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Diet and Fluorosis-Related Stigma on Gihaya Island, Western Province, Rwanda

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ABSTRACT

Introduction: Dental fluorosis, caused by prolonged and excessive fluoride exposure during childhood enamel formation, often leads to aesthetic changes in tooth shape, pitting and color. It is highly prevalent on Gihaya Island, Rwanda. To better understand potential fluoride sources and community impact, our research aimed to identify food and water sources consumed by island residents and to characterize social experiences of young adults impacted by dental fluorosis.
Methods: All families (N=137) with children up to nine years of age were invited to complete surveys on food/water consumption. Mothers with small children and young adults were invited to participate in focus group discussions on food preparation and stigma, respectively.
Results: In total, 136 families participated in the survey. High fluoride content items frequently consumed by children were drinking water from Lake Kivu, infant formula, green marog (amaranth), ugali (made of cassava flour), fish, cooked beans, and porridge (made of sorghum, millet, wheat, etc.). Focus group data identified safe water access as a major community concern and confirmed the presence of social stigma for those with dental fluorosis. This was described as negative impacts on marriage prospects, self-esteem, and social identity. The aesthetic consequences of dental fluorosis, likely caused by combined exposure to fluoride-containing foods and water, negatively impact Gihaya Island residents.
Conclusion: Interventions to reduce dental fluorosis must be multi-dimensional, addressing reduced access to safe water, poverty, the nutritional trade-offs of locally sourced foods, and the social consequences of this stigmatizing condition.

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INTRODUCTION

Fluoride is an essential element that contributes to the health of mineralized tissues, such as teeth and bones, when individuals are exposed at appropriate levels [1]. However, adverse health effects, such

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as dental fluorosis, can result when individuals are exposed above recommended therapeutic concentrations during childhood, pre-eruptive stages of dental development. Dental fluorosis is characterized by hyper-mineralization of enamel causing aesthetic changes in teeth, including staining, severe mottling, pitting, and subsequent weakness of the enamel [2]. Long term exposure continuing into adulthood is associated with skeletal fluorosis, characterized by deformities such as knock-knees and saber tibia [3]. In addition to physical changes to one's appearance, dental fluorosis has also been linked to social stigmatization, and shifts in one's self-esteem [4,5].

People are exposed to fluoride through various sources, including food, water, dust from fluoride-containing soils, and commercial oral health products [6]. Tea leaves, fish, and grain have been shown to contain high levels of fluoride in some contexts [7]. Cooking practices, such as boiling water, or using natural food tenderizers (e.g., magadi, a high fluoride containing trona) can increase fluoride levels in prepared foods [8,9].

Dental fluorosis affects millions of people globally [10] and is observed among people in the Rift Valley region of East Africa [11]. Children under the age of eight years are at highest risk, due to fluoride exposure during early enamel development (both pre-eruptive and post-eruptive fluoride exposure) because of their increased fluoride retention compared to adults [1]. The first two months of an infant's life is a critical period of exposure because fluoride is more readily incorporated into enamel before teeth erupt through the gums [1,12]. In 2018, a study of dental fluorosis on Gihaya Island found 90.7% of children aged 9-15 years to be affected [13]. Dietary habits and social effects of dental fluorosis on the island are not known. The objectives of this study were to (1) identify common foods and water sources used by families with children aged up to nine years of age, and (2) to characterize the social experiences of young adults with dental fluorosis.

METHODS

Study design and setting: This cross-sectional mixed-methods study was conducted in July 2019 on Gihaya Island in Lake Kivu, a volcanic region, located between Rwanda and the Democratic Republic of the Congo [14]. The island is approximately 7 km2 in length with a population of 1300 people who mostly practice subsistence agriculture, growing food crops, raising livestock, and fishing. Most households have low socio-economic status and have limited access to electricity and telecommunication. Three water boreholes are distributed along the length of the island but only the central pump was operational in 2019. Residents obtain healthcare for minor issues from Community Health Workers at a small health post but must travel to the mainland for all other concerns, including oral health.

Data Collection: We developed a quantitative survey to measure frequency of foods ingested by children and adults. Food items and water sources included on the survey were based on the previous visits to the island and conversations with residents. All dietary questions included the option of 'other' to ensure comprehensive inclusion of food and water sources. The survey was developed in English, translated into Kinyarwanda and then back-translated to ensure accurate translation. It was pre-tested with five people in Bugesera District to ensure content validity. Inclusion criteria for survey respondents were male or female heads of households (aged 18 years or older) of all families with children aged nine years old and younger. The selected heads of household were required to know the dietary practices of all members of their household and to have lived on Gihaya Island for at least one year. The only exclusion criteria was any respondent below the age of 18 years old, and who were not current residents of Gihaya Island. Our team employed two Gihaya Island Community Health Workers to identify all households meeting the inclusion criteria, to introduce the team to potential respondents, and to assist with data collection. Data was collected via surveys which were conducted at the respondent's place of residence by data collectors fluent in Kinyarwanda. Survey data was collected on mobile phones using Kobo Toolbox, uploaded to a computer daily, and checked for errors. Quantitative data was uploaded to SPSS software (v25) for descriptive statistical analysis. Frequencies of the various survey responses was the primary analysis performed using SPSS to determine the foods most consumed by the islanders.

Qualitative data regarding household food/water preparation practices and the social experiences of young, single adults with dental fluorosis were

obtained through focus group discussions. The first discussion, focused on food/water preparation, was held at a women's cooperative and included mothers of children up to nine years of age. Two other discussions, divided by gender, were held with unmarried young adults (18-25 years old) on the topic of dental fluorosis. All discussions were held in enclosed spaces to maintain privacy from outsiders. They were facilitated by two Kinyarwanda speakers and were audio-recorded to ensure accuracy of transcripts and notes. Transcripts were translated to English and reviewed by two members of the research team to identify major themes.

RESULTS

Demographics

Overall, 137 household met the study inclusion criteria; of these, 136 agreed to participate in the survey (99% participation rate). The remaining person was off the island for the duration of the study period and unavailable to participate. Respondents were most often women (83%) versus men (16%), with a median age of 34 years (range: 18-62). Most (76%) were born on Gihaya Island with the remainder living there between one and 40 years. Of the households surveyed, 124 had at least one child from the age group of 0-1 years old, 117 had one or more children aged 2-5 years, and 99 had one or more children aged 6-9 years.

Island foods and beverages

Survey data indicated that two-thirds of families consumed small fish from Lake Kivu daily or weekly (65%) and almost all rarely or never consumed meat, eggs (99% each) or cow's milk (92%; Table 1). Most described eating beans daily or weekly (87%). Ugali (porridge) and cassava root were the major sources of carbohydrates, with

Table 1: *Foods consumed by household heads residing in high prevalence region for dental fluorosis (Gihaya Island, Rwanda; N=136)*

	Daily	Weekly	Monthly	Rarely/Never
	n (%)	n (%)	n (%)	n (%)
Cow's Milk	3 (2.2)	7 (5.1)	10 (7.4)	115 (84.5)
Fish	12 (8.8)	76 (55.9)	34 (25)	14 (10.3)
Meat	0 (0)	2 (1.5)	26 (19.1)	108 (79.4)
Eggs	1 (0.7)	0 (0)	10 (7.4)	125 (91.9)
Beans	36 (26.5)	82 (60.3)	15 (11)	3 (2.2)
Cassava root	4 (2.9)	38 (27.9)	27 (19.9)	67 (49.3)
Mango	1 (0.7)	0 (0)	3 (2.2)	132 (97.0)
Avocado	5 (3.7)	16 (11.8)	20 (14.7)	95 (69.1)
Other[1]				
Green Marog	72 (52.9)	19 (14)	0 (0)	2 (1.5)
Ugali	91 (66.9)	8 (5.9)	0 (0)	0 (0)
Green Banana	7 (5.1)	2 (1.5)	0 (0)	0 (0)
Sweet Potato	5 (3.7)	6 (4.4)	1 (0.7)	0 (0)
Cassava Leaves	9 (6.6)	4 (2.9)	0 (0)	0 (0)
Sweet Pepper	1 (0.7)	2 (1.5)	0 (0)	0 (0)
Cabbage	2 (1.5)	1 (0.7)	0 (0)	0 (0)
Irish Potato	1 (0.7)	0 (0)	0 (0)	0 (0)
Soybeans	0 (0)	1 (0.7)	0 (0)	0 (0)
Rice	0 (0)	1 (0.7)	0 (0)	0 (0)
Fish Powder	0 (0)	1 (0.7)	0 (0)	0 (0)
Porridge	0 (0)	0 (0)	0 (0)	1 (0.7)

[1]*Food or beverage items not listed on the survey*

nearly half consuming cassava root daily or weekly (42%), and nearly three-quarters consuming ugali daily or weekly (72.8%). Mangoes (99.2%) and avocados (83.8%) were rarely or never consumed, even though both grew on the island. Respondents reported 'other' food items (i.e., those not on the survey but identified by respondents) eaten daily or weekly as green marog (amaranth) (66.9%), cassava leaves (9.5%), sweet potato (8.1%), green banana (6.6%), sweet pepper (2.2%), cabbage (2.2%), Irish potatoes (0.7%), soybeans (0.7%), rice (0.7%), and fish powder (0.7%). Household heads prepared foods by adding salt (99.3%) and oil (73.5%).

Foods most consumed daily or weekly by children aged 2-5 years were fish (70.1%), beans (88.9%), and ugali (64.8%; Table 3). Half of respondents also provided breast milk (47%), infant formula (48.5%), porridge (48.7%) and green marog (50.4%) to children in this age group daily or weekly. Meat (78.6%), eggs (94.9%), and cow's milk (82.1%) were rarely or never provided. Cassava root (31.7%) and ugali (64.8%) were the main sources of carbohydrates. Most rarely or never gave their children mango (97.4%) and avocado (71.8%). Apart from green marog and ugali,

Table 2: *Foods consumed by children (0-1 years) in a high prevalence region for dental fluorosis (Gihaya Island, Rwanda; N=124)*

	Daily	Weekly	Monthly	Rarely/Never
				n (%)
Breast Milk	120 (96.8)	0 (0)	0 (0)	4 (3.2)
Infant Formula	90 (72.6)	10 (8.1)	5 (4)	19 (15.3)
Cow's Milk	3 (2.4)	8 (6.4)	11 (8.9)	102 (82.3)
Porridge	30 (24.2)	41 (33)	10 (8.1)	43 (34.7)
Other[1]				
Green Marog	9 (7.2)	8 (6.4)	0 (0)	1 (.8)
Ugali	21 (16.9)	1 (0.8)	0 (0)	0 (0)
Green Banana	16 (12.9)	6 (4.8)	0 (0)	0 (0)
Sweet Potato	0 (0)	1 (0.8)	0 (0)	0 (0)
Sweet Pepper	1 (0.8)	2 (1.6)	0 (0)	0 (0)
Irish Potatoes	6 (4.4)	6 (4.4)	0 (0)	1 (0.8)
Rice	1 (0.8)	0 (0)	0 (0)	0 (0)
Fish	4 (2.9)	2 (1.6)	0 (0)	0 (0)
Avocado	1 (0.8)	1 (0.8)	0 (0)	0 (0)
Beans	2 (1.6)	0 (0)	0 (0)	0 (0)

[1]*Food or beverage items not listed on the survey*

'other' foods ingested daily or weekly included cassava leaves (8.6%), sweet potato (8.4%), green banana (2.4%), sweet pepper (1.6%), rice (1.6%), cabbage (0.8%), and Irish potatoes (0.8%).

Participants did not provide infant formula or breast milk to children aged 6-9 years and rarely offered cow's milk (87.9%; Table 4). Both fish (76.7%) and beans (89.9%) were given to this age group weekly by most survey participants. Meat (82.8%) and eggs (92.9%) were rarely or never provided. Ugali (66.6%) and cassava (36.3%) were most common carbohydrate sources. More than half gave their children green marog (53.5%), but most rarely or never gave mango (99%) and avocado (71.7%). 'Other' food items included cassava leaves (8%), sweet potatoes (6%), green banana (2%), sweet pepper (1%), cabbage (1%), soybeans (1%), and rice (1%).

Water was the beverage most frequently consumed daily or weekly (100%; Table 5). Daily drinking water was mostly sourced from the borehole (66.9%), followed by Lake Kivu (30.9%) whereas daily cooking water was most often sourced from Lake Kivu (93.4%) followed by the borehole (6.6%). Respondents did not generally use rainwater for drinking or cooking and often stored water from different water sources in the same container (79.4%). Nearly all participants described previously using a borehole that was no longer available to them (98.5%). Some

Table 3: *Foods consumed by children (2-5 years) in a high prevalence region for dental fluorosis (Gihaya Island, Rwanda; N=117)*

	Daily n (%)	Weekly	Monthly	Rarely/Never
Breast Milk	55 (47)	0 (0)	0 (0)	61 (52.1)
Infant Formula	59 (50.4)	7 (6)	3 (2.6)	48 (41)
Cow's Milk	3 (2.6)	8 (6.8)	10 (8.5)	96 (82.1)
Fish	11 (9.4)	71 (60.7)	21 (17.9)	14 (12)
Meat	0 (0)	2 (1.7)	19 (16.2)	95 (78.6)
Eggs	0 (0)	0 (0)	6 (5.1)	111 (94.9)
Beans	31 (26.5)	73 (62.4)	7 (6)	6 (5.1)
Cassava Root	5 (4.3)	32 (27.4)	15 (12.8)	65 (55.5)
Mango	0 (0)	1 (0.8)	2 (1.6)	114 (97.4)
Avocado	6 (5.1)	14 (12)	13 (11.1)	84 (71.8)
Porridge	17 (14.5)	40 (34.2)	9 (7.7)	51 (43.6)
Other[1]				
Green Marog	60 (51.3)	4 (3.4)	0 (0)	0 (0)
Ugali	74 (63.2)	2 (1.6)	0 (0)	0 (0)
Green Banana	2 (1.6)	1 (0.8)	0 (0)	0 (0)
Sweet Potato	5 (4.2)	5 (4.2)	0 (0)	0 (0)
Cassava Leaves	7 (6)	3 (2.6)	0 (0)	0 (0)
Sweet Pepper	2 (1.6)	0 (0)	0 (0)	0 (0)
Cabbage	0 (0)	1 (0.8)	0 (0)	0 (0)
Irish Potatoes	1 (0.8)	0 (0)	0 (0)	0 (0)
Rice	1 (0.8)	1 (0.8)	0 (0)	0 (0)

[1]*Food or beverage items not listed on the survey*

respondents treated their water to enhance its safety, either by filtration (15.4%) or boiling (23.5%). Other beverages consumed daily or weekly included tea (21.3%), juice (8.8%), beer (7.3%), milk (6.6%), and soda (3.6%). Animals drank from Lake Kivu (87.8%) and/or from the functioning borehole water source (93.9%). Some respondents gave away leftover food or liquid from their cooking (66%).

Food/water preparation

Mothers of small children participating in the first focus group (n=12) identified poverty, market access, and governance as important factors affecting food and water access. Lack of money prevented women from buying the foods they preferred in favor of lower cost items that could be stretched to feed a family. It also explained why children mostly ate the same food as adults.

"We do not eat meat, except for at weddings. One kg of meat costs 3000 RWF [Rwandan francs]. How can you afford it when you brought 1000 RWF to the market? How can you buy it? We live a bad life."

"When you have 1000 RWF you cannot buy 1 kg of rice and feed the whole family but if you have 1000 RWF you buy cassava flour and it fills up the whole family. That is why it is the most common."

The women described a sudden recent change that negatively impacted their access to safe water. They agreed that borehole water was safest and had become available in 2004 after a major cholera outbreak prompted Médecins Sans Frontières to install three boreholes. Two pumps broke and the third supplied most families with drinking water until 2019 when it was suddenly repurposed with solar panels and fitted with a lock by a local social enterprise (Water Access Rwanda). Island residents were then obliged to pay for the only source of clean water, which was often unavailable in the rainy season or when the operator was absent. Many could not afford the

Table 4: *Foods consumed by children (6-9 years) in a high prevalence region for dental fluorosis (Gihaya Island, N=99)*

	Daily	Weekly	Monthly	Rarely/Never
				n (%)
Cow's Milk	2 (2)	7 (7)	3 (3)	87 (87.9)
Porridge	5 (5)	29 (29.3)	7 (7)	58 (58.6)
Fish	6 (6)	70 (70.7)	15 (15.2)	8 (8.1)
Beans	24 (24.2)	65 (65.7)	7 (7.1)	3 (3)
Cassava Root	6 (6)	30 (30.3)	17 (17.2)	46 (46.5)
Mango	0 (0)	0 (0)	1 (1)	98 (99)
Avocado	5 (5)	14 (14.1)	8 (8.1)	71 (71.7)
Meat	0 (0)	4 (4)	13 (13.1)	82 (82.8)
Eggs	0 (0)	0 (0)	5 (5)	92 (92.9)
Other[1]				
Green Marog	47 (47.5)	6 (6)	0 (0)	0 (0)
Ugali	61 (61.6)	5 (5)	0 (0)	0 (0)
Green Banana	1 (1)	1(1)	0 (0)	0 (0)
Sweet Potatoes	1 (1)	5 (5)	0 (0)	0 (0)
Cassava Leaves	5 (5)	3 (3)	0 (0)	0 (0)
Sweet Pepper	0 (0)	1 (1)	0 (0)	0 (0)
Cabbage	0 (0)	1 (1)	0 (0)	0 (0)
Soybeans	0 (0)	1 (1)	0 (0)	0 (0)
Rice	0 (0)	1 (1)	0 (0)	0 (0)

[1]*Food or beverage items not listed on the survey*

cost and reverted to water from Lake Kivu, despite fear of contracting infectious diseases. They were not able to treat water due to scarcity of cooking fuel and lack of filtration devices at markets.

"Diarrhea, cholera, and all those diseases came back recently."

"Now our children are having intestinal worms. A few days ago, I was about to die. I spent two days unable to get off my bed."

"There is no wood for charcoal. How can you find wood to cook water if you don't have wood to cook food?"

The women were frustrated about the lack of consultation, fearful about increases in disease, and felt abandoned by Water Access Rwanda and the local leader who were both located off the island and therefore unaffected by the water shortage. They agreed that island water sources were inferior to that available on the mainland.

"We ask our leaders and receive no response. We ask them, we used to have our own water without a problem, without money. Who is the person who changed our water this way? We do not find anyone to respond to us."

Self esteem

Most survey respondents (80.9%) reported having stained and/or pitted teeth; of those, 89% felt dissatisfaction and 62.8% felt shame with the appearance of their teeth. Focus group participants from the two groups (eight men and seven women) experienced reduced self-esteem as well as stigma and described several possible causes of stained teeth: genetics, disease, malnutrition, eating small fish, and drinking unsafe water. Both men and women had been branded with derogatory language ("umushi", meaning outsider) when travelling off the island and hid their teeth to avoid being mocked.

"Sometimes when we go to a meeting at the other side of the lake, and they tell a joke, you can't laugh. You have to cover your mouth."

"When you cross the lake to the other side, and you smile or laugh you can hear people saying this one is "umushi": they ate a lot of small fishes. This doesn't feel so good, just in case you were passing by and wishing to get along with people across the lake."

Education and employment

Although some students had dropped out of school due to discrimination, neither men nor women believed that their employment prospects were affected. Rather, they were upset that people with dental fluorosis were prevented from sharing food or beverages with those unaffected:

"One of them took a sugar cane and his friend said, 'why did you eat my sugar cane with those bad teeth of yours?' They threw the rest of the sugar cane in the toilet, and those are simply children!"

"When people are drinking our traditional beer which we share using the same straw, someone with that dental problem might be your friend and want to share the beer with you. And then you might be like 'I can't drink from the same straw used by him', and you refuse to share the beer with him."

Stigma

Men and women agreed that stained teeth reduced the number of marriage prospects, affecting women disproportionally. As two men stated,

"Actually, girls are the more vulnerable ones. Because boys are the ones who initiate dates, so there are some factors that a boy follows when asking a girl out."

"Here on the island, some people think dental fluorosis problems are genetic. They would say 'if I marry that girl, she will bear children with the same teeth as hers'. That's really heart breaking. Except for someone who doesn't consider teeth's appearance to be a problem."

A few participants blamed tooth pain on fluorosis and nearly all wanted to repair the appearance of their teeth. However, treatments available in the region were either ineffective or expensive.

DISCUSSION

Dental fluorosis negatively impacts the physical and mental wellness of over 200 million people globally [10]. In this study of diet and stigma, we confirmed that residents of Gihaya Island associated dental fluorosis with physical pain, shame, reduced marriage prospects, and social stigma. Moreover, reduced access to safe borehole water resulted in increased consumption of water from Lake Kivu, which is known to contain unsafe levels of fluoride (range: 1.65-1.75mg/L), as well as other harmful pathogens such as E. coli [13]. Rwanda is a low-income country with ambitious goals to improve WASH (water, sanitation, and hygiene) so that 'universal and equitable access to safe and affordable drinking water' be provided for all by 2030 [15]. This national goal is aligned with the United Nations Sustainable Development Goal 6, and as such, improving access to safe water on Gihaya Island is in line with national and global goals for poverty reduction [16].

The upper limit (UL) of exposure describes the highest level of fluoride exposure that is tolerated before adverse effects of fluorosis are caused [17]. Infants tolerate the lowest level of exposure compared to other age groups, with an UL of 0.7 mg/day (0-6 months), and 0.9 mg/day (6-12 months) [17]. Our dietary survey identified three items consumed daily by most infants up to one year (breast milk, infant formula, porridge). Evidence indicates that maternal fluoride transfers poorly through breast milk, suggesting that infant formula and porridge, both prepared with boiled Lake Kivu water, are likely the greatest fluoride source for infants on the island [18]. Elsewhere, infant formula has been linked to an unsafe increase in fluoride consumption due to the mixture of fluoridated water with infant formula concentrate [1]. Studies found that porridge prepared on Gihaya Island has a fluoride concentration of 0.485 mg/g [13]. The UL of fluoride for children 1-3 years is 1.3 mg/day (1-3 years) and 2.2 mg/day for children 4-8 years [17]. In addition to breast milk and infant formula, most Gihaya Island children aged two years and older ate green marog and ugali daily, and fish, beans, and porridge weekly. Green marog, ugali, small fishes, and cooked beans contained mean fluoride concentrations of 0.305 mg/g, 0.161 mg/g, 0.262 mg/g, and 0.211 mg/g respectively, suggesting that moderate daily servings of each would alone exceed the safe UL for this age group [13]. However, the high levels of calcium and antioxidants contained in green marog could serve to moderate fluoride bioavailability [19]. More information on serving sizes is needed to inform public health efforts to reduce fluoride exposure in this hyperendemic region. Moreover, recommendations must consider the high level of poverty, malnutrition, and locally available food items, and the trade-offs between nutritionally dense foods (such as small fishes) and fluoride content.

Gihaya Island study participants drank water more

often than any other beverage, followed by tea. Drinking water was most often collected from the Water Access Rwanda-controlled borehole, while cooking water was primarily collected from Lake Kivu. Eight months previously, Lake Kivu water was found to contain more than 12 times the concentration of fluoride versus the borehole water (1.75 mg/L versus 0.14 mg/L) [13]. The WHO recommends that fluoride levels in water not exceed 1.5 mg/L; however, it has been suggested that in tropical climates where individuals are expected to drink more water than people in temperate climates, fluoride levels in water not exceed 1.0 mg/L [20]. On Gihaya Island, borehole water is currently the safest water source with respect to both fluoride and pathogenic exposure [13]; however, recent changes in access are a major barrier to use. Alternative sources, such as harvested rainwater and Lake Kivu, are feasible but require infrastructure upgrades to ensure safe access and storage. Furthermore, options for removing both pathogens and fluoride from lake water are limited, and costly. These methods include reverse osmosis, ion exchange, lime softening, use of activated alumina, or coagulation followed by direct filtration through sand beds [21].

Young adults affected with dental fluorosis on Gihaya Island described feeling socially excluded, being called derogatory names, hiding their teeth, and reduced marriage prospects. Research demonstrates that dental fluorosis is an esthetic problem to mothers and their children in other East African countries, which may result in embarrassment, distress, and worry. As a result, social stigma can lead to an overall reduced self-esteem and damage to one's social identity [22]–[24]. Amongst the commonly held socio-political narrative of unification in the country declaring 'we are all Rwandans', residents of Gihaya Island are impacted with a sense of 'otherness' from fellow Rwandans when faced with prejudice due to their teeth. Experiences with dental fluorosis on the island also emphasizes gender inequities due to the impacts it has on relationship and marriage prospects, which may only further negatively affect quality of life for those individuals. Young adults sought options to improve the appearance of their teeth and were disappointed with the limited treatment options. Micro-abrasion of the teeth and/or veneers are costly and unrealistic in this context, with prevention remaining as the best option for those on Gihaya Island [25].

One key limitation of this study was our inability to document the quantities of each food item consumed daily by infants and children. This occurred because families often ate one meal per day at a time when it was not possible for the research team to be on the island. As a result, we were unable to calculate fluoride intake among high-risk groups. However, the uniformity of diet between families and the high concentration of fluoride in commonly consumed foods suggest that even moderate intake of foods containing Lake Kivu water is sufficient to exceed the daily UL. Additional laboratory analyses are also needed to quantify fluoride concentrations of other foods commonly ingested on Gihaya Island so that differences in associated with preparation methods can be better understood. Despite our best efforts, certain food items, such as green marog and ugali, were not originally included as official survey options, and their frequency of consumption could be under-estimated because we relied on participants naming them as 'other'.

CONCLUSION

In Rwanda, efforts to improve access to safe water often focus on reducing transit time to water sources and reducing water-borne pathogens. In this study of Gihaya Island where nearly all children show signs of dental fluorosis [13] we identified several foods (infant formula, porridge, fish, beans, green marog, ugali) and reduced access to safe water as major contributors to fluoride intake among infants and children. Moreover, we documented the negative psychosocial experiences due to stigmatization of dental fluorosis occurring off island. Altogether, this contributes to reduced wellness among an already vulnerable group. An immediate priority for island residents is improving access to water that is low in fluoride and free from waterborne pathogens. While further research is needed to understand the trade-offs of fluoride exposure and nutritional status of commonly ingested foods such as fish, our research suggest that households could reduce exposure by preparing boiled foods with borehole versus Lake Kivu water. Encouraging the sole provision of breast milk over infant formula would reduce fluoride exposure although this might pose a challenge for women with several children among the highest risk age groups. It is vital that

the issue of dental fluorosis be investigated further so as to better serve the health, wellness, and sense of national identity for the population of Gihaya Island. Furthermore, Rwanda's WASH goals for equitable access to safe and accessible water for all by 2030 suggest that improving upon the primary water source on Gihaya Island that is both heavily fluoridated and containing coliforms is of utmost importance.

DECLARATIONS

Ethical approval and consent to participate

Ethical approval for this study was obtained from the University of Rwanda Institutional Research Board (reference no: DVC-AAR 529/2019). Further written approval was obtained from the Mayor of the Rusizi district, the Executive Secretary of Gihundwe Sector, and the General Director of Gihundwe Hospital.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Author's Contribution

All authors contributed to the conception and study design process. AH, JMS, and EMH participated in data collection, analysis, and interpretation. AH and JMS drafted the manuscript. TN developed GIS mapping images of Gihaya Island. All authors reviewed and approved the final version.

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