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Science of the Total Environment 367 (2006) 182–190

Science of the Total Environment
An International Journal for Scientific Research into the Environment and its Relationship with Humankind

www.elsevier.com/locate/scitotenv

The geographic distribution of fluoride in surface and groundwater in Ethiopia with an emphasis on the Rift Valley

Redda Tekle-Haimanot [a,*], Zenebe Melaku [a], Helmut Kloos [b], Clemens Reimann [c], Wondwossen Fantaye [a], Legesse Zerihun [a], Kjell Bjorvatn [d]

[a] *Medical Faculty, Addis Ababa University, P.O. Box 4147, Addis Ababa, Ethiopia*
[b] *Department of Epidemiology and Biostatistics, University of California, San Francisco, CA, USA*
[c] *Geological Survey of Norway, N-7491, Trondheim, Norway*
[d] *Institute for Dental Research, University of Bergen, Arstavei 17 N-5009 Bergen, Norway*

Received 16 March 2005; received in revised form 26 October 2005; accepted 1 November 2005
Available online 19 December 2005

Abstract

This paper analyzes the most extensive database on fluoride distribution in Ethiopia. Of the total 1438 water samples tested, 24.2% had fluoride concentrations above the 1.5 mg/l recommended optimum concentration recommended by WHO. Regionally, by far the highest fluoride levels were recorded in the Rift Valley, where 41.2% of all samples exceeded the 1.5 mg/l level. Only 1.0% of the samples from the central and northwestern highlands and 10.0% in the southeastern highlands exceeded 1.5 mg/l. Larger proportions of deep wells (50.0%) and hot springs (90.0%) than shallow wells (27.2%) and cold springs (12.6%) exceeded the 1.5 mg/l level. The highest fluoride concentrations were recorded for Rift Valley lakes Shala (264.0 mg/l) and Abijata (202.4 mg/l) and the lowest in Lake Tana, and rivers, wells and springs in the highlands. The fluoride concentrations of the Awash River, which originates in the highlands and flows through the Rift Valley, increase downstream, giving concern over the current diversion of high-fluoride water from Lake Beseka. Of the various flourosis prevention methods tried in Ethiopia, the treatment of surface water has been shown to be the most feasible and effective for towns and large commercial farms in the Rift Valley, although defluoridation methods should be considered for smaller rural communities.

Keywords: Spatial distribution of fluoride; Drinking water sources; Fluorosis prevention; Water treatment methods; Ethiopia

1. Introduction

Fluoride is naturally found in volcanic rocks. Significant concentrations have also been found in Precambrian rocks. Fluorite (fluorspar, CaF_2) is the most important fluoride-bearing chemical. The element is mainly stored in clay soils, groundwater and lakes in volcanic areas. Groundwater is the most important source of fluoride. Secondary sources are related to pollution from industries (ceramic factories, coal burning) and agricultural activities, particularly the use of phosphatic fertilizers. Recently it has been noticed that huge amounts of fluoride have been released into indoor environments in China by the combustion of coal, with the consequence of increased gaseous and aerosol fluoride pollution of food sources. This has resulted in serious complications of osteo-dental fluorosis (Ando et al., 2001). The magnitude of the problem in China is enormous, with more than 10 million people in Guizhon Province and

* Corresponding author. Tel.: +251 11 6620588; fax: +251 11 5518613.
E-mail address: redda@ethionet.et (R. Tekle-Haimanot).

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doi:10.1016/j.scitotenv.2005.11.003

surrounding areas reported to be suffering from dental and skeletal fluorosis (Finkelman et al., 1999).

The great African Rift Valley extends from Syria and Jordan in the Middle East to Mozambique. It is associated with high fluoride levels in groundwater. The main drinking sources of fluoride in the semiarid areas of the Rift Valley regions are deep wells. There are significant variations in the fluoride levels of the deep wells within the Rift Valley and even in the same area. This is probably related to the geophysical and geochemical characteristics, as well as the climatic conditions of various portions of the Rift Valley. Consumption of waters from deep wells in the Rift Valley has led to endemic fluorosis in several Northeast and East African countries, notably Ethiopia (Lester, 1974; Olson, 1979; Tekle-Haimanot et al., 1987), Sudan (Smith et al., 1953), Tanzania (Grech, 1966; Latham and Grech, 1967), Kenya (Ocherse, 1953; Kahama, 1997) and Uganda (Moller et al., 1970). The highest fluoride levels have been reported in the Kenyan lakes Elementaita (1640 mg/l) and Nakuru (2800 mg/l) (Williamson, 1953). Thus conclusion of a recent conference that ground water constitutes the most realistic option for increasing the supply of water in rural areas in an attempt to meet the UN millennium development goal of reducing by half the number of people without access to clean water by 2015 (McDonald, 2005) does not apply to the Rift Valley.

The Ethiopian part of the African Rift Valley *bisects* the country in a southwesterly direction (Fig. 1). This seismically active area contains active volcanoes in the Danakil Depression in the north and near-surface, young volcanic rocks in the middle and southern parts of the Rift Valley. The Rift Valley lies mostly in one of the three major climatic zones of Ethiopia, the hot, arid lowland zone (locally known as *kolla*), below 1500 m. The two other zones, the temperate zone (*woyna dega*) (1500–2400 m) and the cool, humid highland zone (*dega*) (above 2400 m) cover most of the remaining area of Ethiopia. Mean annual temperatures and rainfall range from 20 to 25 °C and less than 400 to 1200 mm in the hot lowlands to 10–15 °C and 1200 to more than 2400 mm in the cool highlands (Ethiopian Mapping Authority, 1988). Endemic fluorosis has increasingly become a serious public health problem in the country. High rates of dental and skeletal fluorosis have been demonstrated in longstanding commercial farms such as the sugar estates (Kloos and Tekle Haimanot, 1999). The fluoride problem also extends beyond the Rift Valley into some highland regions of Ethiopia where elevated concentrations of fluoride have been detected (Kloos and Tekle-Haimanot, 1993).

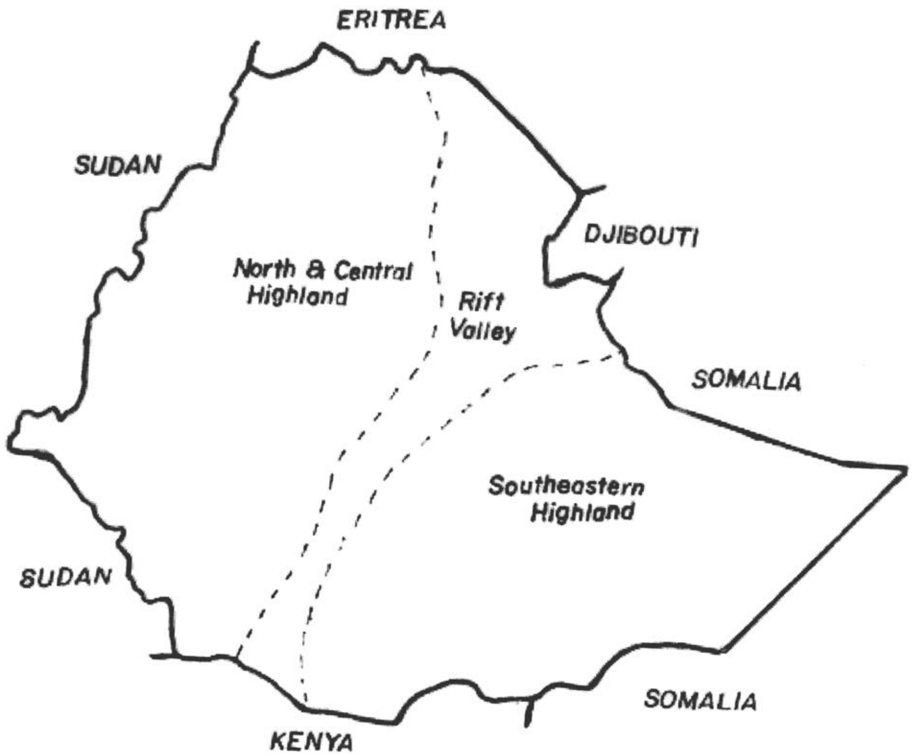


Fig. 1. Map of Ethiopia showing the highland regions and the Rift Valley (Rift Valley escarpments in dotted lines).

Domestic animals are also affected by fluorosis, as indicated by studies in southern Rajasthan state of India which revealed that calves were affected by dental fluorosis, while cattle and buffalos were more affected by skeletal fluorosis. Goats and sheep did not show evidence of osteo-dental fluorosis (Choubisa, 1999). Fluorosis in domestic animals has not been investigated in Ethiopia.

The aim of this study was to map out and describe the fluoride concentration of water samples primarily from sources used for household needs in different geographic regions of Ethiopia, with an emphasis on the Rift Valley, the most severely affected part of the country.

2. Materials and methods

The location of wells and springs were obtained from Water Bureaus of the Ethiopian Ministry of Water Resource in the different administrative Regions and Zones of the country. The inventory of these wells was found to be incomplete because there was no database or an organized registry of community water sources in the rural areas. In addition, a significant number of the deep wells were drilled by different nongovernmental organizations and were not systematically registered by the water bureaus. In order to prepare a fairly comprehensive listing of water sources in the communities and areas surveyed, the research team was required to make an active physical search of water points in a systematic way using interviews with community leaders and officials at each Administrative Zone. In the Rift Valley, attempts were made to sample as many wells and springs as possible. Detailed spot studies were made in several areas of special interest within and at the edge of the Rift Valley. Representative water sources were also sampled and analyzed for fluoride in large areas of the country outside the Rift Valley. The field hydrocensus was undertaken as part of the multinational and multidisciplinary Ethio–Norwegian programme initiated in 1996 by Addis Ababa University, Ethiopia, and University of Bergen, Norway.

Each water source identified in each zone was numbered and marked on a special spot 1:625,000 scale map obtained from the Mapping Institute of Ethiopia. For mapping all sample sites were digitized using the 1:2,000,000 scale topographic map of Ethiopia and the DAS(R) software package of the Institute for Statistics of the Technical University of Vienna. Coordinates were then linked to the F-measurements via the sample location number. Parameters used for grading fluoride concentrations are given on the maps. Water samples were collected from wells as well as lakes, rivers, and springs. Wells were divided into “deep wells” (depth ≥ 60 m) and “shallow wells” (depth < 60 m). The samples from springs were recorded as “hot springs” ($T > 36$ °C) or “springs” ($T < 36$ °C). Sampling of water was carried out by the research team that was provided with a project vehicle for its field work. Inaccessible sites were reached on horseback or on foot. The research assistants who collected the water samples were trained prior to the regional sampling. Factory-new, unwashed 100 ml high-density polyethylene bottles were used for sampling. In the field, the bottles were rinsed three times with the water to be sampled and then filled to the top. In the case of wells, sampling took place directly at the tap or wellhead. All samples were not filtered or acidified before fluoride analysis. Fluoride determination was made by means of fluoride ion electrode according to standard procedure (ORION, 1991) at the project laboratory in Nazareth, a town 100 km southeast of Addis Ababa. Duplicate samples from 200 randomly selected water points were sent to the laboratory of the Institute of Dentistry of University of Bergen for quality control of the fluoride determination. There was a very good agreement between the results of the Nazareth and Bergen laboratories at all fluoride concentrations. After the fluoride results were obtained, the spatial distribution of fluoride was plotted on maps of Ethiopia.

3. Results

Water samples from a total of 1438 sites were collected from all parts of the country except for the sparsely populated southeastern Ogaden region. The majority ($N = 830$) were from the Rift Valley. Of the total samples collected, 53.3% were from deep wells, 24% shallow wells, 16.1% from springs, 3.7% from rivers and 1.2% from lakes (Table 1).

24.2% of all the samples had fluoride levels above 1.5 mg/l, the WHO maximal optimal level for the element (WHO, 1996). To further characterize the fluoride distribution, the country was subdivided in three regions: the central part of the Rift Valley and the predominantly highland areas northwest and southeast of the Rift Valley (Fig. 1). Within the Rift Valley, 41.2% of the water samples had fluoride levels above 1.5 mg/l. In the areas outside the Rift Valley, only 3.5% had fluoride above 1.5 mg/l. In the region northwest of the Rift Valley, which is dominated by the highland regions of the country, 99% of the water samples had fluoride concentrations below 1.5 mg/l, with only 1% exceeding the optimal level. In the region consisting of both highland and lowland areas southeast of the Rift Valley, 10% of the samples had fluoride above 1.5 mg/l (Fig. 2).

From a total number of 668 wells in the Rift Valley, 44.5% had fluoride concentration above 1.5 mg/l. The

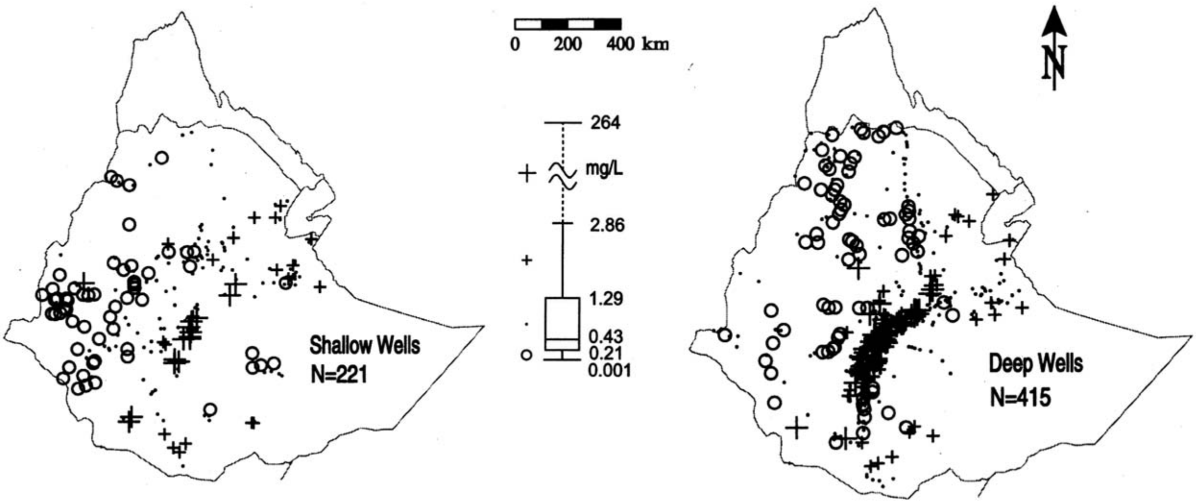
Table 1
Distribution of fluoride concentrations at 1438 water sites in Ethiopia

Fluoride level, mg/l	Within Rift Valley			Outside Rift Valley			The whole country		
	No. of samples	%		No. of samples	%		No. of samples	%	
<1.0	390	47.0	58.8	553	91.0	96.5	943	65.6	74.8
1.0–1.5	98	11.8		34	5.5		132	9.2	
1.51–3.0	132	15.9	41.2	20	3.3	3.5	151	10.5	25.2
3.1–7.0	128	15.4		1	0.2		129	9.0	
7.1–13.0	65	7.8		–	–		66	4.5	
>13.0	17	2.1		–	–		17	1.2	
Total	830	100		608	100		1438	100	

fluoride content of shallow wells was generally lower. Only 27.2% of the shallow wells had fluoride level above 1.5 mg/l as compared to 50.0% of the deep wells (Fig. 2). Water samples collected from defluoridation plants in Wonji-Shoa plantation and factory villages revealed elevated fluoride concentration ranging from 3.8 mg/l to 12.7 mg/l.

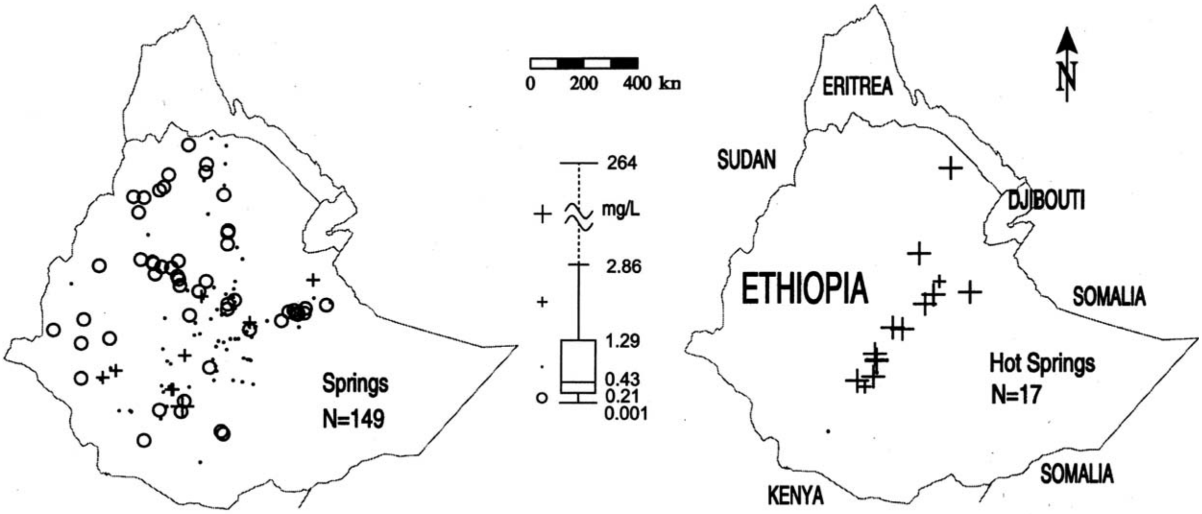
One quarter of the 115 springs sampled in the Rift Valley (90.0% of the 20 hot springs and 12.6% of the 95 cold springs) had fluoride levels above 1.5 mg/l. Eighty percent of the hot springs had fluoride level above 3.1 mg/l and 30% 13 mg/l and above. Whereas the majority of hot springs were found in the Rift Valley, the sampled cold springs were fairly evenly distributed throughout the country, the majority outside the Rift Valley (Fig. 3).

The rivers sampled, except the Awash, had levels below 1.5 mg/l. Along its course, the Awash was found to have fluoride concentrations of 1.01 mg/l at Ejersa (site furthest upstream), 0.8 mg/l below Koka Dam, 2.69 right after the confluence with the Gergedi Hot Springs,



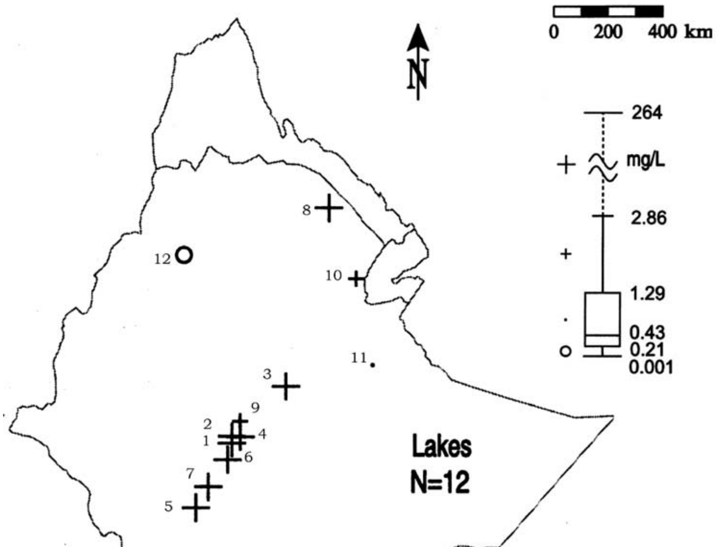
F mg/l	OUTSIDE RIFT VALLEY				WITHIN RIFT VALLEY			
	Deep wells		Shallow wells		Deep wells		Shallow wells	
	No. of samples	%	No. of samples	%	No. of samples	%	No. of Samples	%
< 1.0	225	86.5	169	92.3	192	37.9	90	55.6
1.0 - 1.5	25	9.6	4	2.2	61	12.1	28	17.3
1.51 - 3.0	9	3.5	10	5.5	93	18.4	19	11.7
3.1 - 7.0	1	0.4	-	-	102	20.2	15	9.3
7.1 - 13.0	-	-	-	-	53	10.5	7	4.3
> 13.0	-	-	-	-	5	1.0	3	1.9
Total	260	100	183	100	506	100	162	100

Fig. 2. Fluoride concentrations (mg/l) in deep and shallow wells.



FLUORIDE LEVEL mg/l	OUTSIDE RIFT VALLEY		WITHIN RIFT VALLEY			
	Springs		Springs		Hot springs	
	No. of Samples	%	No. of samples	%	No. of samples	%
< 1.0	133	97.1	79	83.2	1	5
1.0 - 1.5	3	2.2	4	4.2	1	5
1.51 - 3.0	1	0.7	12	12.6	2	10
3.1 - 7.0	-	-	_	_	9	45
7.1 - 13.0	-	-	-	-	1	5
> 13.0	-	-	-	-	6	30
Total	137	100	95	100	20	100

Fig. 3. Fluoride concentrations (mg/l) in hot and cold springs.



Lake	F^-mg/L
1. Shala	264.0
2. Abijata	202.4
3. Beseka	32.2
4. Langano	12.89
5. Chamo	8.4
6. Awasa	8.1
7. Abaya	7.2
8. Afrera Chew	3.9
9. Ziway	1.7
10. Gamari	2.8
11. Alemaya (highland near Harar)	1.1
12. Tana (highland)	1.0

Fig. 4. Fluoride concentration (mg/l) in 10 Rift Valley and 2 highland lakes.

1.21 mg/l at Wonji bridge, 1.23 mg/l at Metahara, 1.58 mg/l at Fentale, 2.07 mg/l at Melka Warer, 2.44 mg/l at Bure Maydatu near Gewani town and 1.43 mg/l at Logia town (site furthest downstream).

Of the 19 lakes tested, 9 (all in the highlands) had fluoride levels below 1.5 mg/l. All the Rift Valley lakes had fluoride above the optimum concentration recommended by WHO. The highest fluoride levels were recorded in the Rift Valley lakes Shala (264.0 mg/l), Abijata (202.4 mg/l) and Beseka (32.2 mg/l) (Fig. 4).

4. Discussion

In this national survey of fluoride distribution in Ethiopia emphasis was given to wells (deep and shallow), which form the main source of household water supply. The collection of water samples from the water sources in the Rift Valley was fairly exhaustive, and sampling from regions outside the Rift Valley was also reasonably representative. It is therefore fair to assume that the spatial distribution of fluoride as presented in the presentation depicts the real situation of fluoride in the country.

Based on levels of fluoride in groundwater fluoride distribution maps have been prepared in Kenya (Nair et al., 1984), Tanzania (Bardecki, 1974), Sudan (Shehata and Ghandour, 1990) and Ethiopia (Kloos and Tekle-Haimanot, 1993). These spatial fluoride distribution maps have contributed a great deal to our understanding of the hydro-geological characteristics of the ground waters of the East African Rift Valley. Furthermore, the distribution maps have provided useful information on the areas most vulnerable to the problems of endemic fluorosis. There is spatial variation in the distribution of fluoride in the Rift Valley even within small areas. Therefore, the data that will be generated from surveys such as ours will be extremely useful to the Ministry of Water Resources and other agencies that are involved in formulating water policies, planning and implementing water development programmes in the county, as well as providing social and health services to fluorosis affected communities and regions.

It is obvious that the Rift Valley is the region in Ethiopia that is most affected by the fluoride problem. The situation is most serious in areas along the Awash River and its tributaries, populated by large farm and increasing town populations. The Awash River, which originates in the central highlands, flows through the Rift Valley into the Afar triangle. It is economically the most harnessed river system in Ethiopia. Large-scale commercial agricultural irrigation schemes and agro-industrial projects along the river have attracted large settler communities. This has led to the development of osteo-dental fluorotic complications affecting a large number of children and adults among the settlers. Tekle-Haimanot et al. (1987) in their survey of the Ethiopian Rift Valley between 1977 and 1985 found dental fluorosis in 80% of children residing in the Rift Valley since birth. Skeletal fluorosis was also identified predominantly among adult males who had consumed water with fluoride, content of more than 8 mg/l for over 10 years. Among the severe cases of crippling skeletal fluorosis there were cases of radiculomyelopathy (Tekle-Haimanot, 1990).

In 1997, a community-based survey of skeletal fluorosis among adults in villages at Wonji-Shoa irrigation scheme revealed an overall prevalence of 65.7%. The investigators found that males had 2.5 times higher risk than females and people 55 years and older had about 20 times higher risk than young adults of age 15–24. An increasing trend was also observed with the length of stay in the villages of residence (Melaku et al., 2002).

In their study of drinking water quality in the Ethiopian Rift Valley, Reimann et al. (2003) found fluoride levels that surpassed the optimum fluoride concentration of 1.5 mg/l recommended by the European Union (EU) and WHO in 33% of the deep well samples. In hot climates where large amount of water is consumed, fluorosis has been recorded at lower fluoride levels. This has lead to the suggestion of lowering the safe fluoride level to 0.7 mg/l (25–27). If this cut-off level was taken, 58% of the Rift Valley samples would have levels above 0.7 mg/l (Reimann et al., 2003).

The present study had 668 wells sampled as compared to 138 in the Reimann et al. (2003) survey. 41% of wells in the Rift Valley were found to have fluoride level above 1.5 mg/l which is higher than the 33% of the Reimann et al. (2003) report. We believe that the larger sample size of the present study would explain the difference. If we are to use the above mentioned argument of 0.7 mg/l optimum concentration for hot climates, 69% of the wells of the Rift Valley identified in the present study would have unacceptable high fluoride levels. This is quite significant considering that in most areas of the semiarid Rift Valley the deep wells are the only source of drinking water for humans and in many cases for livestock as well.

Kloos and Tekle-Haimanot (1993) did not disaggregate their data by type of water source but nearly three quarters of the 65 sites in the Rift Valley they reviewed from the literature were wells and the remaining sites lakes, rivers and springs. Seventy-two percent of the 65 sites had fluoride levels above 1.5 mg/l. This high proportion of high concentrations was largely to be due to objective of most early surveys to focus mostly on suspected high-fluoride sites, especially deep wells in irrigation farms and towns rather than providing more representative data for the Rift Valley as was attempted by Reimann et al. (2003) and this study. Thus, although all 3 studies covered similar areas in the Rift Valley, the latter 2 studies studied larger proportions of low-fluoride shallow wells in smaller rural communities.

Three areas were studied in detail to illustrate different aspects of the fluoride problem in the Rift Valley. Wonji-Shoa Sugar Estate, established in 1952, is a highly developed, densely populated agroindustrial complex located in the central part of the Ethiopian Rift Valley south of Addis Ababa. This sugar agroindustrial complex has a highly developed medico-social service with defluoridation plants put into operation since 1962. The fluoride levels of all the wells and defluoridation plants were extensively analysed in this survey. All the deep wells have very high fluoride levels (above 3 mg/l). The defluoridation plants also showed elevated fluoride concentrations. From the results obtained in this survey and previous studies it is evident that after nearly 30 years of experience, the defluoridation system does not provide a safe and dependable supply of domestic water (Shifera and Tekle-Haimanot, 1999). A viable alternative source of community water supplies for Wonji-Shoa Sugar Estate, and by inference Metahara Sugar Estate and other densely populated commercial farms and agroindustrial complexes in the Rift Valley, is treated surface water. This approach had been proposed by McDonald and Partners Limited to the Ethiopian Sugar Corporation in 1984/85 (McDonald and Partners, 1984/85). The use of treated Awash River water for the drinking water supply of Wonji-Shoa Sugar Estate is likely to be implemented in the very near future. In the Ethiopian contexts attempts at defluoridation will not only be impractical but too expensive and technically unattainable and sustainable for large populations. Defluoridation plants should be considered at the household and small community levels for more isolated populations.

Planning the development of low-fluoride water supplies for a fluoride endemic community requires a thorough knowledge of local hydrogeological conditions. An exhaustive inventory of the water sources being used by the community is essential. The regional water bureaus and the Ministry of Water Resources should have a comprehensive water chemistry database that is regularly updated. This is far from the reality in Ethiopia. A good illustration is the case of the Meskan and Mareko District (*Wereda*) in Gurage Zone in central Ethiopia, situated at the edge of the Rift Valley. The western part of the sub-district is an extension of the highlands of the Gurage area, while the eastern section is part of the hot and dry Rift Valley. During the survey repeated request made to the local representatives of the Ministry of Water Resources for a list of community water supply sources in the district revealed the location of only 16 sites, 5 of which were non-functional wells. However, an intensive search by members of the research team located 44 water supply sources, including shallow wells. The fluoride levels of these water sources revealed a distinct linear demarcation between the low fluoride waters in the highland areas and the high fluoride sources in the lowlands (within the Rift Valley). The intensive analysis of the local water and the subsequent fluoride mapping clearly demonstrated the practical use of such data. Water could be piped from a low fluoride well to an adjacent village where the fluoride content was high. Such an approach has been implemented in the village of Ele (1.2 mg/l), which is going to provide water to neighbouring villages with high fluoride 3–5 mg/l wells. It is clear from this experience that there is an urgent need to improve on the system of inventory of water supply points by both the local and central governmental offices of the Ministry of Water Resources. The information of each water supply site should contain exhaustive water quality data, including results of chemical and bacteriological monitoring. Such data should be made freely accessible for prospective deep well drilling and spring development.

Excess fluoride consumption leads to fluorosis which, in the severe skeletal form, is a crippling disease without any effective therapy once it sets in. All public health activities concerning fluoride should therefore concentrate at preventive measures. The situation around Lake Beseka requires special mention in this regard as it is going to exert a long term influence on River Awash. The hydrogeologically active Lake Beseka is situated near the extinct Fantale volcano, the town of Metahara and Awash National Park, 190 km east of Addis Ababa. It is an evaporation lake which has a high fluoride content of 32.2 mg/l. The water level of this lake has been rising for over 30 years. This has periodically disrupted the rail and road communications between Addis Ababa and the eastern and northeastern parts of the country. The rail line and road had to be raised several times. In the early 1960s the surface area of the then shallow lake was only 5 km^2. In 1976 the area measured 27.5 km^2. With a net annual increase of 5 million m^3 it now (in 2004) covers an area of 40 km^2, with a maximum depth of 11–12 m. This has resulted in the flooding of 35 km^2 of grazing and 50 ha of irrigated land. According to the Lake Beseka Study and Design Project of the Ministry of Water Resources, the water quality of Lake Beseka is similar to that of nearby hot springs and groundwater, suggesting that the cause of the rise in the lake level is the inflow of hot ground water. The Ministry, on expert advice, started a project diverting 22.8 million m^2 of the lake's water into the Awash River under the assumption that the blending of these waters would significantly affect the salinity of the river water or cause an increase of fluoride concentration from 1.37 mg/l to 2.0 mg/l (Ministry of Water Resources, 2004). As evidenced by this study and confirmed by Robi Tekle-Haimanot's (2003) more detailed survey, the Awash River has fluoride concentrations which increase along its course due to the inflow from high-fluoride hot springs. There is no doubt that there is going to be further fluoride pollution of the river by the diversion of Lake Beseka water that will affect downstream communities, most of which depend on Awash River water for domestic purposes, livestock watering, and irrigation. Although the implementing authorities have promised that the discharge of the lake water will be carried out at intervals and during seasonal high river flow in order to maximize the dilution effect, the fluoride levels of communities located downstream of the point of lake discharge into the Awash will have to be monitored very carefully and on a regular basis. A look out for early evidence of dental and skeletal fluorosis in the communities located downstream of Metahara will have to be scientifically planned with baseline surveys as early as possible.

Ethiopia does not as yet have a structured preventive policy on fluorosis. Earlier in this discussion the failure of defluoridation plants using activated alumina adsorption technique at the Sugar Estates had been mentioned. The problems faced there are related the high cost limitation of resource and logistic constraints of operating and maintaining the defluoridation plants. There is also the additional of problem of compliance of the community in using defluoridated water.

Other methods have been tried, some at a pilot study level. These included bone-meal and bone-char methods, which were not acceptable for taste and religious reasons (Tekle-Haimanot, 2005). Clay (laterite) has been found to be effective but further developing is required to make it practical and effective to be used at the household level (Zewge, 1989; Zewge and Moges, 1990; Bjorvatn et al., 2003).

The most effective approach to the fluoride problem in Ethiopia and the other East Africa countries would be the supply of treated surface water to large populations and simple and low-cost defluoridation plants for smaller communities. The initial investment of treated surface water supply may be high. However, it will prove cost-effective in the long run because expensive health and socio-economical consequences would be prevented. A good illustration is the new Nazareth municipal water supply from treated Awash River water, which has proved to be economical to operate and a reliable supply of safe drinking water.

There is of course the need to evaluate existing defluoridation methods and possibly develop even newer ones in order to provide Developing Countries such as Ethiopia with defluoridated water produced at low cost but with acceptable chemical and bacteriological qualities. The social acceptability of the method is also of paramount importance (Heidweiller, 1990).

Acknowledgement

This study was undertaken as part of the Ethio–Norwegian Fluoride Project of the Faculty of Medicine of the Addis Ababa University and financially supported by the Norwegian State Educational Loan Fund, NUFU project 61/96. The investigators are grateful to all research assistants who participated in water sample collection and fluoride analysis, especially Mr. Tesfaye Tadesse and Mr. Samson Tsewameskel. We thank Tor Erik Finne and Liliosa Magombedze for helping with the digitalization and production of the maps.

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