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High fluoride water in Bondo-Rarieda area of Siaya County, Kenya: a hydro-geological implication on public health in the Lake Victoria Basin

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Abstract

Background: Only a few studies to evaluate groundwater fluoride in Eastern Africa have been undertaken outside the volcanic belt of the Great Eastern Africa Rift Valley. The extent and impact of water fluoride outside these regions therefore remain unclear. The current study evaluated fluoride levels in household water sources in Bondo-Rarieda Area in the Kenyan part of the Lake Victoria Basin (LVB) and highlighted the risk posed by water fluoride to the resident communities. The results, it was anticipated, will contribute to in-depth understanding of the fluoride problem in the region.

Methods: A total of 128 water samples were collected from different water sources from the entire study area and analyzed for fluoride content using ion-selective electrodes.

Results: Lake Victoria was the main water source in the area but dams and open pans (39.5%), boreholes and shallow wells (23.5%), and streams (18.5%) were the principal water sources outside walking distances from the lake. The overall mean fluoride content of the water exceeded recommended limits for drinking water. The mean water fluoride was highest in Uyoma (1.39±0.84 ppm), Nyang'oma (1.00±0.59 ppm) and Asembo (0.92±0.46 ppm) and lowest in Maranda Division (0.69±0.42 ppm). Ponds (1.41±0.82 ppm), springs (1.25±0.43 ppm), dams and open pans (0.96±0.79 ppm), and streams (0.95±0.41 ppm) had highest fluoride levels but lake and river water did not have elevated fluoride levels. Groundwater fluoride decreased with increasing distance from the lake indicating that water fluoride may have hydro-geologically been translocated into the region from geochemical sources outside the area.

Conclusions: Lake Victoria was the main water source for the residents of Bondo-Rarieda Area. Majority of in-land residents however used water from dams, open pans, boreholes, shallow wells, ponds and streams, which was generally saline and fluoridated. It was estimated that 36% of children living in this area, who consume water from ground sources from the area could be at the risk of dental fluorosis.

Background

Sufficient dietary levels of fluoride are required for the development of healthy bones and teeth [1]. Fluoride deficiency increases likelihood of teeth decay but prolonged contact with above optimum fluoride levels have serious detrimental effects to good health [2]. The negative health effects of continued exposure to excessive fluoride range from mild colorization of teeth surfaces to sever staining, pitting and loss of the enamel; and crippling skeletal deformations and death may result in chronic cases [2-4]. Non-skeletal health effects of excessive fluoride include: neurological, kidney, endocrine, thyroid and liver disorders as well as interferences in metabolic processes when the dosage is high [5,6]. Fluorosis, a developmental malady of skeletal calcified tissues, however, remains the most notorious toxic effect of long time contact with too much dietary fluoride [6,7]. Children below the age of 8 years, in whom teeth and bones are still developing are therefore most susceptible to all forms of fluorosis. The condition is permanent and once it develops it cannot be reversed. The primary pathway by which people ingest excessive

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fluoride is by constant consumption of high fluoride water, when safe drinking water is not available [8]. Natural waters normally associated with high fluoride are found in calcium-deficient underground aquifers, in geothermal streams, and in certain sedimentary basins [9]. The World Health Organization (WHO) has set 0.7 ppm as the recommended standards of fluoride in drinking water [10] and regular monitoring of fluoride levels in community water to control community exposure to fluoride is therefore highly recommended.

At the moment, increasingly more communities, especially among the developing nations, are being exposed to elevated fluoride levels through drinking water [11,12] due to growing water scarcity, high rates of population growth and adverse climatic changes in the recent past. General inadequacy in fluoride data in certain regions of the world and the tendency of certain nations to adopt and rely on 'blanket' WHO guidelines without regard to specific local fluoride realities have not helped the situation. It has been estimated therefore that 200 million people, in 25 countries world-over, are under the threat of fluorosis because of their continual exposure to high fluoride water [6].

Kenya is among the countries of the world where fluoride occurs in highest proportions in groundwater sources [13]. Thus, even though the western parts of the country are not among areas generally perceived as 'high fluoride' regions in the country, the topography and the radial inward drainage system of Lake Victoria Basin (LVB) make the areas around the lake shores to be liable

to hydro-geological accumulation of water soluble materials that could impact on the quality of the environment and on the public health of the resident communities. The LVB undulates from an altitude of 1100 m at the lake to as high as 4300 m above sea level in certain areas [14]. It stretches to catchment areas up to 400 km into the territories of all the East African Countries of Kenya, Uganda, Tanzania, Rwanda and Burundi [15]. Figure 1 shows that the land within the LVB steadily slopes towards the lake before it undergoes a rapid decrease in gradient in the sedimentary basins close to the lake shores.

This means that as the water flows through the lake basin, it loses momentum and most of its dissolved and suspended matter deposit over the soil colloid surfaces in the lower parts of the basin. Considering that these processes have been on-going for some 750,000 or more years since the LVB was formed [16], the sedimentary rocks in this area have become enriched in solutes, which continually solubilise and enrich groundwater in the lower parts of the LVB. Highlands that embank the LVB, for instance, are well known high-fluoride areas of the world [6,17,18]. Fluorides from these areas can therefore solubilise, get translocated and accumulate in offshore sedimentary basins of the LVB. However, the fluoride levels of groundwater sources in this parts of LVB have not yet been studied and the extent and impact of water fluoride in these offshore areas of LVB therefore still remains unclear. The current study was therefore designed to analyze the distribution of fluoride in potable water sources in the offshore areas of Bondo-
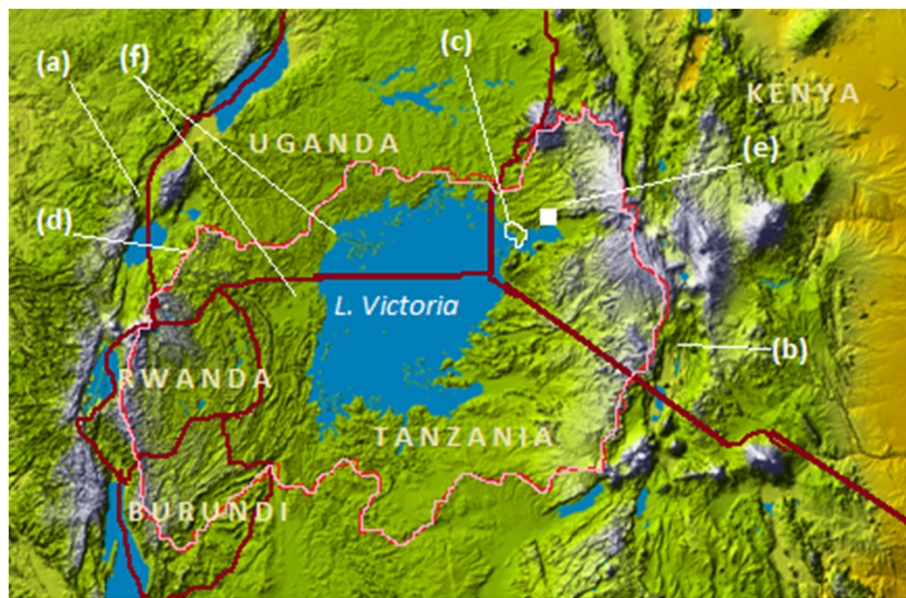

Figure 1 Topography of the Lake Victoria Basin: **(a)** Western and **(b)** Eastern arms of the Eastern Africa Rift Valley, **(c)** Bondo-Rarieda study area, **(d)** Boundaries of the Lake Victoria Basin, **(e)** Kisumu City, **(f)** Sedimentary basins of LVB (*Adopted from Wikimedia Commons with modifications. website: http://en.wikipedia.org/wiki/File:Topography_of_Lake_Victoria.png. Accessed on 23rd April 2014*).

Rarieda Area of Siaya County in the Kenyan part of LVB, and to evaluate the risk posed by water fluorides to the resident communities. A total of 128 water samples were collected from different household water sources to cover the entire study area and analyzed for their fluoride content using fluoride ion-selective electrodes. It was anticipated these results would contribute to in-depth insight into the fluoride problem in the Great Lakes Region and inform future policies that would safeguard human health and the environment.

Methods

The study area

Figure 2 shows the map of (a) the Bondo-Rarieda Area in relation to (b) the map of Kenya. The study area lies on the northern shores of Lake Victoria within latitudes 0.0°02′ N and 0.0°24′ S and Longitudes 34°0.0′ E and 34°26′ E. It covers both Bondo and Rarieda Sub-Counties of Siaya County of Kenya. It is divided into five administrative divisions, which are: Maranda, Nyang'oma and Usigu in Bondo Sub-County, and Asembo and Uyoma in Rarieda Sub-County. It borders Gem Sub-County of Kisumu County in the East and Budalangi Sub-County of Busia County of Kenya in the west. The Yala River runs the entire length of its border with Siaya Sub-County on the north and it is bounded by the shores of Lake Victoria on the south.

The area slopes gently from an altitude of about 1350 m in the north to 1100 m at the lake. It has a hot and moderately wet climate. The rain is bimodal with dry spells between the months of December and March and between Julys and September. The distribution of the rain is strongly influenced by the topography and the south-westerly winds from the lake, and there is a general degradation in the amount of annual rainfall from about 2000 mm in the northern parts to just about 700 mm at the lake. As expected there is a slight elevation in the mean annual temperature and the mean rate of evaporation at the lake compared to the higher altitude areas in the north [19].

The area is about 996,000 km^2 in size and it has a population of about 292,000 people, which is distributed by gender and by the age brackets as depicted in Figure 3. The children under the age of 10, who are most susceptible to the toxic effects of excessive fluoride [18], constitute 32% (or about 93,000 people) of the total population of the area [20].

Even though the Bondo-Rarieda area is bounded by two major surface water bodies, the River Yala on the north and Lake Victoria in the south, potable water sources for the communities living outside walking distances from these natural water bodies are generally few, unreliable and with long walking distances in between. On the whole, the main sources of household water for the residents of this area are: the Lake Victoria (37.4%), and the dams, open pans and ponds (30.14%) and, a significant portion of the population depends on water from boreholes and shallow wells (9.3%), and from streams (8.7%). Piped water (8.6%) is limited to urban centres and to government and private institutions. In all cases however the primary source of tap water is either the lake or the Yala River [20].
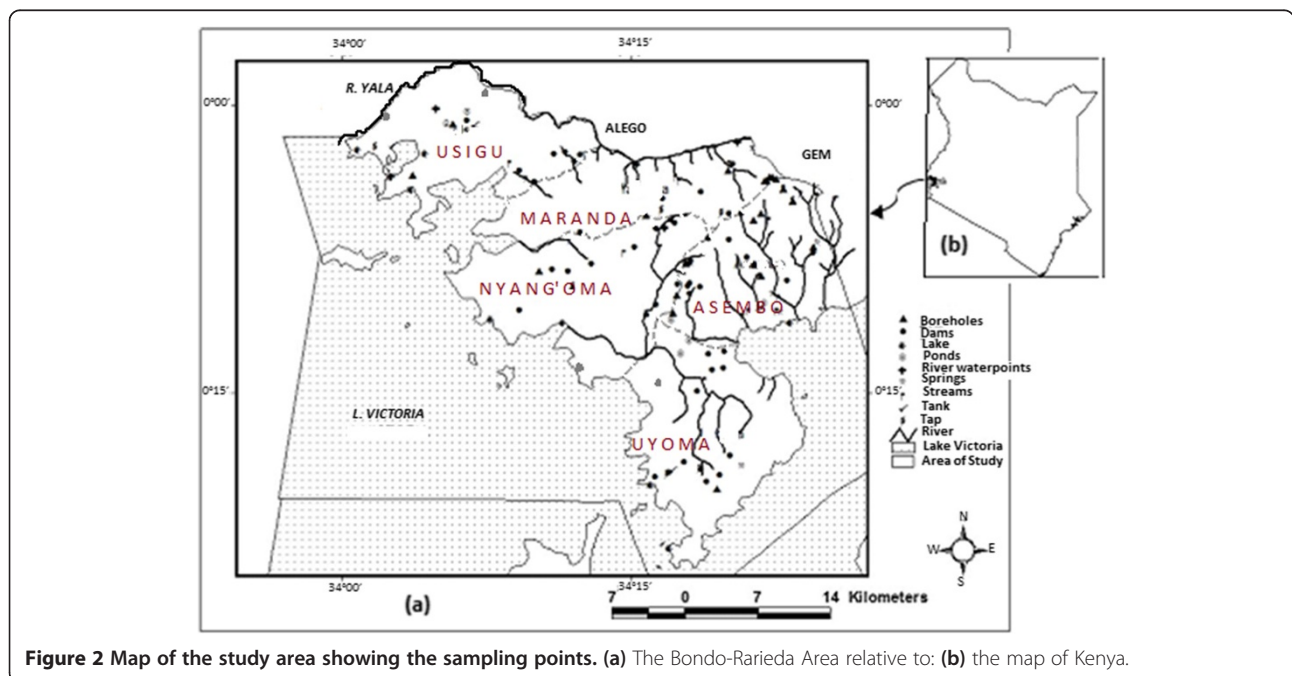

Figure 2 Map of the study area showing the sampling points. (a) The Bondo-Rarieda Area relative to: **(b)** the map of Kenya.
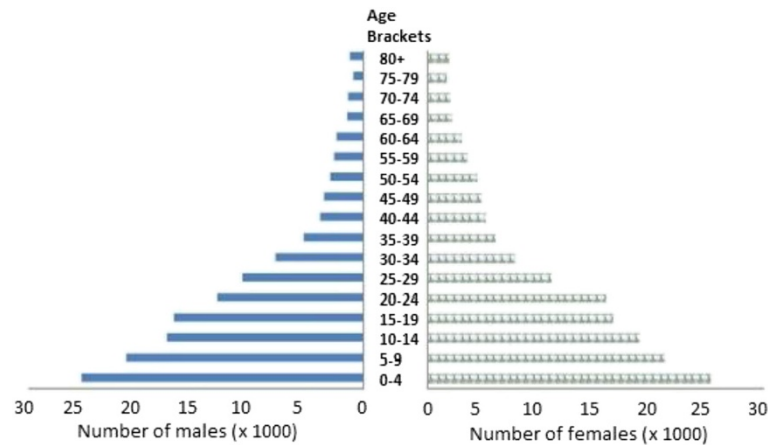
Figure 3 Population distributions in the Bondo-Rarieda Area by gender and age brackets.

Sample collection and analysis

To determine the sample size, *n*, of the number of representative sampling sites to be included in the survey, the Cochran's sample size formula for continuous data [21] was used in the form:

$$ME = z\frac{s}{\sqrt{n}} \tag{1}$$

where, *ME* is the allowable margins of error, which was set at 0.1, *z* being the *z*-score (1.96) corresponding to 95% confidence levels, and *s* the standard deviation or predicted fluoride variability in the area, which was estimated from screening tests as 0.577. Under these conditions the sample size value was determined as 127.7. A total of 128 water samples, including 11 tap water samples were therefore collected from different types of household water sources including boreholes, shallow wells, dams, open pans, lake, ponds, river, springs and streams [20], which were selected to cover the entire study area according to the sample selection criterion presented in Table 1.

The sampling was conducted between 20th and 30th April 2013. During sample collection, three samples were collected from each sampling site into clean 60-mL plastic bottles and transported to the laboratories within eight hours.

At the laboratory, the samples were stored frozen at −10°C awaiting analysis [22], which was conducted within the first week of May 2013. During the analysis, the triplicate samples from each sampling site were combined to form one composite sample. The fluoride concentration of the composite samples was then determined in triplicate using a *Jenway*® combination fluoride ion-selective electrode (ISE) (924305, Lot. S/No: BS0043) with a *Jenway*® Model 3345 direct-ion meter by addition of appropriate volume of total ionic strength adjustment

buffer (TISAB II) solution (*Jenway*® 025107 Lot No: TISAF512E1). The ISE had lower fluoride detection limits of 0.1 ppm. For calibration, standard solutions containing 0.1, 0.5, 1.0, 5.0, and 10.0 ppm fluoride were employed; the standards being prepared by appropriate dilution of a 1000-ppm fluoride stock solution (*Jenway*® 025087 Lot No: ISEF512H1) with doubly de-ionized water [13]. The resultant calibration curve is depicted in Figure 4.

The fluoride concentration in the water samples was determined within ±5% margins of error in the entire range of 0.1-10.0 ppm fluoride. Data analysis was carried out in *Microsoft excel* by calculation of the mean and the standard deviation, and causal relationships determined by determination of the correlation coefficients.

Results and discussions

Common types of water sources

As can be seen from Table 1, a total of 47 water samples were obtained from dams and open pans, and a further 45 samples from boreholes, shallow wells and streams,

Table 1 Distribution of sampling sites in divisions by type of water source

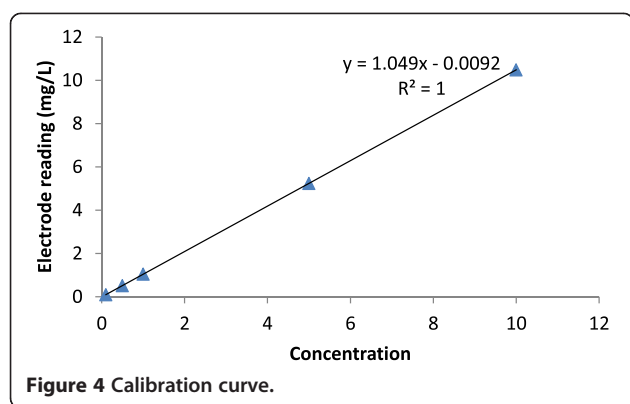| Division Source	Asembo	Maranda	Nyang'oma	Uyoma	Usigu	Total
Borehole	7	13	1	1	1	23
Dams and open pans	10	16	3	5	13	47
Lake	1	2	0	2	3	8
Ponds	2	0	0	0	4	6
River	0	3	0	0	2	5
Springs	4	1	1	0	0	6
Streams	11	7	0	0	4	22
Tap water	2	2	1	3	3	11
Total	37	44	6	11	30	128

Figure 4 Calibration curve.

respectively. This shows that even though the lake (37.4%) was the overall prime source of household water for the residents of the Bondo-Rarieda Area [20], dams and open pans (39.5%), boreholes and shallow wells (23.5%), and the streams (18.5%) were the main household water sources in areas outside walking distances from the lake shores. Most of groundwater sources were however saline from accumulation of salts in the sedimentary rock systems in this area as a result of hydro-geological translocation of soluble matter through underground aquifers and drainage streams into the area.

Fluoride distribution by type of water source

The detailed results of fluoride analyses of different types of water sources are depicted in Tables 2 and 3. All water sources except the lake (0.41±0.28 ppm), Yala River (0.41±0.42 ppm) and piped water (0.54±0.77 ppm) had mean fluoride levels greater than the WHO recommended levels of 0.70 ppm [10]. There was, however, a large variability in fluoride content of river water and tap water. This was ascribed, in part, to variability in the geochemistry of the rock system in the river basin in case of the river water, and to differences in the chemistry of the primary sources for tap water, and to the mode of treatment and storage, and to the duration of storage, in case of tap water [13]. Highest mean fluoride

concentration was found in pond water (1.41±0.82 ppm), spring water (1.25±0.43 ppm), dams and open pans (0.96±0.79 ppm), and in stream water (0.95±0.41 ppm). As expected, the highest percentage of water samples with above optimum fluoride levels was found among springs (66.7%), ponds (50.0%), streams (40.9%), and in dams and open water pans (27.7%). The lowest prevalence of excessive fluoride was, however, recorded in the Yala River water (0.14%), and in the Lake Victoria water samples (0.0%). A sample of tap water drawn at Dungodhako in South Uyoma Division in Rarieda Sub-County contained 2.92±0.32 ppm of fluoride, which was high compared to the fluoride levels of other piped water samples.

All underground water sources including: the boreholes, shallow wells, and the springs were saline, which was somewhat surprising given the close proximity of some of those saline water sources to the shores of Lake Victoria, which is a fresh water lake.

Spatial distribution of fluoride water by division

Table 3 reveals that the overall mean fluoride levels in water for the entire Bondo-Rarieda Area (0.85±0.67 ppm) were above the WHO recommended standards for drinking water (0.70 ppm). Therefore, all divisions except Maranda (0.69±0.42 ppm) had mean groundwater fluoride levels well above WHO recommended limits. Highest mean water fluoride content was in water sources from Uyoma Division (1.39±0.84 ppm) and Asembo Division (0.92±0.46 ppm) in Rarieda Sub-County, and from Nyang'oma Division (1.00±0.59 ppm) of Bondo Sub-County. These are regions that border the lake shores within mean distance of about 30 km. In addition, most household water sources (45.5%) from Uyoma had fluoride levels above the limit of 1.0 ppm, as were also some ten samples (or 28.6%) of groundwater sources from Asembo, and 33.3% and 30.0% of ground water sources in Nyang'oma and Usigu Divisions of Bondo Sub-County, respectively. Again, the area with lowest proportion of water sources with above 1.0 ppm fluoride levels was Maranda (15.6%)

Table 2 Level of fluoride (ppm) in water by type of source

Source	Borehole	Dams	Lake	Ponds	River Yala	Springs	Streams	Tap water	Overall
Mean [F] ppm	0.74±0.48	0.96±0.79	0.41±0.28	1.41±0.82	0.41±0.423	1.25±0.43	0.95±0.41	0.54±0.77	0.86±0.67
Highest	2.09	5.18	0.94	2.43	1.09	1.81	1.85	2.92	5.18
>3.0 ppm	-	1 (2.1%)	-	-	-	-	-	-	1 (0.8%)
1.5-2.9 ppm	1 (4.3%)	6 (12.8%)	-	3 (50.0%)	-	1 (16.7%)	2 (9.1%)	1 (9.1%)	14 (10.9%)
1.0-1.4 ppm	4 (17.4%)	6 (12.8%)	-	-	1 (20.0%)	3 (50.0%)	7 (31.8%)	-	21 (16.4%)
0.5-0.9 ppm	11 (47.8%)	26 (55.3%)	3 (37.3%)	2 (33.3%)	-	2 (33.3%)	9 (40.9%)	3 (27.3%)	56 (43.8%)
<0.4 ppm	7 (30.4%)	8 (17.0%)	5 (62.5%)	1 (16.7%)	4 (80.0%)	-	4 (18.2%)	7 (63.6%)	36 (28.1%)
Lowest	0.17	0.22	0.01	0.37	0.11	0.96	0.34	0.14	0.01
Sample size (*n*)	23	47	8	6	5	6	22	11	128

Table 3 Spatial distribution of fluoride in water sources by division

Division	Asembo	Uyoma	Maranda	Nyang'oma	Usigu	Overall
Mean [F]±SD	0.92±0.46	1.39±0.84	0.69±0.42	1.00±0.59	0.78±0.66	0.85±0.67
Highest	2.27	5.44	1.7	2.23	2.34	5.44
>3.0 ppm	-	01(9.1%)	-	-	-	1(0.8%)
1.5-2.9 ppm	3(8.6%)	2(18.2%)	2(4.5%)	2(33.3%)	5(16.7)	14(10.9%)
1.0-1.4 ppm	9(24.3%)	2(18.2%)	6(13.6%)	0(0.0%)	4(13.3%)	216(16.4%)
0.5-0.9 ppm	20(57.1%)	3(27.5%)	21(47.7%)	3(50.0%)	9(30.0%)	56(43.8%)
0-0.4 ppm	5(14.3%)	3(27.5%)	15(34.1%)	1(16.7%)	12(40.0%)	36(28.1%)
Lowest	0.17	0.01	0.02	0.2	0.11	0.01
% [F] > 1 ppm	28.6	45.5	18.2	33.3	30	28.1
Sample size (n)	37	11	44	6	30	128

in Bondo Sub-County. It was noted however that, the riparian areas of Usigu Division had modest fluoride content of 0.78 ± 0.66 in their ground water sources, which was unexpectedly low compared to similar shoreline areas of Nyang'oma, Uyoma and Asembo Divisions. Being the area at the mouth of Yala River where the river enters into the Lake Victoria, these moderate fluoride levels could be ascribed to the dilution of ground water sources in this area by the low-fluoride River Yala water through underground seepage.

In general, therefore, low altitude areas closest to the lake were the ones that had the highest mean fluoride levels in ground water sources and the fluoride content of groundwater sources decreased with increasing distance and increasing elevation from the lake. This trends showed that high water fluoride in this area could have been hydro-geologically translocated from external geochemical sources into the region through the underlying drainage rather than originating from direct solubilisation of fluoride-enriched parent rock in the area as is the case in other high-fluoride areas in the country [17,18].

Topographical variations

Spatial distribution of high fluoride water sources showed a strong topographical dependence. This relationship was therefore analyzed and the results presented in Figure 5. As expected, high fluoride water sources were clustered in "low-altitude" areas closest to the lake than in more elevated areas in the north of the study area. This showed that as ground water drains into the lower parts of the LVB, it loses momentum and most of its dissolved and suspended matter precipitate and deposit over soil colloids in this region due to a sudden decrease in the slope of the land within the sedimentary basin of the lake. The salt-laden soil colloids in this area have therefore become a natural reservoir of solutes such as fluorides, which solubilise and enrich underground water making it saline. The high ambient temperatures around the lake and the

prevailing south-westerly winds enhance evaporation from overland water sources and increases the salinity and fluoride concentration of the water. The continuous circulation of the lake water through underground and surface drainage channels do not, however, allow similar accumulation of salts and the lake water remains fresh as a result.

Public health risk assessment

In view of the risk that high-fluoride water pose to general public health, the impact of fluoride water on the resident communities in Bondo-Rarieda Area was analyzed and the results presented in Table 4. It was assumed that the overall percentage of the population at risk of toxic effects of excessive fluoride in water was the percentage of the population that depended on household water from water sources with above optimum fluoride concentrations. The overall percentage of people exposed to excessive fluoride through drinking water, $P_{(F)}$, was then calculated according to the expression:

$$P_{(F)} = \sum_{\substack{all\ water \\ types}} \left(P_{(i)} P_{(iF)} \right) \tag{2}$$

where, $P_{(i)}$ is the percentage of the population that depend on water from a particular type of water source i and $P_{(iF)}$ is the percentage of that particular type of water source i, which had greater than optimum fluoride content.

Fluorosis normally develops in children below the age of 8 years [18,23] when their skeletal tissues are still developing [24]. By applying Equation (2) to the data accrued from the present work and based on official demographic records [20], it was estimated that 36% of the children, who constantly consume water from ground water sources from this area, are exposed to excessive fluoride and they could therefore be at risk of dental fluorosis and other undesirable effects of exposure to excessive fluoride. The proportion of the children at the risk of
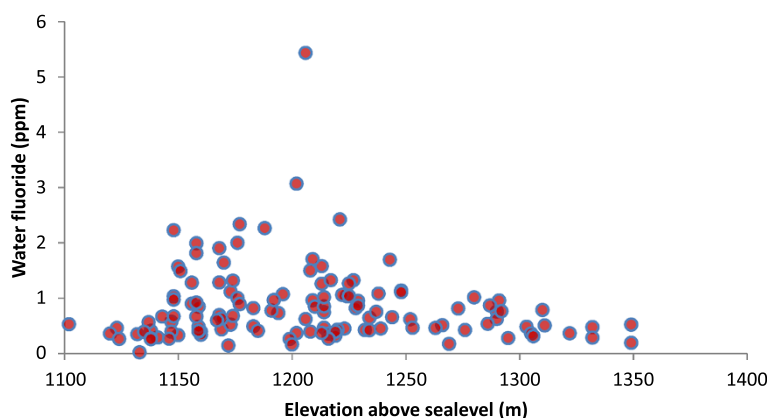
Figure 5 Variation in the level of water fluoride with altitude.

dental fluorosis and of manifestation of other signs of fluoride toxicity could however be higher among the riparian communities in the low-altitude areas of Asembo, Uyoma, Usigu and Nyang'oma Divisions, where excessive fluoride in water sources was most prevalent. Children among households that rely on the lake water and those in riparian areas of the Yala River, where insufficient levels of fluoride were recorded in household water sources could, on the other hand, be at the risk of heighten incidences of tooth decay.

Conclusions

In general, Lake Victoria (37.4%) was the overall most important source of household water for the residents of Bondo-Rarieda Area. Dams and open pans (39.5%), boreholes (23.5%) and streams (18.5%) were, however, the more significant sources of household water for residents in areas outside walking distance from the lake. The overall mean fluoride levels in water (0.86±0.67 ppm) were higher than WHO recommended levels of 0.70 ppm but spatial variations were characterized by high fluoride levels up to 5.18 ppm in 'low-altitude' areas close to the lake and very low fluoride levels with less than 0.4 ppm fluoride in

higher altitude areas in north. Pond, spring, dam, open pans and stream water had highest levels of fluoride (0.95-1.41 ppm) whereas River Yala and lake water had lowest levels of fluoride (≈0.41 ppm). The spatial distribution of fluoride in groundwater sources indicated hydrogeological translocation of soluble fluorides from high-fluoride areas outside the study area and its accumulation into the lower parts of LVB. It was estimated that 36% of children under the age of 10 years, who live within this area and constantly consume water from groundwater sources from the area could be at the risk of dental fluorosis. Higher proportions of prevalence of fluorosis were, however, expected among the riparian communities in low-lying areas of Uyoma, Asembo and Nyang'oma Divisions, where highest levels of fluoride were recorded in groundwater sources. In general, with respect to water fluoride distribution, the Yala River and the Lake Victoria were the safest sources of household water for the residents of the Bondo-Rarieda Area. The two natural sources are, however, far apart. The communities in middle regions depend on ground water sources, which were saline and fluoridated. Rain water, which could be an alternate source of safer drinking

Table 4 Determination of the proportion of the population that would be affected by above-optimum level of fluoride in household water in the Bondo-Rarieda Area, Siaya County, Kenya

Type of water source	Percentage of the population that use each water source type, $P_{(i)}$*	Percentage number of water sources with excessive fluoride, $P_{(iF)}$	Percentage of population that is exposed to excess F in water, $P_{(F)} = P_{(i)}P_{(iF)}$
Borehole & shallow wells	9.3	43.5	4.0
Dams, open pans and ponds	30.2	66.1	20.0
Lake	37.4	12.5	4.7
River Yala	0.0	20	0.0
Streams and Springs	8.7	74.6	6.5
Tap Water	8.6	9.2	0.8
Overall		27.3	$\sum P_{(i)}P_{(iF)} = 36.0$

*SOURCE: Kenya National Bureaou of Statistics: *Population Distribution by Political Units (vol. 1B)*. Nairobi, Kenya: Ministry of Planning; 2010:139–140.

water is inadequate because the rainfall in this area is sporadic and unreliable. Defluoridation of existing waters based on low-cost technologies, and constant monitoring of existing water sources is therefore recommended.

Competing interests

The authors declare that there are no competing interests.

Authors' contributions

EWW designed the study and carried out the field and laboratory procedures for the collection of water samples, estimation of fluoride content in water samples and performed the statistical analysis. He conceived, drafted and edited this manuscript. SGA participated in design of the study and laboratory procedures for the collection of the water samples and estimation of fluoride content in water samples. BA participated in design of the study. WA participated in design of the study and in editing of the initial manuscript. TA participated in design of the study and in design of laboratory procedures for sample analysis. All the authors read and approved the final manuscript.

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References

1. Dean HT, Elvove E: **Some epidemiological aspects of chronic endemic dental fluorosis.** *Am J Public Health Nations Health* 1936, **26**:567–75.
2. Mahvi AH, Heibati B, Mesdaghinia A, Yari AR: **Fluoride adsorption by pumice from aqueous solutions.** *E-Journal Chem* 2012, **9**:1843–1853.
3. Xu YH, Ohki A, Maeda S: **Removal of arsenate, phosphate, and fluoride ions by aluminium-loaded shirasu-zeolite.** *Toxicol Environ Chem* 2000, **76**:111–124.
4. Wambu EW, Onindo CO, Ambusso W, Muthakia GK: **Removal of fluoride from aqueous solutions by adsorption using a siliceous mineral of a Kenyan origin.** *CLEAN - Soil, Air, Water* 2013, **41**:340–348.
5. Adelana SM, Bi E, Hycinth SF, Cletus SB, Woincham LN, Uehara Y, Zhang J, Fantong WY, Satake H, Ayonghe SN, Suh EC, Fantong EBS, Banseka HS, Gwanfogbe CD, Uehara Y, Zhang J: **Geochemical provenance and spatial distribution of fluoride in groundwater of Mayo Tsanaga River Basin, Far North Region, Cameroon: implications for incidence of fluorosis and optimal consumption dose.** *Environ Geochem Health* 2010, **32**:147–63.
6. Ayoob S, Gupta K: **Fluoride in drinking water: a review on the status and stress effects.** *Crit Rev Environ Sci Technol* 2006, **36**:433–487.
7. Sushela AK, Kumar A, Bhatnagar M, Bahadur R: **Prevalence of endemic fluorosis with gastrointerstinal manifestations in people living in some North-Indian Villages.** *Fluoride* 1993, **26**:97–104.
8. Mascarenhas AK: **Risk factors for dental fluorosis: a review of the recent literature.** *Am Acad Pediatr Dent 269* 2000, **22**:269–277.
9. Teutli-Sequeira A, Solache-Ríos M, Balderas-Hernández P: **Modification effects of hematite with aluminum hydroxide on the removal of fluoride ions from water.** *Water Air Soil Pollut* 2011, **223**:319–327.
10. *Private well water and fluoride.* http://www.cdc.gov/fluoridation/fags/ wellwater.htm.
11. Burt BA: **The changing patterns of systemic fluoride intake.** *J Dent Res* 1992, **71**:1228–1237.
12. United Nations: *The millennium development goals report.* New York, United Nations; 2008:1–56.
13. Wambu EW, Muthakia GK: **High fluoride water in the Gilgil area of Nakuru County, Kenya.** *Fluoride* 2011, **44**:37–41.
14. Muhweezi AB, Sikoyo GM, Chemonges M: **Introducing a transboundary ecosystem management approach in the Mount Elgon Region.** *Mt Res Dev* 2007, **27**:215–219.
15. East African Community Lake Victoria Basin Commission: *A project to prepare investment plans for 15 secondary urban centres under the Lake Victoria Basin water and sanitation initiative in Kenya, Tanzania, Uganda, Burundi and Rwanda.* Arusha: East African Community Lake Victoria Basin Commission; 2008:1–23.
16. Nagl S, Tichy H, Mayer WE, Takazaki N, Takahat N, Klein J: **The origin and age of haplochromine fishes in Lake Victoria, East Africa.** *Proc Biol Sci* 2000, **267**:1047–1061.
17. Gikunju JK, Mbaria JM, Murcithi W, Kyule MN, Maitho TE: **Water fluoride in the Molo division of Nakuru district, Kenya.** *Fluoride* 1995, **28**:17–20.
18. Moturi WWK: **Household water sources and their contribution towards fluoride consumption in Njoro Division, Nakuru household water sources and their contribution towards fluoride.** *African J Aquat Sci* 2010, **29**:275–277.
19. Nyaoro W: **Choice and use of rural water supply systems: the environmental and socio-cultural dimensions.** In *Local Environ Chang Soc Africa.* 2nd edition. Edited by Salih MAM. London: Kluwer Academic Publishers; 2001:41–68.
20. Kenya National Bureaou of Statistics (KNBS): *Population distribution by political units (vol. 1B).* Nairobi, Kenya: Ministry of Planning; 2010:139–140.
21. Bartlett JE, Kotrlik JW, Higgins CC: **Organizational research: determining appropriate sample size in survey research.** *Inf Technol Learn Perform J* 2001, **19**:43–50.
22. Chilton J, Dahi E, Lennon M, Jackson P, Fawell J, Bailey K, Fewtrell L, Magara Y: *Fluoride in drinking-water.* London: IWA Publishing; 2006:83–93.
23. Smith MC, Lantz EM, Smith HV: **The cause of mottled enamel, a defect of human teeth.** *Tech Bull Univ Arizina Coll Agric Agric Exp Stn* 1931, **32**:253–282.
24. Kahama RW, Kariuki DN, Kariuki HN, Njenga LW: **Fluorosis in children and sources of fluoride around Lake Elementaita Region of Kenya.** *Fluoride* 1997, **30**:19–25.