphasis on the Rift Valley. Sci. Total Environ. 367 (1), 182–190. https://doi.org/10.1016/j.scitotenv.2005.11.003.

Thorndike, A.N., Riis, J., Sonnenberg, L.M., Levy, D.E., 2014. Traffic-light labels and choice architecture: promoting healthy food choices. Am. J. Prev. Med. 46 (2), 143–149. https://doi.org/10.1016/j.amepre.2013.10.002.

Tomašek, I., Mouri, H., Dille, A., Bennett, G., Bhattacharya, P., Brion, N., et al., 2022. Naturally occurring potentially toxic elements in groundwater from the volcanic landscape around Mount Meru, Arusha, Tanzania and their potential health hazard. Sci. Total Environ. 807, 150487.

Tumwebaze, I.K., Mosler, H.J., 2014. Shared toilet users' collective cleaning and determinant factors in Kampala slums, Uganda. BMC Publ. Health 14 (1), 1–10. https://doi.org/10.1186/1471-2458-14-1260.

Tumwebaze, I.K., Mosler, H.J., 2015. Effectiveness of group discussions and commitment in improving cleaning behaviour of shared sanitation users in Kampala, Uganda slums. Soc. Sci. Med. 147, 72–79. https://doi.org/10.1016/j.socscimed.2015.10.059. **Error! Hyperlink reference not valid.**

United Nations Human Settlements Programme Staff, 2003. The Challenge of Slums: Global Report on Human Settlements. UN-HABITAT, 2003.

Van Der Voorn, T., 2008. The hidden language of rural water supply programmes. Taylor & Francis. https://doi.org/10.1201/9780203894569.ch38.

Vogel, T., Wanke, M., 2016. Attitudes and Attitude Change. Psychology Press.

Vuhahula, E.A.M., Masalu, J.R.P., Mabelya, L., Wandwi, W.B.C., 2009. Dental fluorosis in Tanzania great Rift Valley in relation to fluoride levels in water and in 'magadi'(trona). Desalination 248 (1–3), 610–615. https://doi.org/10.1016/j.desal.2008.05.109.

Ward, L.A., Cain, O.L., Mullally, R.A., Holliday, K.S., Wernham, A.G., Baillie, P.D., Greenfield, S.M., 2009. Health beliefs about bottled water: a qualitative study. BMC Publ. Health 9 (1), 1–9.

Yadav, K.K., Gupta, N., Kumar, V., Khan, S.A., Kumar, A., 2018. A review of emerging adsorbents and current demand for defluoridation of water: bright future in water sustainability. Environ. Int. 111, 80–108.