

**Review Article**

# Fluoride Levels in Surface and Groundwater in Africa: A Review

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**Abstract:** Fluoride has been reported to be among natural pollutant of water in Africa. High fluoride levels beyond the recommended World Health Organization limit of 1.5 mg/l has been observed in various Africa countries. However, the information is scattered in different publication medium. Therefore, objective of this work was to put together the information on fluoride levels in surface and groundwater in Africa, and describe the status and distribution of fluoride in water among African countries. This study assembled the secondary data of fluoride concentrations in surface and groundwater from the various literatures in African countries. Such countries represent southern, northern, eastern and western Africa. Descriptive statistics was used and results showed that elevated fluoride concentration occurred in countries such as Tanzania, Kenya, Algeria, Nigeria, Ghana, Malawi, Sudan, Uganda, the Republic of South Africa and Ethiopia. The highest fluoride concentration reported was 2,800 mg/l in Lake Nakuru in Kenya. The high fluoride concentrations in water can be linked to volcanic activities, presence of thermal waters especially those with high pH, gases emitted from earth's crust, granitic and gneissic rocks. The high fluoride in water is severe in countries located in East African Rift Valley like Kenya, Tanzania and Ethiopia. However, all the incidences of highest fluoride levels in water in the Rift Valley countries were found in surface water bodies. This is contrary, as it is expected groundwater to be more concentrated as compared to surface water due to more water rock interaction than in surface water bodies. There was no single study among many studies has reported the long term trend of concentration of fluoride in water with time. Thus, the effort to establish long term trend of fluoride concentration in water should be taken in consideration. This helps to predict future concentration of fluoride and possibility to minimize future risks. Also, fluorosis has also been reported to be endemic in fluoritic areas of Africa though, little is known on other fluoride negative effects. Therefore, more efforts should concentrate on finding appropriate defluoridation techniques to be applied while considering the cost of operation, efficiency, practicability, easy application and environmental friendly.

**Keywords:** Fluoride, Distribution, Surface Water, Groundwater, Africa

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## 1. Introduction

Fluorine is the most electronegative element and has the high reactivity, therefore, it does not occur in elemental form rather it occurs in ionic form [1-3]. In aquatic environments with pH less than 5, it has the tendency of forming complexes with metal ions, while at higher pH values it tends to exist as a single fluoride ion (F<sup>-</sup>) [2].

Although, the World Health Organization (WHO) has set the fluoride guideline limit of 1.5 mg/l in drinking water [4],

over 260 million people globally consume drinking water with high fluoride concentration above the WHO standard [1]. Six countries in continental America, eight in Asia and the Middle East, and fourteen in Africa consume water with fluoride concentration greater than 1.5 mg/l in drinking water [1]. Majority of population in these countries are faced with the problems of dental and osteofluorosis [5].

Fluoride has been reported to be among natural pollutant of water in Africa particularly in those countries traversed by the great East African Rift valley [5-44]

High fluoride levels beyond the recommended World Health Organization limit of 1.5 mg/l has been observed in various Africa countries [1, 2, 41]. However, the information is scattered in different publication medium. Therefore, the main objective of this work was to put together the information on fluoride levels in surface and groundwater in Africa, and describe the status and distribution of fluoride in water among African countries. Although, not all countries that are reported to have fluoride concentration above maximum permitted standard by WHO have been discussed in this article, the representative countries from each region namely southern, northern, eastern and western region have been discussed.

## 2. Sources of Fluoride in Surface and Groundwater in Africa

Occurrence of fluoride in African waters has been associated with volcanic activities, presence of thermal waters especially those with high pH, gases emitted from earth's crust, granitic and gneissic rocks [2, 31, 41, 45]. The occurrence of fluoride in water has also been considered to result from water rock interaction through weathering of fluoride rich rocks and circulation processes of water in soils and rocks [1, 2, 46]. As a result, fluoride is leached out and dissolves in groundwater and thermal gases [2, 33, 47].

Some of the important rocks bearing fluoride minerals include volcanic, gneissic and granitic rocks [45]. Fluoride tends to occur in areas where fluoride bearing minerals such as fluor spar ( $\text{CaF}_2$ ), cryolite ( $\text{Na}_3\text{AlF}_6$ ), apatite ( $\text{Ca}_5(\text{PO}_4)_3\text{F}$ ) and hornblende [ $(\text{Ca}, \text{Na})_2(\text{Mg}, \text{F}, \text{Al})_5(\text{Si}, \text{Al})_8\text{O}_{22}(\text{OH})_2$ ] are most abundant [2, 41].

### 2.1. Igneous Rocks

The fluoride concentration in both extrusive and intrusive igneous rocks has been reported to be as high as 100 ppm in ultramafic, and greater than 1000 ppm in alkali rocks [1, 31]. High fluoride concentration in ultramafic and mafic rocks is a result of fractionation process during crystallization and differentiation processes of the magma [1, 48]. Furthermore, fluoride that is not incorporated in crystalline phase during crystallization and differentiation during magmatic processes is concentrated in hydrothermal solutions [2]. Therefore, groundwaters interacting with crystalline rocks, especially (alkaline) granites (deficient in calcium) and hydrothermal solutions are likely to have relatively high fluoride concentrations [2].

### 2.2. Sedimentary Rocks

Although, fluorine is reported to be the most abundant halogen in the sedimentary rocks, it is generally low except in areas with specific mineralization [49, 50]. High fluoride concentrations have been observed in groundwaters especially in arid and semi-arid sedimentary aquifers [50]. As high as 200 ppm of fluorine have been reported in limestone formations and about 1000 ppm have been reported in shale

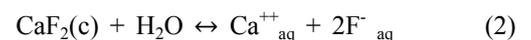
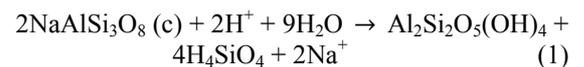
deposits [1]. The main fluoride bearing minerals in these rocks are fluorite that accounts for 48.7%, apatite which accounts for 3.5%, mica which accounts for 0.14 to 0.22%, illite which accounts for 0.11 to 0.26% and montmorillonite which accounts for 0.03% [49]. Similarly, high fluorine concentrations can also be observed in sedimentary phosphate beds (shark teeth) [1], bentonite and volcanoclastic deposits [49]. Bentonite was reported to have average fluorine of 1000 ppm and volcanoclastics an average fluorine of 5950 ppm [51, 52]. Furthermore, fluoride is said to be abundant in sediment originating from marine as compared to those of non-marine origin [50].

### 2.3. Metamorphic Rocks

Fluoride has been reported in metamorphic rocks in relative high concentration [31]. The original minerals are enriched with fluorine by metasomatic processes [1]. Fluorine ranges between 100 ppm (regional metamorphism) and greater than 5000 ppm (contact metamorphism) in metamorphic rocks. The highest fluoride level between 30 and 21000 ppm have been reported in amphiboles found in metamorphic rocks [53].

## 3. Fluoride Release Mechanism in Water

The mechanism of fluoride release in water begins with rainfall enrichment with  $\text{CO}_2$  from air as it falls. On the land rain water gets enriched in  $\text{CO}_2$  from soil air, it is further enriched by  $\text{CO}_2$  from bacterial action and oxidation of organic matter as it percolates [54]. The dissolution of  $\text{CO}_2$  tends to enhance the hydrogen ion concentration in groundwater [1, 54]. These hydrogen ions strongly influence weathering of silicate and the accessory minerals found. The solutions of dissolved silicates or accessory minerals result in cations release as it is shown in the equations below [1, 54].

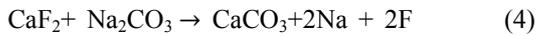
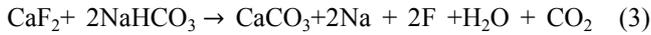


During weathering and circulation processes of water in soils and rocks, fluorine can be reached out and dissolve in groundwater. However, this will depend on type of rock that has come into contact with groundwater [56]. Additionally, fluoride release in water depends on dissolution activity of fluoride minerals rather than fluoride-bearing minerals present in rock. The factors such as adsorption, desorption, dissolution, residence time, water rock interaction and precipitation reactions play significant role in fluoride release and capture [47, 56].

It is reported that fluoride minerals such as fluorite and cryolite are sparingly soluble in water under normal pressure and temperature conditions [56, 57].

Under physical-chemical conditions such as acidic condition (low pH) fluoride adsorbs on clay whereas at basic (high pH) conditions it desorbs and become available to water [56, 57]. Also, the excess groundwater aqueous ionic concentration such as sodium bicarbonates or sodium

carbonates increase the dissociation activity of fluoride and precipitates  $\text{CaCO}_3$  as it is shown on the equation below [58, 59].

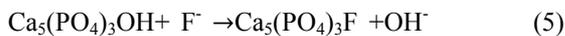


It can be noted that, long residence time of water in rocks favours more contact time and exposure. Thus, if the rock has dissolvable fluoride bearing minerals and favourable conditions are available fluoride can easily be released into water [2, 57, 60]. Furthermore, the fluorine in mica is leached out rapidly whereas that from apatite is very stable [47]. Also, fluorite ( $\text{CaF}_2$ ) dissolves slowly by the circulating water.

The fluoride content of surface water also varies greatly depending on the fluoride content of groundwater feeding a given stream [61]. However, in lakes it varies with the chemical class of lake and the Na-rich lakes have shown to be rich in fluoride [47]. Therefore, apart from fluoride release discussed above, the detail of fluoride released for long time in different rock types need to be investigated.

#### 4. Health Effects of Fluoride

The advantages of ingesting fluoride to human health are limited to fluoride levels of about 1.0 mg/l in potable water. Water with such levels of fluoride is said to improve skeletal and dental health [2, 12, 26, 62-66]. The science behind the beneficial effects of fluoride on the skeletal structure is based on the ion exchange reactions between hydroxide and fluoride ions in the calcium hydroxy-phosphate as it is indicated in the equation below [41]



From the equation 5 above, acid resistant structure, fluoroapatite is formed due to replacement of hydroxide with fluoride ions [41]. Fluoroapatite prevents dental caries since it is more resistant to acid attack compared to hydroxyapatite [26, 41].

Drinking water with high fluoride levels above 1.5 mg/l results to negative health impacts [2, 64, 67]. For example, fluoride in water between 1.5 and 3.0 mg/l is likely to cause mottling and browning of teeth which is referred to as dental fluorosis [68], this makes the teeth brittle and very hard [41, 65]. Similarly, the science behind the negative effects of fluoride on the skeletal structure is based on the ion exchange reactions whereby reaction goes beyond replacement of hydroxide during excess fluoride intake as it is shown in the equation below:



From equation 6 above, ion exchange takes place between fluoride and phosphate ions which results to very hard and brittle material (Calcium decafluoride). This compound is not suitable for the skeletal structure [41, 69].

The levels of fluoride between 4 to 8 mg/l are likely to

result in skeletal fluorosis whereas crippling fluorosis occurs when fluoride levels greater than 10 mg/l are consumed for an extended period of time [2, 32, 34, 41, 65]. Skeletal fluorosis is a condition that results to bone malformation that brings about movement difficulties while crippling fluorosis is characterized by weakening of the bone junctions and bones causing immobility [41, 65, 68]. Other health effects caused by elevated fluoride levels include low haemoglobin levels, muscle fibre degeneration, excessive thirst, red blood cell deformities, skin rashes, headache, gastrointestinal problems, depression, nausea, urinary tract malfunction, tingling sensation in fingers and toes, abdominal pains, reduced immunity and neurological manifestations [41, 68, 70]. It also alters the functional mechanisms of kidney, liver, respiratory system, digestive system, central nervous system, reproductive system and excretory system [71]. However, much attention has been given to dental and skeletal fluorosis as compared to the other fluoride negative impacts that are likely to occur in fluoridated areas.

#### 5. Distribution of Fluoride in Africa

In Africa, high fluoride levels have been reported mostly in the Great East African Rift Valley which extends from Jordan valley down through Sudan, Ethiopia, Uganda, Kenya and Tanzania [31] (Fig. 1). Ghana, Malawi, Nigeria, Algeria and the Republic of South Africa have also been reported to have high fluoride levels [41] (Fig. 1).

Similarly, the highest fluoride levels in Africa were reported in Kenya, Tanzania, and Ethiopia (Fig. 1) [10, 22, 31, 41]. The distribution of fluoride in surface and groundwater by country is discussed below.

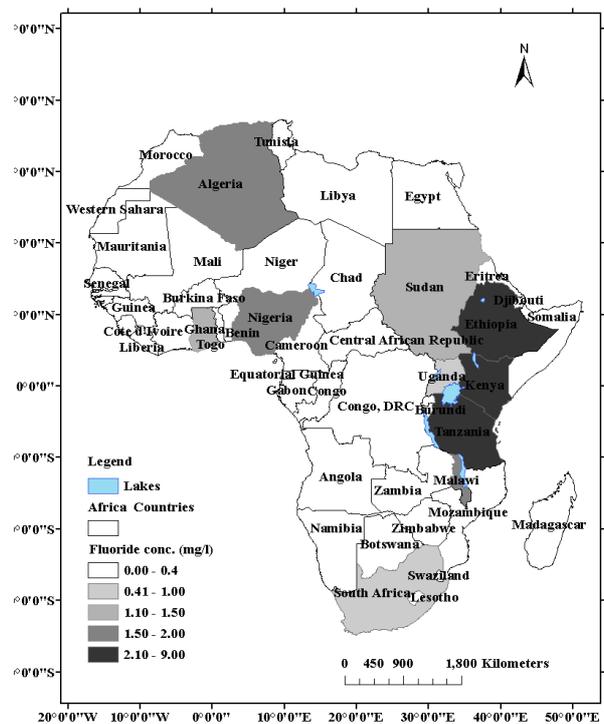


Figure 1. Map of Africa showing countries with high fluoride in water.

### 5.1. Fluoride in Tanzania

High fluoride levels have been reported in surface and groundwater in Tanzania. The problem of fluoride in the country was reported from 1950 [26]. Initially 8 mg/l fluoride concentration was adopted as a temporary standard for rural water supplies in the country [72]. Since, adopting the WHO standard of 1.5 mg/l could result in abandoning of about 30% of water sources that had been used [9]. Currently, 4 mg/l fluoride concentration has been adopted as a standard for drinking water due to lack of reliable defluoridation technology and expenses involved. However, this is still high and it has potential to cause fluorosis.

During this study about 595 fluoride concentrations data points have been collected from the various literatures in some parts of Tanzania. The data showed that the mean fluoride concentration was  $4.02 \pm 29.86$  mg/l and median of 0.80 mg/l (Table 1). This mean fluoride concentration was above both WHO (1.5 mg/l) and Tanzanian standard (4 mg/l). The highest level of fluoride was 690 mg/l that was reported in Lake Momella [31]. Therefore, based on the above information, it has been observed that significant number of water sources

exceed both international and national fluoride standard. Therefore, serious intervention should be considered to minimize negatives effects of high fluorides such as dental, skeletal and crippling fluorosis.

#### *Fluoride Distribution in Various Water Sources*

Fluoride has been reported to vary with water sources in some of the selected regions in Tanzania. The boreholes have been found to have mean fluoride concentration of  $3.07 \pm 8.31$  mg/l with median of 0.98 (Table 1). Although, the mean fluoride concentration in borehole was found to be below the Tanzanian standard (4 mg/l), it is above the WHO standard (1.5 mg/l) and is likely to cause fluorosis. The minimum and maximum values were 0 and 111, respectively (Table 1). The maximum fluoride concentration was found in Singida region and the minimum was found in Tanga region.

Fluoride levels in various reported springs showed some variation with the mean concentration of  $6.72 \pm 16.47$  mg/l with median of 1 mg/l (Table 1). The maximum concentration (99 mg/l) was found in Manyara whereas the minimum was (0 mg/l) in Tanga region (Table 1).

**Table 1.** Fluoride concentration by country and by water sources in some African countries (Data Source: [1, 8, 24, 33, 34, 38, 40, 43, 73-97]).

Fluoride Concentration (mg/l) by Country in Africa												
Country	N	n=F>1.5	n=%F>1.5	n=F>4	n=%F>4	Min.	Max.	Mean $\pm$ SD	Median	25 <sup>th</sup> Perc.	75 <sup>th</sup> Perc.	
Uganda	62	4	6.45	0	0	0	3.31	0.44 $\pm$ 0.66	0.22	0.07	0.46	
South Africa	311	30	9.65	15	4.82	0.1	8.2	0.64 $\pm$ 1.18	0.24	0.16	0.44	
Ghana	338	95	28.11	8	2.37	0.01	5.8	1.14 $\pm$ 1.12	0.63	0.37	1.7	
Sudan	27	5	18.52	2	7.41	0.2	7	1.37 $\pm$ 1.56	1	0.7	1.4	
Algeria	48	25	52.08	0	0	0.38	2.61	1.47 $\pm$ 0.5	1.58	1.25	1.85	
Nigeria	93	42	45.16	1	1.08	0.03	4.4	1.78 $\pm$ 1.26	1.48	0.73	2.9	
Malawi	189	53	28.04	34	17.99	0.06	10.3	2.02 $\pm$ 2.32	1.06	0.66	1.91	
Tanzania	593	179	30.19	76	12.82	0	140	2.87 $\pm$ 9.92	0.8	0.27	1.97	
Kenya	92	47	51.09	24	26.09	0.1	68	4.14 $\pm$ 8.63	1.6	0.81	4.2	
Ethiopia	182	116	63.74	75	41.21	0.1	175	8.88 $\pm$ 19.21	2.6	1.2	9.33	
Fluoride Concentration (mg/l) by water sources in Africa.												
Ethiopia												
Boreholes	41	22	53.66	12	29.27	0.1	75	5.87 $\pm$ 12.87	1.9	1	4.5	
Wells	17	5	29.41	0	0	0.72	2.2	1.39 $\pm$ 0.41	1.3	1.15	1.55	
Dug wells	18	6	33.33	2	11.11	0.1	9.5	1.77 $\pm$ 2.13	1.25	0.83	1.75	
Thermal wells	9	8	88.89	8	88.89	0.6	67	33.91 $\pm$ 18.84	27.8	26	45	
Cold springs	25	17	68	7	28	0.1	51	6.76 $\pm$ 11.73	2.1	1	4.5	
River	9	6	66.67	3	33.33	0.7	39	10.34 $\pm$ 15.76	2.5	1.5	6	
Hot springs	9	5	55.56	1	11.11	0.1	22.7	3.68 $\pm$ 7.18	1.7	0.6	1.9	
Springs	4	0	0	0	0	0.14	0.25	0.19 $\pm$ 0.06	0.19	0.14	0.24	
Lakes	5	4	80	4	80	1.3	250	113.86 $\pm$ 106.51	130	13	175	
Uganda												
Surface water	20	2	10	0	0	0	2	0.45 $\pm$ 0.56	0.25	0.19	0.42	
Groundwater	24	2	8.33	0	0	0.17	3.31	0.74 $\pm$ 0.82	0.41	0.31	0.94	
South Africa												
Boreholes	83	20	24.1	14	16.87	0.1	8.2	1.27 $\pm$ 1.97	0.27	0.13	1.11	
Dam	6	0	0	0	0	0.2	0.37	0.31 $\pm$ 0.07	0.32	0.27	0.36	
Surface water	50	0	0	0	0	0.1	0.53	0.25 $\pm$ 0.10	0.23	0.18	0.33	
Tape water	82	0	0	0	0	0.1	0.71	0.29 $\pm$ 0.17	0.22	0.16	0.42	
Ghana												
Boreholes	252	76	30.16	6	2.38	0.01	5.8	1.19 $\pm$ 1.16	0.63	0.37	1.73	
Wells	65	12	18.46	1	1.54	0.05	4.37	0.90 $\pm$ 0.86	0.5	0.37	1.2	
Nigeria												
Groundwater	70	21	30	0	0	0.03	3.95	1.44 $\pm$ 1.19	0.92	0.64	2.34	
Surface water	23	21	91.3	1	4.35	0.52	4.4	2.78 $\pm$ 0.88	2.88	2.37	3.41	
Well	24	0	0	0	0	0.1	0.96	0.24	0.7	0.5	0.87	
Borehole	24	2	8.33	0	0	0.03	2.5	0.94 $\pm$ 0.67	0.8	0.46	1.35	
Tanzania												

Fluoride Concentration (mg/l) by Country in Africa												
Country	N	n=F>1.5	n=%F>1.5	n=F>4	n=%F>4	Min.	Max.	Mean ± SD	Median	25 <sup>th</sup> Perc.	75 <sup>th</sup> Perc.	
All water source	595	180	30.25	77	12.94	0	690	4.02 ± 29.86	0.8	0.28	1.98	
Boreholes	235	95	40.43	40	17.02	0	111	3.07 ± 8.31	0.98	0.37	3	
Springs	60	25	41.67	15	25	0	99	6.72 ± 16.47	1	0.62	4.25	
Lakes	24	7	29.17	4	16.67	0	63	32.67 ± 140.59	0.81	0.24	2.18	
Surface	72	9	12.5	2	2.78	0	26	1.05 ± 3.65	0.28	0.05	0.54	
Wells	204	41	20.1	16	7.84	0	140	2.01 ± 9.97	0.75	0.3	1.34	

Note:

n=F>1.5: Number of Samples with fluoride concentration greater than 1.5 mg/l

n=%F>1.5: Percentage of samples with fluoride concentration greater than 1.5 mg/l

n=F>4: Number of Samples with fluoride concentration greater than 4 mg/l

n=%F>4: Percentage of samples with fluoride greater than 4 mg/l

These data exclude extremely high fluoride lakes such as Lake Elementaita and Lake Nakuru in Kenya, Lake Momella in Tanzania, Lake Kikorongo in Uganda and Lake Chitu in Ethiopia

The fluoride concentration in wells has showed to be low. The mean concentration of fluoride was  $2.01 \pm 9.97$  mg/l with median of 0.75 mg/l. The minimum concentration was 0 mg/l and the maximum was 140.00 mg/l. Although the mean concentration was found to be low as compared to Tanzanian Standard of 4 mg/l, it is still above the WHO standard of 1.5 mg/l (Table 1). Therefore, it has the potential to cause fluorosis.

Surface water (rivers and streams) has showed the lowest fluoride concentration among all water sources sampled. The mean fluoride concentration in surface water was found to be  $1.05 \pm 3.65$  mg/l with the median of 0.28 mg/l (Table 1). The minimum concentration was 0 mg/l and the maximum was 26 mg/l at Ngarenanyuki River.

The lakes, dams and ponds have shown wide variations in fluoride concentration. The mean fluoride concentration was found to be  $32.67 \pm 140.59$  mg/l and median 0.81 mg/l (Table 1). The minimum was found to be 0 mg/l and the maximum was 690 mg/l. The lakes, dams and ponds which showed high fluoride concentration include lake Momella (690 mg/l), Kitefu pond (63 mg/l), lake Manga (8.65 mg/l), Lake Singidan (4.46 mg/l), lake Duluti (2.36 mg/l), Lake Kindai (2.61 mg/l) and Nyumba ya Mungu dam (1.79 mg/l).

*Fluoride Distribution in Tanzania by Regions*

Like some other rift valley countries, Tanzania is affected by fluoride in water. Some of the surface and groundwater were found to have high fluoride concentration. This fluoride distribution is not uniform throughout the country as there are some of the regions affected much than others. The most affected regions include Arusha, Kilimanjaro, Mara, Manyara, Mwanza, Shinyanga and Singida [16, 26, 32, 41] (Fig. 2). Moderately affected by fluoride regions are Dodoma, Kigoma, Tanga and Tabora [26] (Fig. 2).

The general trend showed that Arusha region had the highest concentration of fluoride in water with an average fluoride concentration of  $13.57 \pm 64.16$  mg/l and the median of 3.38 mg/l (Table 2). Also, Manyara was found to be the second region with the higher fluoride concentration in water with average concentration of  $7.98 \pm 5.73$  mg/l and the median of 11.80 mg/l (Table 2). The next region with high fluoride concentration in water was Kilimanjaro that had average fluoride of  $7.44 \pm 13.26$  mg/l and the median of 0.56 mg/l (Table 2). All these average concentrations have been found to

exceed both Tanzanian (4mg/l) and WHO (1.5mg/l) standard fluoride concentration in water. In contrast, Dar es Salaam region was found to have the lowest fluoride concentration in water having mean concentration of  $0.12 \pm 0.11$  mg/l and median of 0.08 mg/l (Table 2).

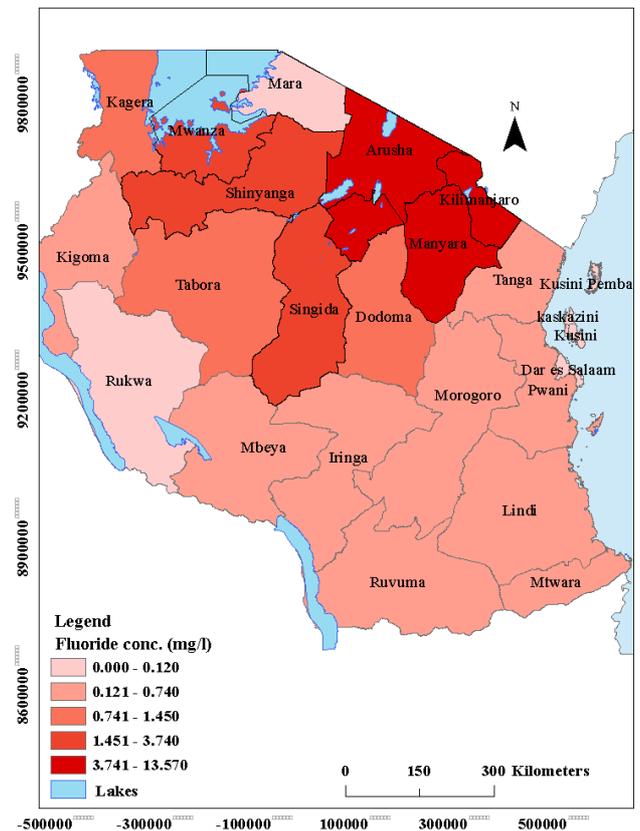


Figure 2. A map of Tanzania showing fluoride distribution by regions, Data Source: [16, 26, 32, 41].

Furthermore, Arusha was found to be the region with largest number of water samples exceeding the current Tanzanian fluoride Standard (4 mg/l). It was observed that 57 (46.72%) samples out of 122 samples collected in Arusha region exceeded the Tanzania standard (Table 2). The second was Singida region with 12 (15%) samples out of 80 samples collected in Singida region exceeded the Tanzania standard (Table 2). Dar es Salaam had all water samples within

Tanzania acceptable fluoride standard followed by Tanga region which had only 3 (0.84%) samples out of 356 samples that exceed Tanzanian standard (Table 2). Therefore, Dar es

Salaam and Tanga are among the low fluoride regions known in Tanzania.

**Table 2.** Fluoride concentration in some selected water sources in some Tanzanian regions, Data source: [24, 73, 74, 96, 97].

Region	N	Min	Max	Mean	SD	Median	25 <sup>th</sup> Perc.	75 <sup>th</sup> Perc.
All data	595	0	690.00	4.02	29.86	0.80	0.28	1.98
Arusha	122	0.39	690.00	13.57	64.16	3.38	1.48	7.10
Dar es Salaam	9	0	0.38	0.12	0.11	0.08	0.06	0.15
Kilimanjaro	19	0.15	36.00	7.44	13.26	0.56	0.27	2.41
Manyara	9	0.39	12.60	7.98	5.73	11.80	0.56	12.30
Singida	80	0.16	111.00	3.74	12.43	1.44	0.80	3.20
Tanga	356	0	8.65	0.63	0.84	0.38	0.15	0.90

## 5.2. Fluoride Distribution in Kenya

With regard to this study, about 92 fluoride concentrations data points have been collected from various literatures in Kenya. The data showed that the mean fluoride concentration was  $4.14 \pm 8.63$  mg/l and median of 1.6 mg/l (Table 1). The maximum fluoride value was 68 mg/l and the minimum value was 0.1 mg/l (Table 1). Although, such high fluoride concentration was found in this study, the highest fluoride level was reported by [10]. They observed as high fluoride as 1,640 mg/l and 2,800 mg/l in lakes Elementaita and Nakuru, respectively. Furthermore, they found that over 1,000 groundwater samples collected over the whole country, 61% exceeded 1 mg/l, about 20% exceeded 5 mg/l and 12% exceeded 8 mg/l. Also, [13] reported high fluoride in lakes such as Naivasha (2.4 mg/l), Magadi (84 mg/l), Nakuru (344 mg/l), Elementaita (463 mg/l), Bogoria (738 mg/l), and Baringo (5.4 mg/l).

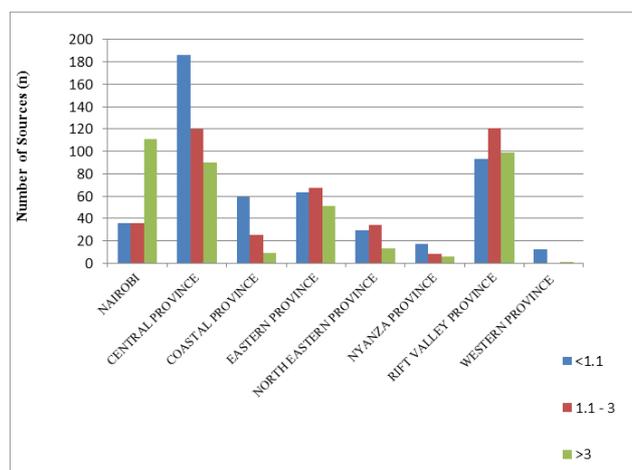
### Fluoride Distribution by Province in Kenya

The distribution of fluoride was considered based on the provinces. Three groups were identified, namely, those sources whose fluoride concentration was above 3 mg/l, sources whose fluoride concentration ranged between 1.1 to 3 mg/l and those whose fluoride concentration was below 1.1 mg/l (Fig. 3). It was observed that Nairobi province had the highest number of the water sources ( $n = 111$ ) with fluoride level greater than 3 mg/l (Fig. 3). It was followed by Rift Valley Province ( $n = 99$ ) and Central province ( $n = 90$ ) (Fig. 3). Similar information was reported by [41]. He found that the highest levels of fluoride in groundwater were found in the volcanic areas of the Rift Valley, Nairobi and Central Provinces in which maximum groundwater fluoride levels ranged between 30–50 mg/l. Lowest number of water sources with fluoride greater than 3mg/l was found in Nyanza ( $n=6$ ) and western ( $n=1$ ) provinces (Fig. 3).

Similarly, Central province was identified as the province with the highest number of water sources that had fluoride below 1.1 mg/l ( $n= 186$ ) it was followed by Rift Valley Province ( $n=93$ ) (Fig. 3). Lowest number of water sources with fluoride less than 1.1 mg/l was found in West province ( $n=12$ ) (Fig. 3). In Nairobi province the lower number of samples that had fluoride concentration below 1.1 mg/l ( $n=36$ ) as compared to those with fluoride above 3 mg/l ( $n= 111$ ) reflect water quality problems in that area (Fig. 3). This is true

since few sources ( $n=36$ ) had fluoride below standard ( $<1.1$  mg/l) and many ( $n=111$ ) above the standard ( $>3$  mg/l) (Fig. 3).

In terms of water quality specifically fluoride, central province was identified as the province with good quality of water. About 186 sources had fluoride below 1.1 mg/l despite of presence of about 90 sources with fluoride concentration above 3 mg/l (Fig. 3). With exception of Nairobi and Rift valley provinces, the rest of the provinces had greater number of sources that had fluoride concentration below 1.1mg/l than that which had above 3 mg/l (Fig.3). However, there was no sufficient information for western province to draw the conclusion. It indicates that the rest of the provinces had wide range of water sources that had low fluoride than those with high fluoride reflecting good quality water availability (low fluoride). Therefore, the issue of water quantity to sources with low fluoride concentration needs to be investigated in order to have reliable water sources.



**Figure 3.** Fluoride distribution in Provinces in Kenya, Data source: [10, 41].

## 5.3. Fluoride in Uganda

In Uganda, fluoride is one of the most serious inorganic contaminants of health concerned [98]. Uganda has adopted the WHO guideline value of 1.5 mg/l as it fluoride standard in drinking water. However, some water sources exceed such standard value [98]. The information from different literatures showed that the incidences of high fluoride above the standard value exist in both surface and groundwater [98]. Based on literature review it was found that mean fluoride concentration

in Uganda was as low as  $0.44 \pm 0.66$  mg/l with median of 0.22 mg/l (Table 1). The maximum fluoride value was reported to be 3.31 mg/l. This value is high as compared to the standard value for drinking water in Uganda 1.5 mg/l. Furthermore, it has been found that 6.45% of water sources exceeded the standard value for drinking water in Uganda (Table 1). The areas that have been affected much include the volcanic areas of the Elgon, Mbale, Moroto and in the Rift Valley of Western Uganda [98] (Fig. 4).

*Fluoride Distribution by Water Sources in Uganda*

When fluoride distribution in water was considered based on water sources, it was found that groundwater had high concentration as compared to other water sources. The mean fluoride concentration in groundwater was  $0.79 \pm 0.85$  mg/l with median of 0.45 mg/l (Table 1). Although, this concentration was higher as compared to other water sources, it was low as compared to Uganda guideline value (1.5 mg/l). High fluoride in groundwater may be linked to long residence time. Generally, surface water showed low fluoride concentration (mean  $0.52 \pm 0.68$  mg/l) (Table 1), in contrast as high as 4.5 mg/l was reported in some of crater lakes such as Lake Kikorongo in Western Uganda [14].



Figure 4. A map showing fluoride distribution in Uganda.

**5.4. Fluoride in South Africa**

The issue of fluorides, fluorosis and fluoridation in South Africa has been given attention since 1935 [19]. The country's Water Quality Guidelines adopted 4 mg/l as the maximum permissible standard in portable water, whereas the Committee for Scientific Industrial Research (CSIR) and

Bureau of Standards recommended 1.5 mg/l as a standard [19]. Essentially, high fluoride levels above WHO standard of 1.5 mg/l in South Africa have been reported in several areas including the North Western, Western and Central Free State, Limpopo, North-West and Kwa-Zulu-Natal Provinces and Northern Cape [19, 30, 41] (Fig. 5).

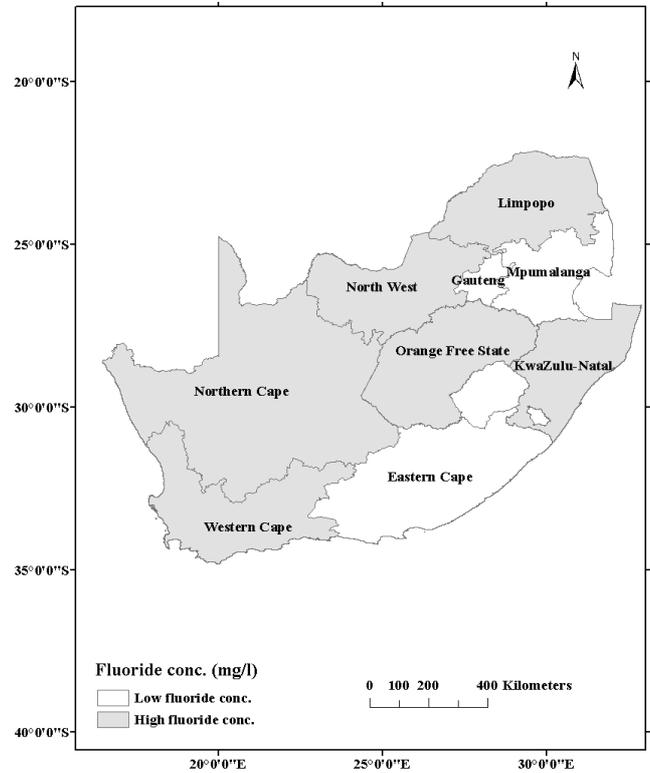


Figure 5. Fluoride distribution in Provinces in South Africa.

Based on this literature review, the general water quality in terms of fluoride concentration is in an acceptable limit. The country mean fluoride concentration was found to be  $0.64 \pm 1.18$ mg/l with the median of 0.24 mg/l and the maximum value was found to be 8.2 mg/l (Table.1). Although, mean fluoride concentration is in an acceptable standard, there are cases where it is beyond the recommended standard value. It has been found that about 9.65% of water sources in South Africa exceed the standard of Committee for Scientific Industrial Research (CSIR) and Bureau of Standards recommended (1.5 mg/l). Also, 4.82% of water sources in South Africa exceed the country's Water Quality Guidelines standard (4 mg/l). Apart from this study, the highest fluoride level was reported by [78], as high as 42.05 mg/l of fluoride in water was found.

The fluoride problem was dominant in the Northern Cape and Limpopo provinces as compared to other provinces since large population is still located in rural areas which in most of the cases utilize groundwater for drinking purposes. Also, high fluoride is likely to be linked to igneous and sedimentary rocks that are dominant in the areas. Moreover, 117 of 6042 samples studied were revealed to have fluoride concentration ranging between 4.0 and 8.0 mg/l while 19 water sources had fluoride ion concentrations higher than 8.0 mg/l [78].

### Fluoride Distribution in South Africa by Water Sources

Although, many of the data did not show water sources, those data that showed the water sources were analysed and it was found that the boreholes had the highest fluoride concentration compared to other sources. The mean fluoride concentration of the boreholes was  $1.27 \pm 1.97$  mg/l and median of 0.27 mg/l (Table.1). High fluoride in boreholes might be linked to high water rock interaction. However, this fluoride concentration in borehole was within the standard of the Committee for Scientific Industrial Research (CSIR) and Bureau of Standards (1.5 mg/l). Also, among all water sources, boreholes showed the largest number of water sources with fluoride level above the Committee for Scientific Industrial Research (CSIR) and Bureau of Standards recommended (1.5 mg/l). Since, 20 (24.10%) boreholes out of 83 had fluoride level above 1.5 mg/l (Table.1).

Similarly, boreholes showed the largest number of water sources with fluoride level above the country's Water Quality Guidelines standard (4 mg/l). It was found that 14 (16.87%) out of 83 sources had fluoride above 4 mg/l (Table.1). Therefore, the populations that rely on groundwater from boreholes specifically those boreholes that have fluoride level above 1.5 mg/l is likely to be exposed to high fluoride. This can eventually result into fluoride negative health impacts.

Like in many places in the world, surface water in South Africa that comprised of rivers and streams showed the lowest (mean =  $0.25 \pm 0.10$  mg/l and median was 0.23 mg/l) fluoride level. Therefore, the use of surface water (low fluoride) will reduce human exposure to fluoride and its negative health impacts.

### 5.5. Fluoride in Ethiopia

Like other African countries crossed by Rift Valley, Ethiopia has high level of fluoride above the WHO standard (1.5 mg/l) nearly throughout the country [22]. This work reviewed various studies on fluoride concentration in water in Ethiopia. It was found that the country mean and median fluoride concentration were  $10.20 \pm 26.17$  mg/l and 2.6 mg/l respectively (Table. 1). Also, it was observed that 117 (63.93%) water sources out of 183 sources had fluoride above 1.5 mg/l (Table. 1). Such elevated fluoride in large percent of water sources gives the picture of severity of fluoride problem in Ethiopia. Besides, lack of appropriate defluoridation techniques increases the community exposure to fluoride. Therefore, in order to rescue the large population of Ethiopia

from fluoride exposure and its effects, urgent intervention is required.

#### 5.5.1. Fluoride Distribution by Water Sources in Ethiopia

Among all water sources studied, the lakes showed the highest mean ( $113.86 \pm 106.51$  mg/l) and median (130 mg/l) (Table.1). The lakes had 4 (80%) samples out of 5 with fluoride level above 1.5 mg/l (Table.1). The highest fluoride level in the lakes was found in Lake Chitu (250 mg/l). Furthermore, thermal wells were found to have the largest number samples exceeding 1.5 mg/l as 8 (88.89%) samples out of 9 exceeded 1.5 mg/l (Table.1). In contrast, springs were found to be sources with the lowest fluoride concentration as no sample exceeded 1.5 mg/l (Table.1).

#### 5.5.2. Fluoride Distribution Between Rift Valley and Other Areas

When fluoride concentration was compared between the Rift valley and the rest of the area in Ethiopia, it was found that the highest fluoride levels in water were found in the Rift Valley, in the lowland areas that had experienced recent volcanic activity [22]. Generally, it has been found that 342 (41.2%) out of 830 sources had fluoride above 1.5 mg/l in the rift valley (Table 3). However, the situation is different outside the rift valley as 21 (3.5%) sources out of 608 sources had fluoride above 1.5 mg/l (Table 3).

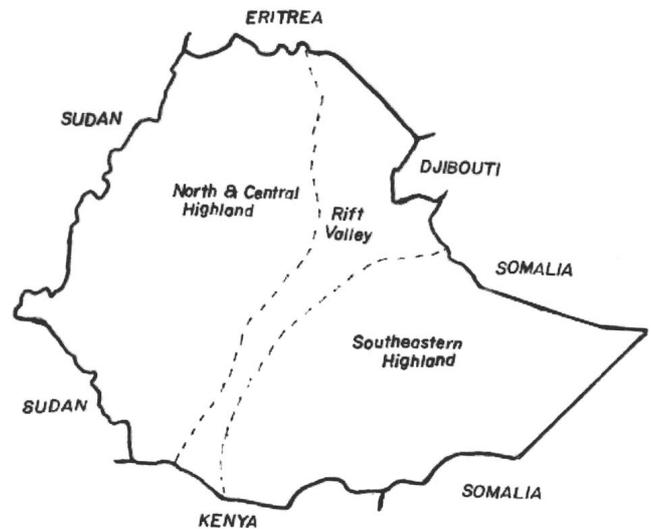


Figure 6. Map of Ethiopia showing the highland regions and the Rift Valley; Data source: [99].

Table 3. Fluoride distribution between Rift valley and other areas in Ethiopia, Data source: [99].

F Level (mg/l)	Within Rift Valley		Outside Rift Valley		The whole country	
	No. of samples	%	No. of samples	%	No. of samples	%
< 1.0	390	47	553	91	943	65.6
1.0–1.5	98	11.8	34	5.5	132	9.2
>1.5	342	41.2	21	3.5	363	25.2
Total	830	100	608	100	1438	100

When fluoride concentrations in Rift valley were compared to that of highlands, it was found that 53 (53%) sources out of 152 sources had fluoride concentration above 5 mg/l in Rift valley (Table 4). In this area, the hot springs showed the

highest frequency of water sources with fluoride greater than 5 mg/l since all 3 (100%) hot spring exceeded the 5 mg/l (Table 4). It was followed by lakes with frequency of 7 (78%) out of 9, Shallow wells with frequency 6 (54%) out of 11, borehole

with frequency of 38 out of 113 (34%) (Table 4). Large number of waters sources with fluoride level above 5 mg/l in the Rift valley was also reported by [22]. He found that about 35% out of 152 public water sources with 5 mg/l and above fluoride levels in the Rift Valley. In contrast, no rivers and springs that showed fluoride concentration of higher than 5 mg/l (Table 4). Therefore, it might not be conclusive to say that rivers and springs can be reliable source of safe water (low fluoride) since they might have fluoride above 1.5 mg/l (WHO standard).

Contrary to Rift valley, the highland regions were found to have only 3 (100%) water sources out of 118 which had fluoride above 5 mg/l and both were boreholes (Table 4). Thus, the comparison between Rift valley and highlands areas show that the number of water sources with fluoride greater than 5 mg/l is greater in Rift valley than in highland areas. However, this does not mean that the highland areas are safe (low fluoride) as might have fluoride above 1.5 mg/l which is toxic. The used comparison value of 5 mg/l is so greater and it was used only to show extreme fluoride in water.

**Table 4.** Fluoride distribution between Rift valley and highland areas in Ethiopia, Data source: [99].

Rift Valley														
Fluoride concentration (mg/l)	All water sources		Boreholes		Shallow wells		springs		Hot springs		Rivers		Lakes	
	n	(%)of sources	n	(%)of sources	n	(%)of sources	n	(%)of sources	n	(%)of sources	n	(%)of sources	n	(%)of sources
0*	4	3	3	3	0	0	0	0	0	0	0	0	0	0
< 1.0	43	28	30	27	3	27	6	86	0	0	3	33	1	11
1.0-4.9	52	34	42	37	2	18	1	14	0	0	6	67	1	11
>5	53	35	38	34	6	54	0	0	3	100	0	0	7	78
Subtotal	152	100	113	100	11	100	7	100	3	100	9	100	9	100
Highlands														
0*	13	11	11	17	0	0	1	4	0	0	1	5	0	0
< 1.0	84	71	40	63	2	6	23	85	0	0	16	76	3	75
1.0-4.9	18	15	9	14	1	33	3	11	0	0	4	19	1	25
>5	3	3	3	5	0	0	0	0	0	0	0	0	0	0
Subtotal	118	100	63	100	3	100	27	100	0	0	21	100	4	100
Grand total		270		176		14		34		3		30		13

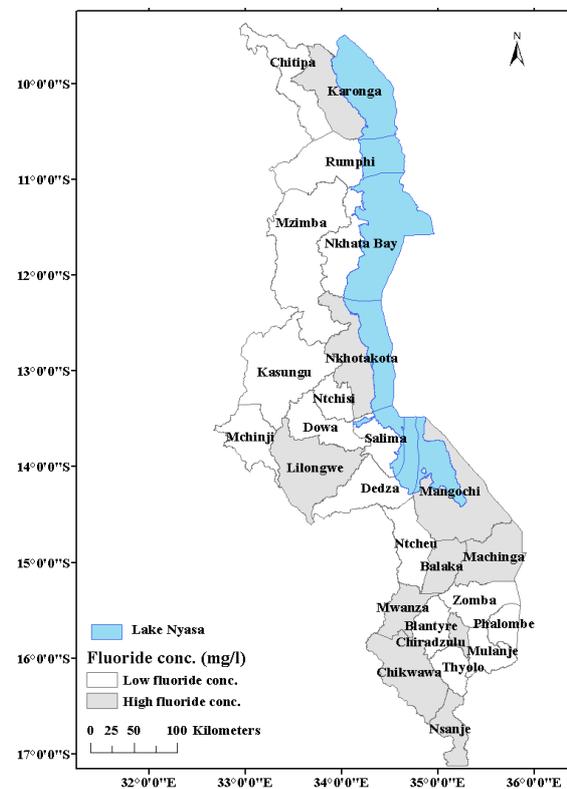
In addition to such high fluoride reported, water sources used by the large population were found to have fluoride levels of 3.5 to 13.0 mg/l [99]. In the Rift Valley, the majority of the population in the arid Rift Valley is in scarce of surface water resources such as rivers and springs that are typically low in fluoride (less than 1.5mg/l). Therefore, a large number of people in the Rift Valley have been forced to use the boreholes which have the high level of fluoride in water. Moreover, [7] found that these levels were responsible for dental fluorosis in children and prolonged exposure causes skeletal and crippling fluorosis.

**5.6. Fluoride in Malawi**

High fluoride concentration has been reported in Malawi. The surface and groundwater fluoride data have been collected from different studies throughout the country. Based on the collected data the country mean fluoride concentration was found to be 2.02 ± 2.32 mg/l with the median of 1.06 mg/l (Table 1). The minimum was 0.06 mg/l where as the maximum was 10.3 mg/l (Table 1).

It was found that 53 (28.04%) sources out of 189 had fluoride concentration above the WHO standard value (Table 1). Therefore, it has been observed that more than quarter percent of the water sources have fluoride above 1.5 mg/l. Since they are used by the societies for various uses including drinking, severe fluoride negative impacts are inevitable.

**5.6.1. Fluoride Distribution by District in Malawi**



**Figure 7.** Map of Malawi showing fluoride distribution in districts.

High fluoride have been reported in a number of localized areas, the most known areas include central and southern regions. These include Nathonje, Nkhotakota Boma, Karonga, Mangochi, Machinga, Mwanza, Balaka, Chikwawa, Chiradzulu, Lilongwe and Bangula [29, 34] (Fig. 7). Similarly, [34] reported fluoride levels beyond the levels recommended by WHO (1.5 mg/l) in southern Malawi. Moreover, it is pointed out that, in Nsanje district, 83% of the samples had fluoride between 1.65 and 7.50 mg/l, Machinga district had 73% of all samples having fluoride levels above 2 mg/l, the highest value (3.64 mg/l) was recorded within Mangochi district. Also dental, skeletal and crippling fluorosis have been the problem in fluoride endemic areas in Malawi [41].

### 5.6.2. Fluoride Relationship with Some Other Physical Parameters

The correlation study of some physical chemical parameters such as EC, pH and TDS with fluoride concentration was done. Although, not all data points had all four parameters, correlation was made for complementary parameters. The data showed that there was a strong positive correlation between fluoride and EC ( $r = 0.77$ ) (Fig. 8). Also, there was a strong positive correlation between fluoride and pH ( $r = 0.71$ ) (Fig. 8). The rest of the parameters did not show any significant correlation with fluoride.

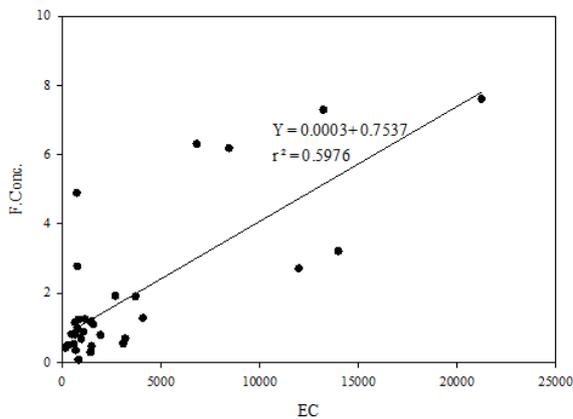


Figure 8. The relationship between fluoride (mg/l) and EC ( $\mu\text{S}/\text{cm}$ ) in some water sources in Malawi, Data Source; [34, 81, 93].

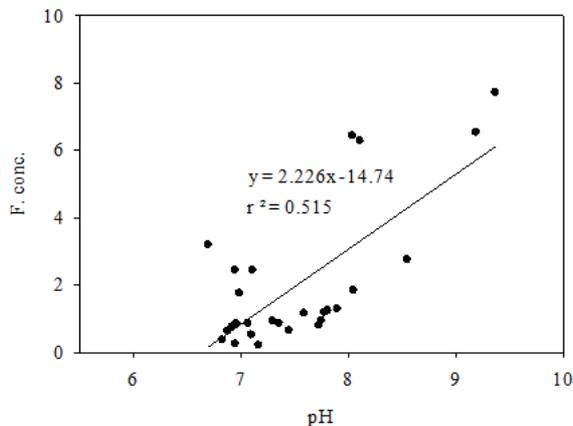


Figure 9. The relationship between fluoride (mg/l) and pH in some water sources in Malawi, Data Source; [34, 81, 93].

## 5.7. Fluoride in Nigeria

Fluoride data from some water sources in different studies have been collected in Nigeria. Based on this study the country mean fluoride concentration was found to be  $1.78 \pm 1.26$  mg/l and the median was 1.48 mg/l (Table 1). The maximum fluoride value was 4.4 mg/l while the minimum fluoride value was 0.03 mg/l (Table 1). Also, it has been found that 42 (45.16%) water sources out of 93 sources had fluoride above the WHO standard which accounted for of all water sources studied (Table 1). Therefore, presence of slightly high fluoride concentration in water relative to WHO standard and presence of almost fifty percent of water sources with fluoride concentration above 1.5 mg/l in Nigeria, increases the chances of fluoride exposure. This in turn increases fluoride negative impact in Nigeria that makes fluoride affected Country.

### 5.7.1. Fluoride Concentration by Water Sources

Generally, when fluoride concentration in water was considered based on surface and groundwater, it was found that the surface water had the high fluoride concentration as compared to the groundwater. The surface water mean fluoride concentration was  $2.78 \pm 0.88$  mg/l and median 2.88 mg/l where as the groundwater mean fluoride concentration was  $1.44 \pm 1.18$  mg/l and median 0.92 mg/l (Table 1). Also, the high concentration in surface water relative to groundwater was reflected in minimum and maximum values. The minimum fluoride concentration in surface water was 0.52 mg/l and in groundwater was 0.03 mg/l. The maximum fluoride concentration in surface water was 4.4 mg/l and in groundwater was 3.95 mg/l (Table 1). Furthermore, high fluoride in surface water compared to groundwater was revealed by presence of 21 (91.30%) sources out of 23 sources with fluoride above 1.5 mg/l (Table. 1). High fluoride in surface water might be related high evaporation. In contrast, the groundwater had 21 (30%) sources out of 70 sources with fluoride above WHO standard groundwater (Table. 1).

### 5.7.2. Fluoride Distribution in Geographical Areas

Apart from country mean fluoride concentration being high, the areas affected much include Central and Northern Nigeria [11, 100]. Moreover, areas with fluoride concentration ranging from 2.5 to 3.9 mg/l were reported to experience mottling of teeth [43, 101]. Furthermore, it was found that inhabitants of high fluoride groundwater provinces showed symptoms of dental fluorosis among various age groups [101].

## 5.8. Fluoride in Ghana

Like some of the above mentioned African countries, fluoride was investigated in some areas in Ghana. For the purpose of this review secondary data from different studies have been used. About 338 samples representing water sources have been collected throughout Ghana. The results show that the mean fluoride concentration was  $1.14 \pm 1.12$  mg/l, median was 0.625 mg/l and the minimum was 0.005 mg/l (Table 1). These values are generally low as compared to WHO standard (1.5mg/l). However, the maximum was 5.8 mg/l (Table 1). This maximum value is likely to cause negative

health impacts to the exposed population. Furthermore, it has been found that 95 (28.11%) samples out of 338 samples had fluoride concentration above the 1.5 mg/l (Table 1). Therefore, presence of fluoride concentration in water below the 1.5 mg/l implies the water is generally good in terms of fluoride concentration. However, presence of maximum fluoride of 5.8 mg/l may result in serious fluoride negative health effect.

### 5.8.1. Fluoride Concentration by Water Sources in Some Areas in Ghana

When fluoride concentration from different studies were considered based on water sources it was found that the boreholes had the highest mean and median fluoride concentration  $1.19 \pm 1.16$  mg/l and 0.63 mg/l respectively, (Table 1). However, the wells had low mean ( $0.9 \pm 0.86$  mg/l) and median (0.5 mg/l) fluoride concentration (Table 1). Therefore, wells when utilized effectively can be reliable and safe (low fluoride) source of water. Similarly, the analysis of number of water sources showed that 76 (30.16%) boreholes out of 252 boreholes had fluoride concentration 1.5 mg/l (Table 1). Furthermore, 12 (18.46%) wells out of 65 wells had fluoride concentration above 1.5 mg/l (Table 1). Therefore, borehole fluoride concentration generally high as compared to well. Thus, wells may be used as low fluoride water sources in large parts of Ghana in order to avoid fluoride negative effects.

### 5.8.2. Geographical Distribution of Fluoride in Ghana

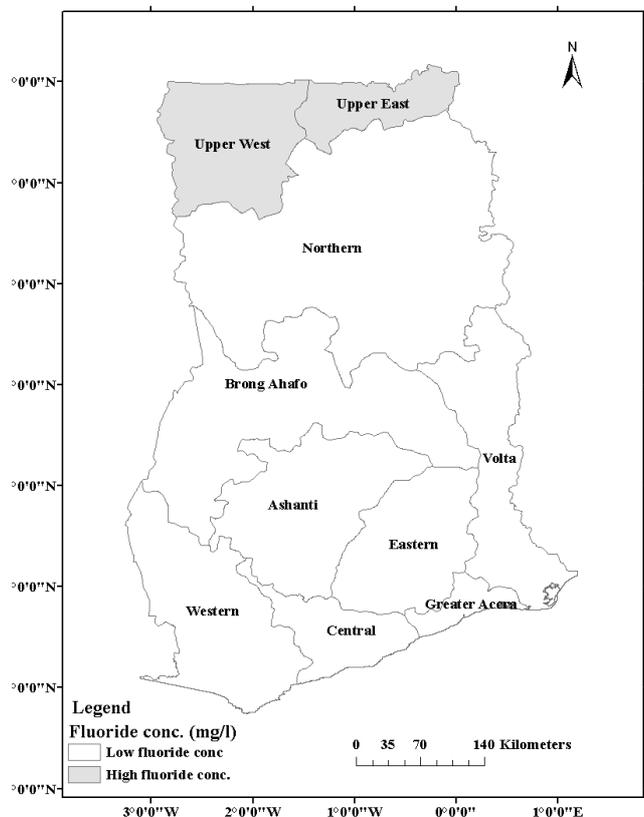


Figure 10. Map of Ghana showing Regions, Data Source [102].

High fluoride concentrations have been found in granitic formations in the Upper West and East Regions [21] (Fig. 10).

[42] showed that the occurrence of elevated fluoride levels in some areas such as Bongo area corresponded to geology. In addition, fluoride concentration was found to vary inversely with precipitation, low during wet season and high during dry season. Thus, exerting great risk to population during dry season [42].

Besides, fluoride was observed to vary with depth in groundwater e.g Bongo granite specifically in the Bolgatanga area [18]. Increasingly, the shallow hand-dug wells were observed to have lower fluoride concentrations compared to groundwater from boreholes [37]. This may be linked to high water rock interaction in shallow hand dug wells as compared to boreholes.

### 5.9. Fluoride in Sudan

The review of fluoride distribution in Sudan based on the former republic of Sudan before separation of South and North Sudan. However, fluoride studies are found to be limited in Sudan, high level of fluoride in drinking water has been reported in some areas in the country [6, 17]. About 27 fluoride data have been collected from various studies in Sudan and it was found that the mean fluoride concentration was  $1.37 \pm 1.56$  mg/l, median was 1 mg/l, minimum was 0.2 mg/l and maximum value was 7 mg/l (Table 1). The minimum, median and mean are below the WHO standard value. This implies that water quality in terms of fluoride is generally good. Furthermore, it has been found that the 5 (18.52%) water sources out of 27 sources had fluoride above the WHO standard value (Table 1).

Therefore, 18.52% may be considered as small but when this percentage covers the areas with high population may result in significant fluoride health problems. Similarly, severe dental fluorosis was observed in some of the areas with high fluoride [17]. Surprisingly, more than 90% of dental fluorosis was reported in the areas with as low fluoride concentration as 0.25 mg/l.

Furthermore, fluoride level in well water was observed to decrease with pumping rate increase [38]. This is caused by continuous washing of fluoride from aquifer rock formation during pumping. Also, dilution of groundwater resulting from seepage from Blue Nile River could contribute to decrease in fluoride in well water. In contrast, low pumping rate increases contact time which favours water rock interaction and results into more fluoride release into ground water [6, 38].

### 5.10. Fluoride in Algeria

Although, not commonly known as high fluoride country, high level of fluoride in drinking water has been reported in Algeria [39]. Since the fluoride studies in Algeria are limited to Southern and Saharan region of Algeria, about 48 fluoride data were collected from different studies in these areas in Algeria. From these data it was found that the country mean fluoride concentration was  $1.47 \pm 0.50$  mg/l and the median was 1.58 mg/l (Table 1). The results showed that the mean country fluoride is slightly below the WHO standard (1.5 mg/l) while the median was above the WHO standard value. Since

the fluoride concentration was found not to be normal curve, therefore it is appropriate to use median rather than mean. Also the minimum fluoride concentration was found to be 0.38 mg/l while the maximum was 2.61 mg/l (Table 1). Furthermore, it was found that about 25 (52.08%) water sources out of 48 sources had fluoride above WHO standard value for drinking water. Such exposure is big enough to cause the severe negative health impacts to large population, however, it may be reduced by defluoridation before water supply.

Also, it was found that in some areas high fluoride water was accompanied by severe and excessive total mineralization

[40]. Sometimes, the water was reported to be the only source for drinking. It was also, believed that the hot and dry climate force people to consume a lot of water that may lead to raise the daily fluoride consumption rate. Besides, Algerian Sahara has been spotlighted as fluorosis endemic areas [39].

### 6. Discussion

High fluoride levels have been observed in most of African countries. Such countries include Algeria, Ethiopia, Ghana, Malawi, Nigeria the Republic of South Africa, Sudan, Uganda, Kenya and Tanzania [5-35, 37-44] (Fig. 11).

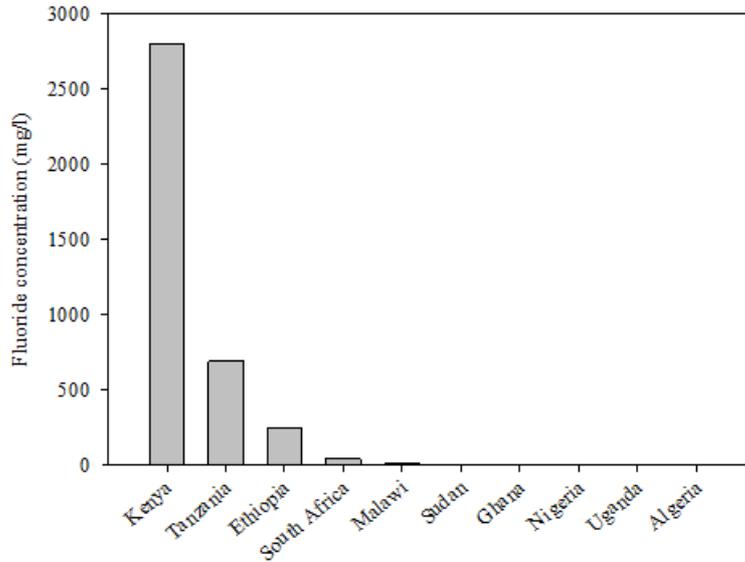


Figure 11. The maximum fluoride concentration reported in water in some African countries.

It was observed that the countries with highest maximum fluoride levels in Africa are those falling within the Rift Valley especially the East African Rift Valley [10, 22, 31, 41] (Fig. 12). Such countries include Kenya, Tanzania and Ethiopia with maximum fluoride levels ranging between 250 and 2800 mg/l (Fig. 12).

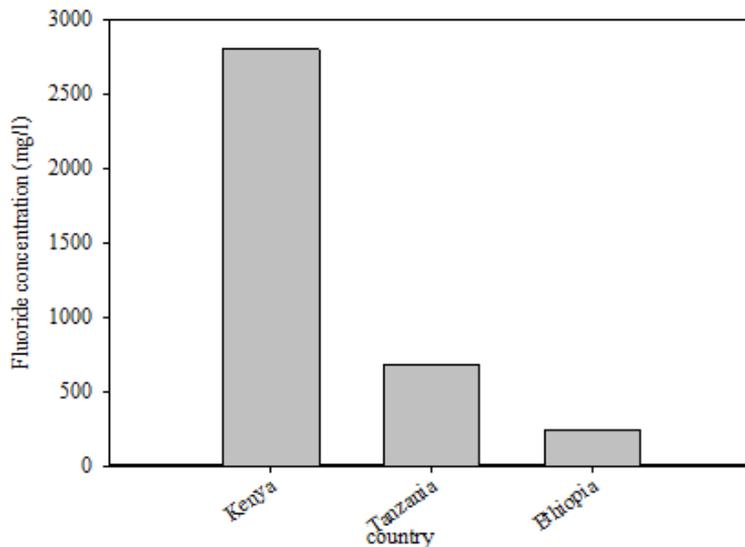


Figure 12. The maximum fluoride concentration reported in some East African Rift Valley countries.

In East African rift valley, Kenya was reported to be the country with the highest level of maximum fluoride, 2, 800

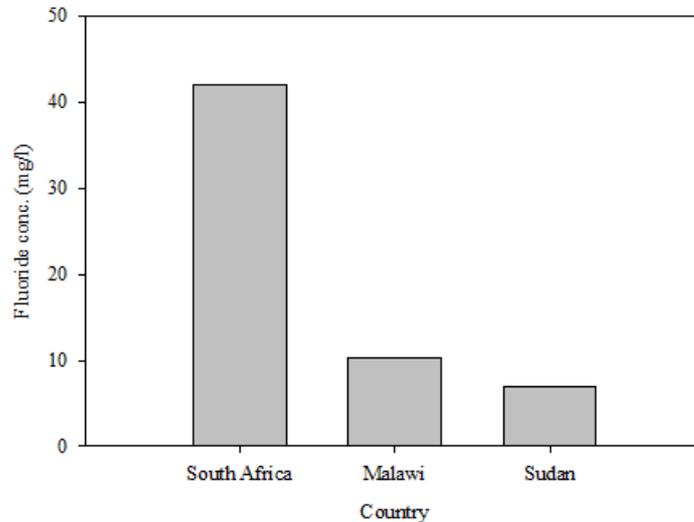
mg/l that was found in Lake Nakuru [10] (Fig. 12). This is the one of the Rift Valley Lakes in Kenya. Besides, different

studies [10, 13, 27] reported different levels of fluoride from the same water sources in Kenya. Generally, the pattern showed decreasing trend in concentration of fluoride in water with time. This might be resulting from either difference in sampling season, measuring methods, sensitivity of instruments, sensitivity of fluoride measurement methods or change in fluoride in water bodies. This merits long term monitoring of fluoride levels in water in order to identify what is happening and define the trend. Also, the highest fluoride level in Tanzania is as high as 690 mg/l [31] (Fig. 12). This is also found in surface water body known as Lake Momella in Arusha region. The lake is close to Mount Meru that had experienced a recent volcanic activity. The region was found to have a high mean fluoride level in the country with 7.11

mg/l [9]. Although, there is such high level in the country, the trend of fluoride concentration in water is not clear. It is important to establish a trend in order to understand future risks.

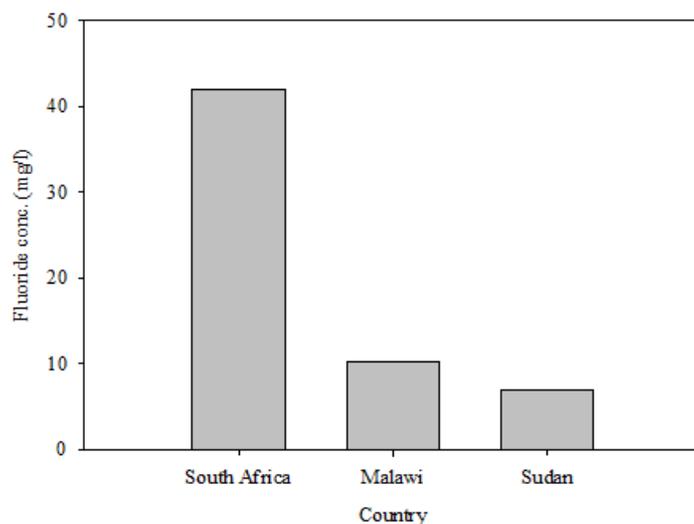
Similarly, high fluoride levels in Ethiopia have been reported in surface water body. As high as 250 mg/l was found in lake Chitu [79] (Fig. 12). This is also an alkaline rift valley Lake in the country.

Although, African countries like Algeria, Nigeria, Ghana, Malawi Sudan, Uganda and the Republic of South Africa were reported to have high fluoride [5-35, 37-44] only South Africa, Malawi and Sudan had the maximum value exceeding 6 mg/l with maximum concentration value of 42.05, 10 and 7 mg/l, respectively (Fig. 13).



**Figure 13.** The maximum fluoride concentration reported in water in some African countries with fluoride range 1.5 - 45 mg/l.

Additionally, Ghana, Nigeria, Uganda, and Algeria showed maximum fluoride level below 6 mg/l (Fig. 14) Leaving the fact that these concentrations are low compared to those observed in some East African countries, still there are enough to cause toxic effects when taken by human. Therefore, they should not be neglected.



**Figure 14.** The maximum fluoride concentration reported in some African countries, fluoride range 1.5 - 6 mg/l.

Some studies have showed that fluoride levels in some African countries were varying with season [12, 42]. The high

levels were reported in dry seasons as compared to wet seasons [42]. Occurrence of high concentration during the dry

season results from high evaporation reducing water volume. While during wet season low concentration results from dilution effect exerted by rainfall that increases water recharge and volume [12, 42]. This does not hold water in some cases where fluoride increases during the wet season. This is based on the fact that water may increase chemical reaction of fluoride bearing rock which may favour its release. In order to clearly explain the influence of seasons on fluoride concentration, the long term data of fluoride concentration during dry and wet season need to be collected. Also, it is important to know the behaviour of fluoride during the intermediate season between dry and wet season although it requires long term data

Fluoride concentration in water was observed to decrease with pumping rate [38]. This is through washing of fluoride ion from aquifer formation with time. Besides, it was reported to increase with low pumping rate [6, 38]

This is due to the fact that low pumping rate favours long time water storage in aquifer. This in turn accelerates rock water interaction which increases fluoride level in water [6, 38]. This is however, reported in few countries in Africa and in those in which it is done the study was limited to time frame.

Fluoride was observed to vary with depth in groundwater [18]. The shallow hand-dug wells were observed to have lower fluoride concentrations compared to groundwater from borehole [37]. This was due to dilution by recent recharge in shallow wells [37]. Also, fluoride increase with depth was reported in some areas [18]. This was due to increase of residence time as water infiltrates deeper.

Nearly all African countries having the incidence of fluoride level above 1.5 mg/l were found to have dental fluorosis [7, 10, 16, 17, 20, 25, 31, 39, 41, 43, 98, 101]. Although, the severe cases were observed in rift valley countries, some areas with fluoride levels below 1.5 mg/l had also the incidences of dental fluorosis. Indicating that, in addition to geology, climate, specifically temperature is responsible for amount of water intake and eventually fluorosis. It is important that African countries should review their maximum allowable fluoride concentration standards in drinking water since they are affected by the tropical climate.

Although fluoride in a range of 0.5 to 1.5 mg/l is said to improve skeletal and dental health, fluoride concentration beyond 1.5 mg/l is responsible for various skeletal and non skeletal health effects. Such health effects include dental fluorosis, skeletal fluorosis, crippling fluorosis, low haemoglobin levels, muscle fibre degeneration, excessive thirst, red blood cell deformities, skin rashes, headache, gastrointestinal problems, depression, nausea, urinary tract malfunction, tingling sensation in fingers and toes, abdominal pains, reduced immunity and neurological manifestations. It also alters the functional mechanisms of kidney, liver, respiratory system, digestive system, central nervous system, reproductive system and excretory system. Apart from all these health effects, only dental, skeletal and crippling fluorosis have been observed in most of fluoride endemic areas [2, 32, 34, 41, 64, 65, 67, 68, 71]. The rest of the effects have not been given enough attention. Therefore, more

research is needed to avail negative effects of fluoride apart from fluorosis in African countries.

Since many African countries are affected by high fluoride in drinking water, there have been several initiatives to remove it. The most applied technologies to defluoridate drinking water in Africa require highly trained personnel, expensive and inefficient. Thus, limit their applicability in rural areas especially in developing countries. Therefore, researches to find alternative cheap defluoridation materials should be intensified.

## 7. Conclusion and Recommendation

High fluoride concentration is one of the major water quality problems affecting some of the African countries such as Tanzania, Kenya, Algeria, Nigeria, Ghana, Malawi, Sudan, Uganda and the Republic of South Africa and Ethiopia. The typical high fluoride in water was severe in countries located in Rift Valley like Kenya, Tanzania and Ethiopia. However, all the incidences of highest fluoride levels in water in the Rift Valley countries were found in surface water bodies. This is contrary, as it is expected groundwater to be more concentrated as compared to surface water due to more water-rock interaction than in surface water bodies. However, no single study among many studies has reported the long term trend of concentration of fluoride in water with time.

Fluorosis has also been reported to be endemic in fluoritic areas of Africa though, little is known on other fluoride negative effects. Although, many defluoridation researches have been undertaken in Africa, no single study that gave defluoridation method that was efficient, cost effective, environmental friendly and easy to use in local community either in household or public system. Therefore, more efforts should concentrate on finding appropriate defluoridation techniques to be applied while considering the cost of operation, efficiency, practicability, easy application and environmental friendly. The effort to establish long term trend of fluoride concentration in water should also be taken in consideration. This helps to predict future concentration of fluoride and possibility to minimize future risks.

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