

Spatial Distribution of Fluoride Concentration in Drinking Water Sources in Northern Tanzania

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Abstract

Study on Fluoride concentration levels and spatial distribution was carried out in a total of 366 drinking water sources in Arusha city, Ngorongoro, Arumeru, Monduli, Karatu, Meru, and Longido districts in Arusha Region, Northern Tanzania. The main objective of the study was to map occurrence and level of Fluoride concentrations in the existing and potential sources of drinking water supply in the case study areas. Determination of Fluoride concentration was analysed by electrochemical methods using a Fluoride ion selective electrode. The obtained results indicate that out of the 22 water sources assessed in Arusha city, only 14 (63%) meets the recommended Fluoride concentration level (4 mg/L) for drinking water standards of Tanzania. In Karatu district out of the 22 water sources assessed, 9 sources (41%) do not meet the Tanzania standards of Fluoride concentration levels in drinking water sources, while in Longido all 18 boreholes had Fluoride concentration levels above the recommended Tanzania standards. Out of the 11 assessed spring water sources, 6 (55%) had concentration above the recommended levels. However, Fluoride concentrations in all rivers in Longido district were found to be within the allowable standards. In Monduli district 2 dug wells had Fluoride concentration between 0.34 and 1.0 mg/L, respectively. Fluoride concentration in Lake Manyara was found to be as high as 18 mg/L, which is far beyond the recommended concentration level in Tanzania as well as by World Health Organization (WHO). Fluoride concentrations in almost all spring water sources in Monduli district have Fluoride concentrations allowable both by Tanzania and WHO standards. In Meru district the percentage of water sources with Fluoride concentration within the allowable levels in Tanzania and can thus be tapped for safe water supply are boreholes 64.3%, springs 66.7%, shallow wells 25.7% and rivers 71.5%. In Arusha District springs constitute the main water source. Out of these 77% have Fluoride concentration within Tanzania allowable standards. As for Ngorongoro out of 51 water sources assessed only 4 have Fluoride concentration above 4.0 mg/L, suggesting a major leeway and flexibility in terms of selection of water supply sources in this district. Results of this study indicate a challenging situation in terms of selection of source of safe water supply in Arusha city and Meru district as many of their water sources have Fluoride concentration above the permissible levels in Tanzania. However, the situation is different in Karatu, Longido and Monduli, Arumeru and Ngorongoro districts where substantial water sources have Fluoride concentration within levels acceptable for drinking water supply in Tanzania.

Keywords: Fluoride Concentrations, Allowable Concentration levels, Drinking Water Sources

1.0 INTRODUCTION

Fluoride is an ion of the chemical element fluorine which belongs to halogen group. Because of its reactivity, fluorine is never found free in nature, but is found as some type of fluoride especially in industrial processes (Handa, 1975). When fluorine is present as fluoride, it can be quite beneficial to people. However, there is an increasing concern worldwide over high levels of fluoride ingestion by people and its adverse health effects (Fawell et al., 2006 and WHO, 2004). Generally human beings ingest fluoride mostly from drinking water sources. At low or optimum concentrations of 1.0 to 1.5 mg/L, fluoride stabilizes the skeletal system by increasing the size of apatite crystals and reducing their solubility (WHO, 2004). According to Brouwer et al., (1988), fluoride concentration of between 0.7-1.2 mg/L has dental caries prevention effects especially in children. In excessive exposure (3-6 mg/L) it can result in a number of adverse impacts including skeletal fluorosis, while beyond 10 mg/L it leads to crippling fluorosis (Fawell et al., 2006 and Shepherd et al., 2012). According to Murray (1986), fluoride intake per person per day should range from 0.2 (mg/L) for infants and 5.0 (mg/L) for adults.

Recognition of toxicity effects of high fluoride ingestion has led to restrictions and guideline setting on the amount of fluoride concentration in drinking water sources. The maximum permissible level for fluoride ingestion set by World Health Organization (WHO) is 1.5 mg/L (WHO, 2004). This limit has however, been seen to be unacceptable in some countries. This is perhaps because according to Brouwer et al., (1988), in some parts of the world, symptoms of fluorosis have been reported where concentration of fluoride were below the WHO recommended upper limit levels. As a result lower specific country standards have been set, e.g. 1 mg/L in India and 0.6 mg/L in Senegal (Susheela, 2007). Until 2009 the allowable standard in Tanzania was 8 mg/L (Water Utilization, Control and Regulation, amendment Act, 1981). Since 2009 it was adjusted downward to 4

mg/L (Water and Wastewater Quality Monitoring Guidelines for Water Utilities, 2014).

Apart from drinking water sources, human exposure to excessive fluoride has been attributed to ingestion of fluoride-contaminated foodstuffs. WHO, (2004) reported some vegetables and fruits to have fluoride concentrations in the range of 0.1–0.4 mg/kg and therefore also contributing to high fluoride ingestion by human beings. In Tanzania Kaseva, (2005) and Mabelya *et al.*, (1997) reported that in Arusha, Kilimanjaro and Singida regions, high concentrations of fluoride are ingested through a locally obtained salt called ‘magadi’ also known as “Trona”, which is added to food in order to speed up the cooking process. Trona (sodium carbonate- $\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 \cdot \text{H}_2\text{O}$) is highly contaminated with fluoride as it may contain as high as 20-14,960 mg/L of fluoride (Kaseva 2005 and Mabelya *et al.*, 1997).

In spite of high concentrations in some food items, fluoride from drinking water sources remains the major cause of fluorosis in Tanzania. Previous studies (Mungure, 1987, Mjengera, 1988, Gumbo and Mkongo, 1995) reported high fluoride concentrations ranging from 4-22 mg/L in surface and ground water sources in Arusha, Kilimanjaro, Shinyanga and Singida regions. Again Kaseva (2005) established fluoride concentrations in various drinking water sources in Embaseni, Ngurdoto, Kitefu and Nkoanekoli both in Arumeru district, Arusha region in Northern Tanzania to vary from 1.7 to 41.3 mg/L.

This study was carried out with the aim of establishing the current trend and levels of fluoride concentrations in Arusha region. The study also aimed at mapping the occurrence and level of fluoride concentrations as a pointer on the fluoride concentration levels of water sources in the case study areas where drinking water supply projects may be implemented.

2.0 MATERIALS AND METHODS

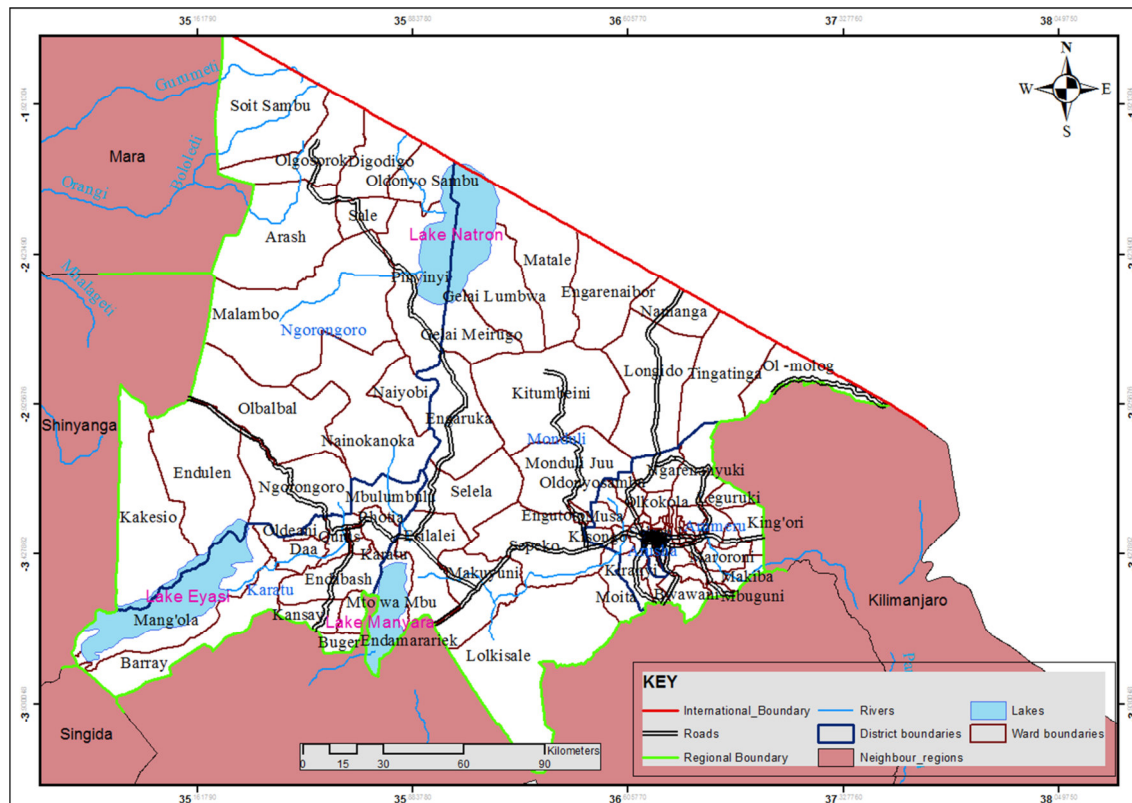
2.1 Location of the case study area and collection of water samples

The study was carried out in Arusha region, specifically in Arusha city, Ngorongoro, Arumeru, Monduli, Karatu, Meru, and Longido districts. A total of 366 water samples were collected from boreholes (91 samples), streams (3 samples), shallow wells (40 samples), river (22 samples), spring (177 samples), Lake (2 samples), dug well (4 samples) and dam (28 samples). Table shows details of the case study areas including districts, numbers and type of water sources from which samples were collected, while Map 1 shows specific locations of sampling in the case study areas.

As can be shown on Table, majority of the samples (117) were collected in Meru district, largely from the springs (57) and shallow wells (35). The least number of samples (22) were collected from sources within Arusha city.

Table 1: Types and number of water sources sampled in the case study areas (n= number of sampling points/water sources)

District	n	Type of water source							
		Borehole	Stream	Shallow well	River	Spring	Lake	Dug well	Dam
Arusha city	22	17	0	0	1	4	0	0	0
Ngorongoro	51	22	0	1	3	24	0	0	1
Arumeru	59	0	3	0	4	52	0	0	0
Monduli	49	7	0	0	0	17	1	2	21
Karatu	29	9	0	4	4	11	0	0	1
Meru	117	14	0	35	7	57	1	2	1
Longido	39	18	0	0	3	12	0	0	4
TOTAL	366	87	3	40	22	177	2	4	28



Map 1: Map of Arusha region showing case study areas/location of the water sources

2.2 Sampling, laboratory analysis and mapping

Water samples were collected from the 366 locations as detailed in Table for laboratory analysis in Arusha City. Determination of Fluoride concentration was done by electrochemical methods using a fluoride ion selective electrode (ISE) Sampling and Fluoride analyses was done in accordance to Standard methods for the examination of water and wastewater (APHA 2005).

For the purpose of mapping the Fluoride concentrations in Arusha region, coordinates of the locations for water sources/sampling points were gathered by Garmin eTrex10 GPS and later geo-referenced on Arusha region map.

3.0 RESULTS AND DISCUSSION

3.1 Fluoride levels and spatial distribution in the case study area

3.1.1 Arusha city

In Arusha city, Fluoride concentration was analyzed in 22 water sources. These include 17 Boreholes, 4 springs and 1 river. Details of the location of the specific water sources and their respective Fluoride concentrations levels are presented in Figure . Concentration of Fluoride in 4 spring water sources in the city varied from 1.1 to 3.3 mg/L, while concentration for the river was 3.6 mg/L. Both spring and river source in the city meets requirement recommended by the Ministry of Water and irrigation (Fluoride concentration less than 4mg/L). Fluoride concentration in BH varied from 0.97 to 8.2 mg/L. Fluoride concentrations above the recommended level (i.e. above 4 mg/L) was observed in 8 boreholes. This represents about 47% of the total boreholes in Arusha city. These are Kiranyi (4.4 mg/L) Loruvarani Bondeni and Ilkoriti (4.7 mg/L), Sombetini (5.2 mg/L), Ilkiulei (5.4 mg/L), Sakina (5.7 mg/L), Mianzini (8.1 mg/L) and Ilboru (8.2 mg/L). Results of this study indicate that out of the total water sources (22) in Arusha city only 14 (9 boreholes, 4 springs and 1 river source) meets the recommended Fluoride concentration level by Tanzania standards. The rest of the water sources (8) cannot be safely used as drinking water sources without treatment. As can be noted from Figure , the highest Fluoride level observed in Arusha city water supply source was a borehole whose concentration was 8.2 mg/L. This is slightly higher than 8.0 mg/L previously recommended limit of fluoride concentration in Tanzania water sources (Water Utilization, Control and Regulation, amendment Act, 1981). Cases and symptoms of dental and skeletal fluorosis in Arusha in spite of not so high Fluoride concentration in water sources might have contributed to the revision and lowering of the maximum allowable fluoride level in Tanzania (Water and Wastewater Quality Monitoring Guidelines for Water Utilities 2014). This might also represent a case of Fluorosis symptoms in areas with Fluoride concentrations within allowable limits as reported by Brouwer *et al.*, (1989) and thus underline

findings reported by Kaseva, (2005) and Mabeya *et al.*, (1997), that high concentrations of Fluoride are ingested through other sources such as Magadi (Trona) salt.

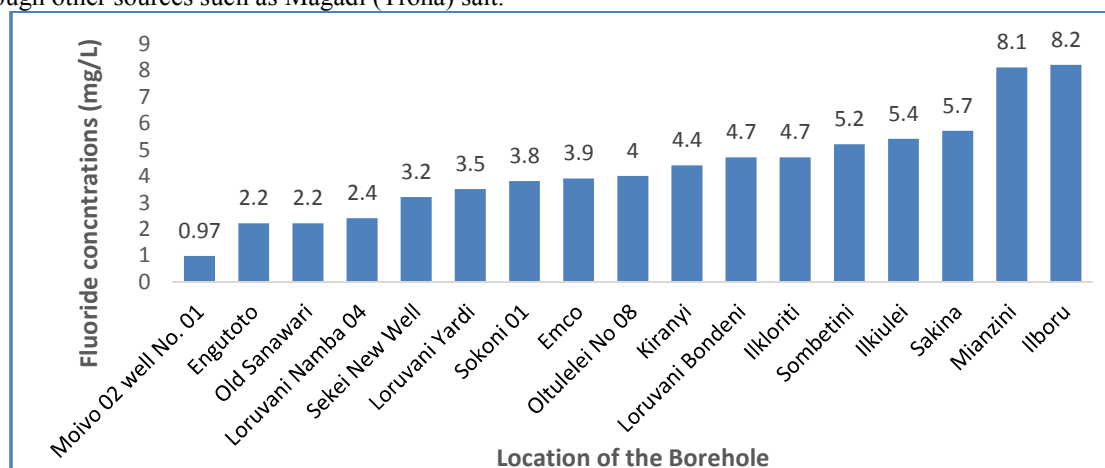


Figure 1 : Boreholes and Fluoride concentrations in Arusha city

3.1.2 Karatu district

In Karatu district Fluoride concentration was analyzed in 29 water sources which are 1 dam, 4 Shallow wells, 9 Boreholes, 11 springs and 4 rivers. Levels of Fluoride concentrations in these water sources are indicated in Table. Fluoride concentrations in shallow wells were found to vary from 2.5–6.5mg/L, while for the boreholes water sources, concentration ranged from 0.22 to 0.65 mg/L. Fluoride concentrations in spring water source ranged from 0.18 to 0.45 mg/L and for the river sources the ranges are between 0.17 to 0.56 mg/L. All the water sources are within the allowable Tanzania standards except for the dam water source which was found to have a concentration of 5.2 mg/L.

Table 2: Water sources and Fluoride concentrations in Karatu district

Water source	Name of the source	F- mg/L	Remarks
Dam	Karatu	5.2	F-mg/L concentrations above the allowable levels in Tanzania
Shallow well	Kambi ya simba	0.51	All within allowable Tanzania level
	Gendaa	0.65	
	Hydesh	0.65	
	Shuleni	2.5	
Boreholes	Ngila Estates	0.22	All within allowable Tanzania level
	Gangefi Boostee	0.31	
	Kwa Jubilate Mnyenye	0.37	
	Elioni Kisamo	0.39	
	Kwa Jubilate Mnyenye	0.41	
	Kwa Clemence Mushi	0.42	
	Mazingira Bora DP	0.59	
	KKT Karatu	0.65	
	Darajani	2.0	
Springs	Zahanati	0.18	All within allowable Tanzania level
	Saidori dispensary	0.19	
	Ofisi ya Kijiji	0.22	
	Kambi ya Simba	0.22	
	Kitete KNCU	0.24	
	Kitelew Primary School	0.28	
	Qang'dend	0.29	
	Pump house	0.30	
	Njoro DP	0.33	
	Mikocheni	0.45	
	Lositete Primary school	3.7	
Rivers	Moyo Division Box	0.17	All within allowable Tanzania level
	Mama Hawa Division box	0.18	
	Kiwandani DP	0.21	
	Kirurumo	0.56	

3.1.3 Longido district

Thirty nine (39) water sources in Longido district were analyzed for Fluoride concentrations. Water source in this district that were analyzed are 4 dams, 18 boreholes, 12 springs and 3 rivers. Fluoride concentration in the boreholes varied from a minimum of 0.12 mg/L to a maximum value of 11 mg/L. Out of 18 boreholes, 3 equivalent to 17% have Fluoride concentration levels above the recommended Tanzania standard. These include boreholes located at Birika, (4.3 mg/L), Darajani Namanga (4.1 mg/L) and Matiani (11 mg/L) as indicate in Figure 2. Table 3 presents results of fluoride concentration in springs, dams and rivers in Longido district. Fluoride concentration in spring water sources in the district ranged from 0.63 to 6 mg/L. Out of all 11 spring water sources in the district, 6 or equivalent of 55% of the sources have concentration above the recommend Tanzania standards. The highest was found to be 6 mg/L concentration at Engikaret spring. Fluoride concentration in 2 dams namely Kimokoi and Kiseriani was found to be 10 mg/L and 4 mg/L respectively. These are the only dam water sources with Fluoride concentrations above the Tanzania recommended standards. Fluoride concentration in all river water sources in Longido district was found to be within the allowable standards

Table 3: Water sources and fluoride concentrations in Longido district

Water source	Name of the source	F- mg/L	Remarks
Dams	Sinonik	0.55	
	Kiseriani	4.0	All within allowable
	Kimokoa	10.0	Tanzania level except
	Lesingita	0.2	Kimokoa Dam
Boreholes	Mndalala	1.1	
	Moirowa	1.1	
	Sinonik	1	
	Sinonik embopong	0.83	
	Ngoswak	0.22	
	Oltepes	0.58	
	Tembo	0.55	
	Namanga/CGC	0.27	All within allowable
	Birika	4.3	Tanzania level except
	Msikitini Barabarani	0.31	Birika , Darajani and Matiani
	Darajani Namanga	4.1	Boreholes
	Alhidaya	2.5	
	Almasjid Mutahideen	0.12	
	Matiani	11	
	Sinya 2	0.72	
	Sinya 1	0.15	
Ilangata	0.2		
Mamra	0.7		
Springs	Kitarin	0.83	
	Engong'u	0.81	
	Olchoronyokia	0.63	
	Gelailumbwa	0.69	
	Gelaibomba	1.3	
	Lomisikio	1.7	All within allowable Tanzania
	Koika	0.97	level except Engikaret spring
	Chemchem Mlima Namanga	3.3	
	Olmog	0.08	
	Engikaret	6.0	
Lorotetii	1.0		
Rivers	Kamwanga	0.18	All within allowable Tanzania
	Lerang'wa	0.25	level
	Simba	0.19	

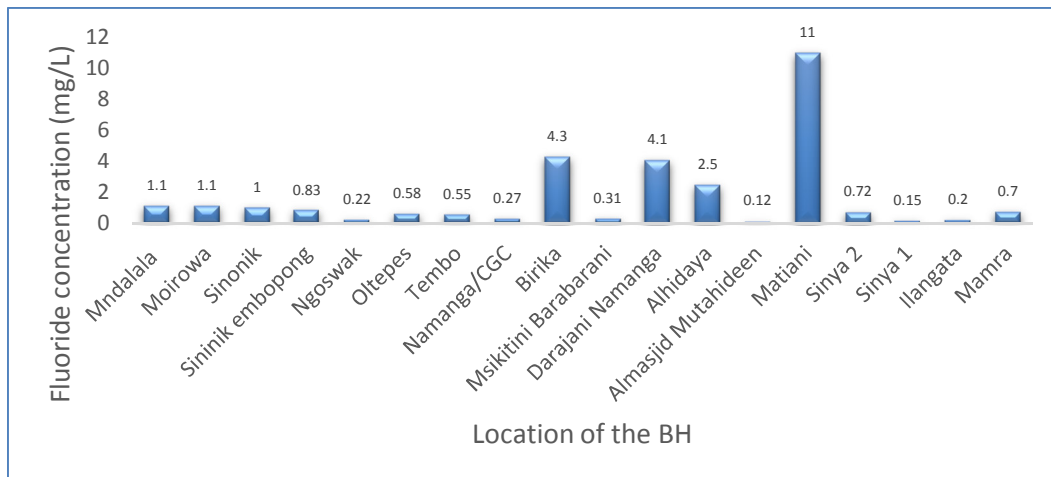


Figure 2: Fluoride concentration in borehole water sources in Longido district

3.1.4 Monduli district

The analyzed water sources in Monduli district were 21 dams, 2 shallow wells, 7 boreholes, 17 springs, and Lake Manyara. Two dug wells Endepes A and Endepes B both located at Esilalei village had Fluoride concentration of 0.34 and 1.0 mg/L, respectively which are within the recommended levels in Tanzania. The Fluoride concentration in Lake Manyara is as high as 18 mg/L which is far beyond the recommended concentration level in Tanzania as well as WHO recommended levels.

Table 4 indicates that Fluoride concentration in spring water sources in Monduli district varies between 0.37 to 5.1 mg/L and that all these sources except one (at Kopok) have fluoride concentrations below both Tanzania and WHO allowable levels. On the other hand 13 dam water sources have concentration levels within Tanzania allowable Standards and the rest have concentrations above the allowable 4.0 mg/L. Further analysis of information presented in Table 4 indicate that, out of all dam and spring water sources in Monduli district, only 8 sources have fluoride concentrations above the allowable levels in Tanzania.

Table 4: Fluoride concentration in spring and dams water sources in Monduli district

Water source	Name of the source	F- mg/L	Remarks
Dams	NAFCO Moses	0.52	
	Esilalei Pr/school B	1.0	
	Esilalei Pr/school A	1.1	
	Esilalei Josho	1.3	
	Lashaine	1.4	
	Lengolwa	1.4	
	Migwara	1.7	
	Nadosoito	2.0	
	Oltukai	2.1	
	Songambele	2.5	
	Nanja TANROADS	2.9	
	Mbashi Leken	3.4	
	Nanja	3.9	
	Naiti	3.9	
	Mswakini juu Nguvukazi	5.5	
	Lepruko	5.6	
	Old Lepruko	5.7	
Moita dam	5.9		
Manyara ranch	7.5		
Emairete	7.8		
Kipok	12		
Dug Wells	Endepes A	0.34	All within allowable Tanzania level
	Endepes B	1.0	
Springs	Selela Kabambe DP	0.37	
	Mlimani Water tank tap	0.38	
	Olorashi DP	0.4	
	Kirurumo Getini bandas	0.43	
	Migombani Mzava farm	0.47	

Mgombani kati Focus tap	0.49
Majengo Kwa shamba tap	0.49
Mferejini Oribili	0.52
Engaruka chini Vibanda DP	0.53
Migombani kati Ofisi ya kijiji	0.53
Manyara hifadhini Old gate	0.58
Lolkasale A DP	0.61
Makuyuni Ugoro	0.63
Enguiki tap	0.67
Baraka Pr/ school	0.73
Migombani juu DP	1.4
Kipo G/School tap	5.1

3.1.5 Meru, Arumeru and Ngorongoro districts

Fluoride concentration in Dam and Lake water in Meru district were observed to be 38.0mg/L and 3.3mg/L, respectively. Table 5 presents a summary of various types of water sources, number of sources, and range of fluoride concentrations as observed during this study.

Majority of water sources in Meru district include Boreholes (12%), springs (49%) and shallow wells (30%) and rivers (6%). Figure 4 indicate that most of the shallow well water sources (74.3%) in this district have Fluoride concentrations above 4.0 mg/L. The corresponding values for Boreholes, springs and rivers are respectively 35.7%, 33.3% and 28.6%. Fluoride concentration levels in ranging from 4.3 to 8.1 mg/L in shallow wells this district have also been reported (Kaseva, 2005).

As can be noted Fluoride concentration in the dam (38 mg/L) far exceeds WHO and Tanzania allowable concentrations, suggesting that this source cannot be safely used as water supply source. On the other hand although Fluoride concentration in the lake water source exceeds the WHO allowable concentration, it is within the allowable levels by Tanzania standards.

Table 5: Distribution of fluoride in water sources in Meru, Arumeru and Ngorongoro districts

District	Type of source	Number of sources	Range	Fluoride concentration (mg/L)		
				0-1.5	1.6-4.0	Above 4.0
Meru	BH	14	0.09-11.0	6	3	5
	Spring	57	0.81-31.0	22	16	19
	S/W	35	0.89-32.0	4	5	26
	River	7	1.2- 30.0	2	3	2
	D/W	2	2.1-4.8	-	2	-
	Dam	1	38.0	-	-	1
	Lake	1	3.3	-	1	-
Arumeru	BH	0	-	-	-	-
	Spring	52	0.22-18.0	27	13	12
	S/W	0	-	-	-	-
	River	4	1.4-3.6	1	3	-
	Stream	3	4.0-7.5	-	1	2
Ngorongoro	BH	22	0.2-6.5	19	2	1
	Spring	25	0.28-5.5	19	5	1
	S/W	1	0.92	1	-	-
	River	3	0.36-8.6	1	-	2
	Dam	1	1.3	1	-	-

Information presented in Figure 3 indicate percentage of various water sources with fluoride concentration within WHO allowable concentration levels (borehole 42.9%, springs 38.6%, Shallow wells 11.4% and rivers 28.6%) as well as sources with concentrations within Tanzania allowable levels (Borehole 21.4%, springs 28.1%, shallow well 14.3% and rivers 42.9%). The key information as observed from these data is on the percentage of water sources with fluoride concentration within the allowable levels in Tanzania and can thus be tapped for safe water supply in Meru district. These are Boreholes 64.3%, springs 66.7%, shallow wells 25.7% and rivers 71.5%.

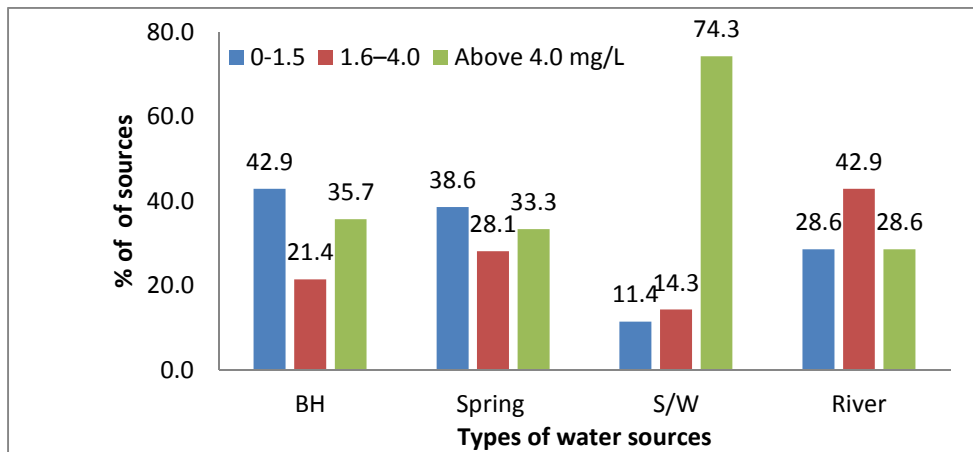


Figure 3: Percentage of water sources and range of fluoride concentrations in Meru district

Springs constitute the main (88%) of water source in Arumeru district. Others are rivers 7% and stream 5%. Table 6 indicate that concentration of fluoride in rivers in Arumeru district varies from 1.4 to 3.6 mg/L, while for streams fluoride concentration varies from 4.0 to 7.5 mg/L. Information presented in Table 6 also indicate that the four rivers sources can be used for safe water supply in Arumeru district as the fluoride levels are within the allowable Tanzania standards. On the other hand out of the three streams only one has the fluoride concentrations within the allowable levels.

Figure 4 indicate that out of spring water sources in Arumeru 52% have fluoride concentration ranging from 0-1.5 mg/L, while 25 and 23% have concentration ranging from 1.6 – 4.0 mg/L and above 4.0 mg/L, respectively. This suggests that 77% of the spring water sources in Arumeru district have water sources with Fluoride concentration within Tanzania allowable standards.

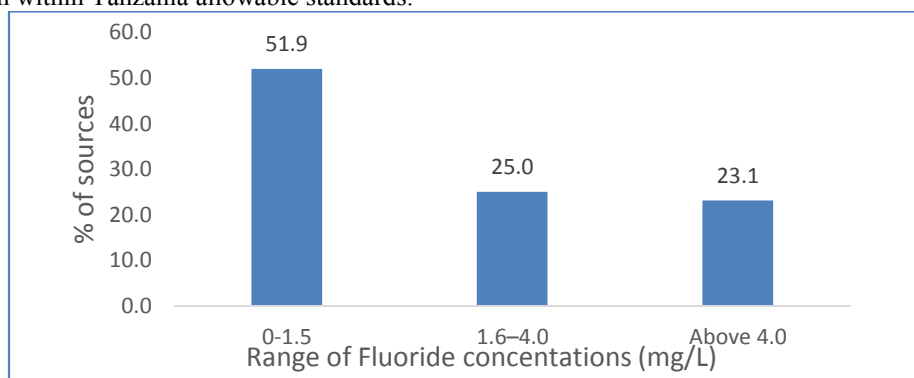


Figure 4: Spring water sources and fluoride concentration ranges in Arusha district

In Ngorongoro district water analysis for fluoride concentration was carried out in 52 sources. These includes two sources namely; springs (which constitute 47% of the sources in the district), boreholes (43% of the sources. Other sources are rivers (3 sources), dam (one source) and one shallow well. Figure 5 indicate that 86.4% of the boreholes in the district have fluoride concentration ranging from 0- 1.5mg/L. The corresponding value for spring water sources is 76%. Spring and borehole water sources with fluoride concentration ranging from 1.6 to 4 mg/L amounts to 20 and 9.1%, respectively.

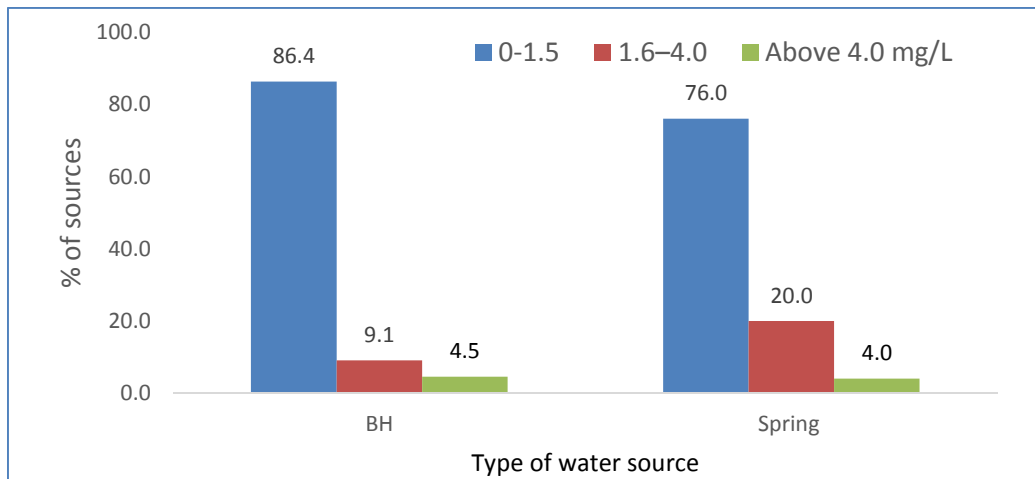
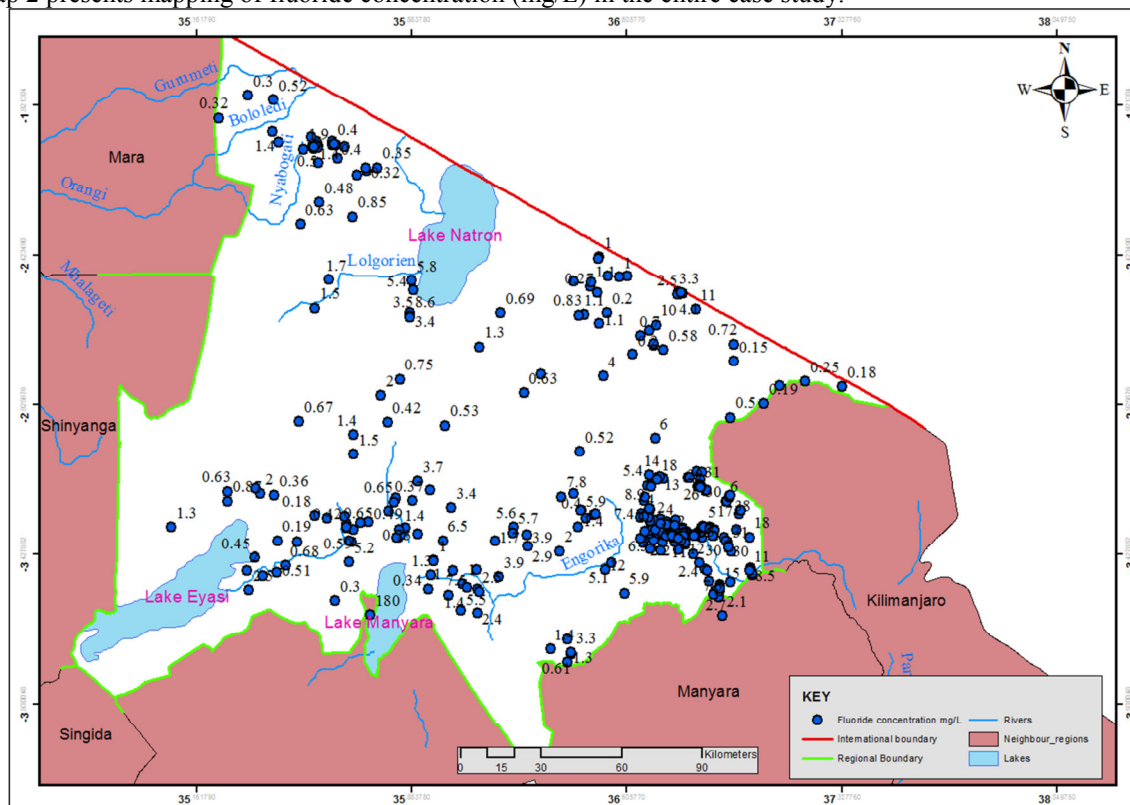


Figure 5: Spring and Borehole water sources and fluoride concentration ranges in Ngorongoro district

The general picture based on the information presented in Figure 5 and Table 5 indicate the Fluoride concentration levels in Ngorongoro district water sources. As such out of 51 water sources analyzed for Fluoride only 4 have Fluoride concentration above 4.0 mg/L, which is allowable based on Tanzania standards, suggesting a major leeway and flexibility in terms of selection of water supply sources in Ngorongoro district.

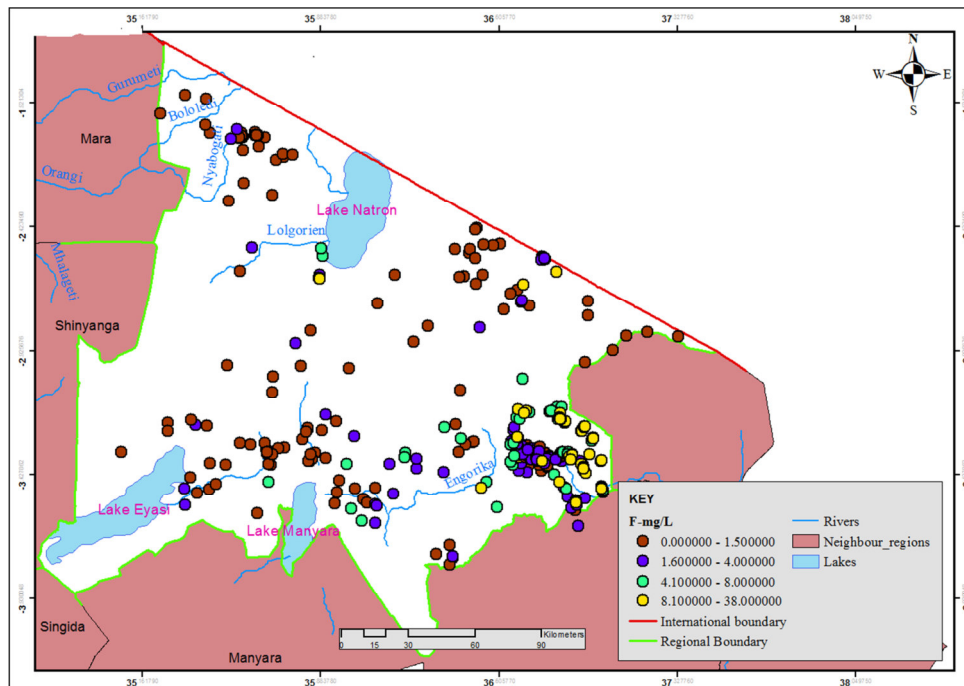
3.1.6 Overall Fluoride distribution in all seven districts

Map 2 presents mapping of fluoride concentration (mg/L) in the entire case study.



Map 2: Mapping of fluoride concentration the case study area

Map 3 presents mapping (in the range of 0-1.5, 1.6-4.0, 4.1-8.0 and 8.0 to 38.0 mg/L) of Fluoride concentration in the case study area



Map 3: Mapping (in the range of 0-1.5, 1.6-4.0, 4.1-8.0 and 8.0 to 38.0 mg/L) of fluoride levels in the case study area

4.0 CONCLUSION

Results of this study indicate a challenging situation in terms of selection of safe water supply for Arusha city and Meru district. Only 14 water sources out of 22 sources around Arusha city have fluoride concentrations within the permissible levels in Tanzania. The picture is different in Karatu, Longido, Monduli, Arusha and Ngorongoro districts. In Karatu district for example, most of the water sources have fluoride concentrations within the allowable levels, with minor isolated cases particularly in ground (shallow well) sources. Similarly, in Longido, district many of the analyzed water sources meets Tanzania allowable standards. A number of springs and dam water sources however exhibited concentrations outside the recommended levels.

In case of selection of water supply sources in Monduli district, attention and care should only be drawn to dam water sources where for example out of 22 dam water sources analyzed 7 had concentrations beyond the Tanzania acceptable level. In Arusha and Ngorongoro districts the main source of water supply (springs) have concentration within the recommended Tanzania standards. Gloomy picture in terms of high fluoride concentration in water sources is also reflected in Meru district, where a number of water sources (53 out of 117) have concentration above the Tanzania allowable levels. On the other hand however, there might be some flexibility in the selection due to presence of more water sources as compared to the rest of the case study areas in Arusha Region.

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