The Right to Smile: Fluoride and Fluorosis in Central Rift Valley (Ethiopia)

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The Right to Smile: Fluoride and Fluorosis in Central Rift Valley (Ethiopia)

Sara Datturi, Assefa Kumsa, Seifu Kebede, Frank van Steenbergen and Martin van Beusekom

Unlocking the Potential of Groundwater for the Poor

1. Introduction

This magazine presents the outcomes of a study in the Ethiopian Central Rift Valley (ECRV), where an estimated 8 million people are exposed to high levels of naturally occurring fluoride. Consumption of drinking water, beverages, and food puts them at risk of dental and skeletal fluorosis.

This study compares the efficacy of the two main fluoride mitigation measures, defluoridation (the Nalgonda and bone char techniques) and safe sourcing, in terms of sustainability, cost-effectiveness, and vulnerability. The study's outcomes suggest that sourcing drinking water from safe sources is the preferred approach, because it reduces management burden and enables wider coverage. When safe sources are absent, community based bone char fluoride removal systems are proven to be a good alternative. Furthermore, community involvement before the project is implemented plays a crucial role in the success of defluoridation.

2. Background

Fluorine is a common element, widely distributed in the Earth's crust. It exists as the anion fluoride (F^-) in natural waters, with higher concentrations expected in ground waters (Dace et al. 2002). Fluorine has benefits for dental health, although despite these benefits the optimal dose of F^- has a narrow range. Excessive doses of F^- are detrimental to health and can lead to dental fluorosis (DF, see figure 1), and in more extreme cases skeletal fluorosis (SF) (Farewell et al. 2006).

According to UNESCO (Feenstra and Griffioen, 2007) more than 200 million people worldwide rely on drinking water with F^- concentrations exceeding the present World Health Organization (WHO) guideline of 1.5 mg/l (WHO, 2008). Long-term use of drinking water with fluoride significantly above the WHO guideline value of 1.5 mg/l can have serious effects on health (Tekle-Haimanot 2005a; Farewell et al. 2006; Rango et al. 2010). In 2006, the WHO registered 28 countries where DF and SF were associated with exposure to high fluoride concentration in drinking water. Among these, the most affected were India, Ethiopia, and China (Farewell et al. 2006; Susheela 2013).

In the Ethiopian Central Rift Valley (ECRV) an estimated 8 million people are exposed to high levels of naturally occurring F^- (Tekle-Haimanot 2005a; Rango et al. 2010, 2013; Kravchenko J et al. 2014). Daily intake of fluoride (primarily through drinking water and beverages but also via food) put a large part of the rural population in the ECRV at risk of dental and skeletal fluorosis. Fluorosis does not only affect people's health, it also has serious economic and social consequences. For instance, appearance-related and psychological problems caused by the aesthetic value of dental fluorosis, particularly among the young, should not be underestimated. The prevalence of fluorosis and the related widespread health problems may stigmatize entire villages (Rodd and Devidson 1997; Mcknight et al. 1998; Melaku and Shabbir 2002; Tekle-Haimanot and Grabet Tehadiso 2014).

The ECRV is part of a large basin that extends from Syria and Jordan to Malawi and Mozambique. Due to its geological

Figure 1: Children with dental fluorosis, in the Ethiopian Central Rift valley.

and climatic characteristics, it has some of world's highest concentrations of fluoride, mainly in deep wells in the semi-arid parts (Tekle-Haimanot 2005b). The main source of F^- are the acid volcanic rocks, which have both high F^- and low calcium concentrations. Over 40 % of deep and shallow wells are contaminated with F^- concentrations up to 26 mg/l (Tekle-Haimanot 2005b). However, the distribution of F^- in the deep wells is very variable, even among wells that are closely spaced.

Although the major cause of fluorosis is the elevated level of fluoride in drinking water, temperature, nutrition and health status, and deficiency of calcium and vitamins have been found to be important contributory risk factors for developing skeletal and dental fluorosis (Kaseva 2005; Zewge 2011; Rango et al. 2012; Dessalegne et al. 2013; Tekle-Haimanot and Tehadiso 2014). Studies have indicated that an increased intake of calcium (through for instance milk, yogurt and cheese), vitamins C (orange, carrots, lemons and tomatoes) D and E (nuts, beans etc.) and antioxidants (garlic, ginger, pumpkins) help reduce the fixation of fluoride to the apatite in the human bones (Susheela & Madhu2002; Malde et al. 2010). Additionally some research showed that a high intake of other food items such as tea leaves or teff(a major food crop in Ethiopia) can increase the quantity of fluoride entering the human body (Dessalegne et al. 2013).

Recent research by Kravchenko et al. (2014) demonstrated that consuming milk on a daily basis, and breastfeeding in the early phase of dental formation led to a less severe form of DF. They also found that the severity of DF increased with age, probably due to the increasing exposure to excessive F^- in water and food. Another study conducted by Dessalegne and Zewge (2013) found that in households relying on drinking water with high concentrations of F^- (> 10mg/l), 86 % of the daily F^- intake was from water (30 mg/day), with the remainder from food sources.

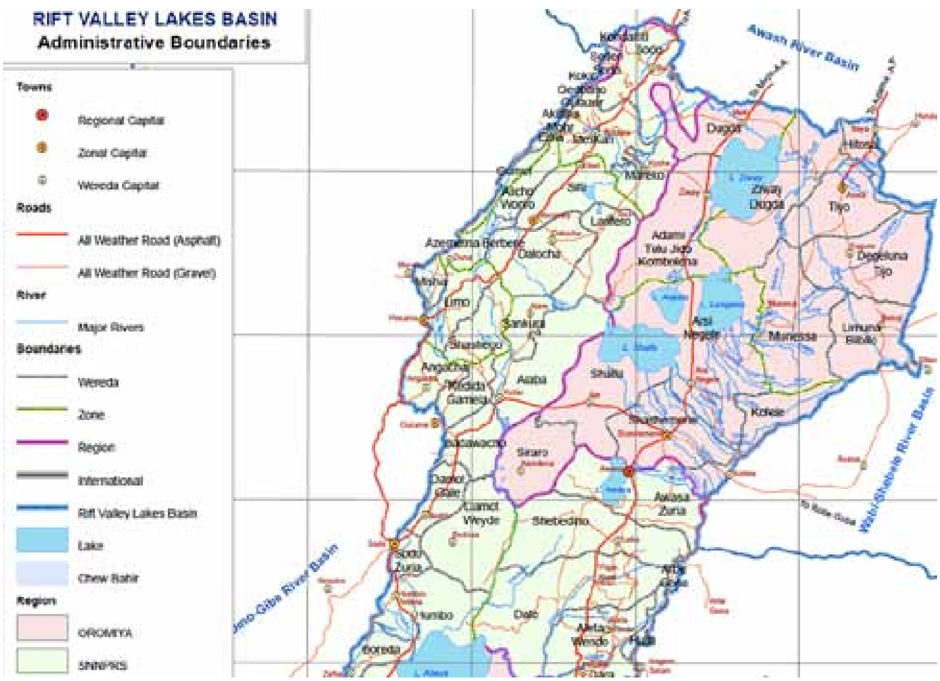


Figure 2: Source- Rift Valley Lakes Basin Integrated Resources Development Master Plan Study Project (2009).

3. Water Access

According to the last publication realized by the Water Supply and Sanitation Directorate National Fluorosis Mitigation Project Office (2013), in Ethiopia, the regions that are facing excessive fluoride in groundwater are Afar, Oromia and the Southern Nations and Nationalities Regional State (SNNPR). These regions are located in the Ethiopian Rift Valley part of the Great African Rift Valley. This area of the world extends from Syria and Jordan in the Middle East to Mozambique and it usually associated with high level of fluoride in groundwater (Tekle-Haimanot 2005b). The Ethiopian part of the African Rift Valley bisect the country in a South westerly direction and it is characterized by volcanic and basaltic rocks, which are more likely to release a high concentration of fluoride.

The study area of this project is part of the Ethiopian Central Rift Valley (ECRV), which falls within the administrative borders of Oromia National Regional State and Southern Nations and Nationalities Regional State (SNNPR). Important sub-basins are Ziway-Shala, Abaya-Chamo and the Awasa catchment (see figure 2). Surface water sources contribute 38 % to the annual water balance in this area (Hengsdijk & Jansen 2006). Important lakes in the region are Ziway, Langano, Abijata, Shalla, Awasa, Abaya and Chamo, of which some have also high fluoride concentrations. Key rivers are Meki, Bulbula, and Ketar. Groundwater contributes 62 % of the annual water balance (Hengsdijk & Jansen 2006). Although clean sources of water are available in Oromia, only 50.2 % of the rural population have access to an improved system of water supply within 1.5 km of its household (National WASH Inventory 2012). The non-functionality of the rural water schemes in Oromia Region is 25 % according to the same report. However, official report from the Oromia Water, Mines, Energy Bureau (2014) claims that the current coverage is just above 70 %.

In the ECRV, the low-income population relies on agriculture and cattle rearing as their main source of income. Access to water is limited. In vulnerable households, children and women are in charge of collecting water for their families, walking an average of 10 - 15 kilometres per day (UN women, 2011). During the dry season, access to water becomes even more problematic due to increased pressure on water sources and the lowered water tables leads to failure of pumps. However, the linkage between potable water and fluorosis is not always recognized by communities. Cultural beliefs are still in place, for instance some water users link dental fluorosis to the will of local spirits (Huber & Mosler 2013). This awareness is changing thanks to the various intervention programs in the region.

4. Governance

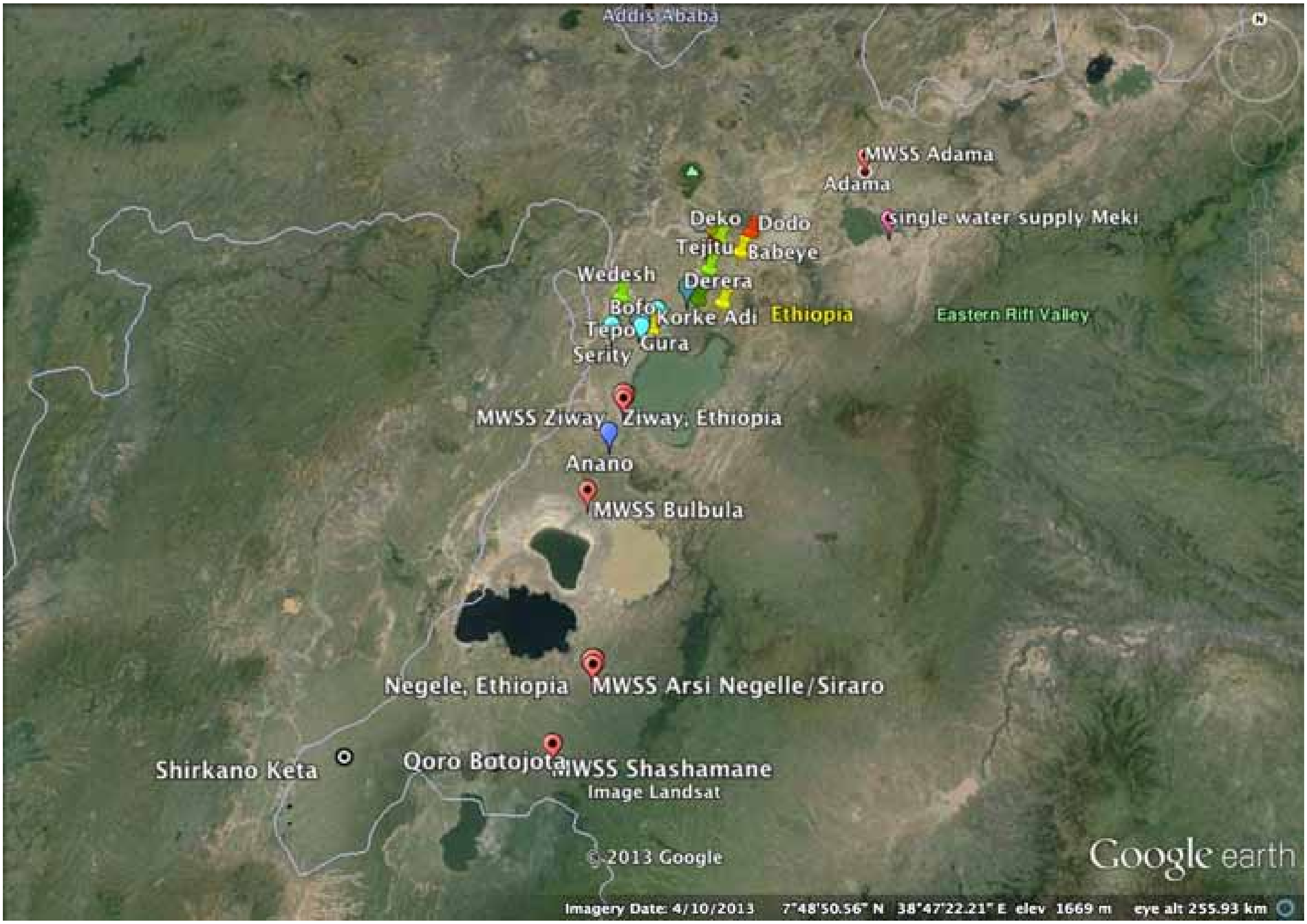
Several actors with different kind of interventions are trying to control Fluorosis. Figure 3 shows the location of 10 defluoridation schemes and five multiple-village water supply schemes (MWSS) surveyed. Defluoridation schemes included six community bone char filters implemented by Oromia Self Help Organization (OSHO), eight Nalgonda schemes developed by Catholic Relief Service (CRS), half of them non-functional and two Nalgonda schemes developed by Lay International Volunteer Association (LVIA)- but not functional. The last two were visited in order to understand the vulnerabilities of defluoridation schemes. As for multiple village water supply schemes, water supply offices were visited in Adama, Ziway, Bulbula, Arsi Negelle/Siraro and Shashamane.

Furthermore, several policies at the national (Universal Water Access Plan - targets fluoride control) and regional levels (National Fluorosis Mitigation Project – established fluoride steering committees) were designed to manage impacts and map prevalence. The National Fluorosis Mitigation Project (NFMP) in collaboration with the Oromia and Southern Nations, Nationalities, and Peoples' Region (SNNPR) Water Bureaus aim to map the distribution of fluoride, assess the chemical risk of water sources and to carry out projects on alternative water supply.

Besides, stakeholders such as NGOs (e.g. OSHO and CRS), research institutes (e.g. Swiss Federal Institute of Aquatic Science and Technology Eawag and UNICEF) have carried out studies and piloted defluoridation schemes to test ways to supply low fluoride water in the ECRV. An overview of the experiences of above-mentioned organizations is provided later in this magazine.

5. Implemented Fluoride Mitigation Strategies

Since the discovery of high fluoride in drinking water in the Ethiopian Rift Valley in 1970, scientists have developed



Symbol	Type of schemes	Symbol	Type of schemes
⊙	LVIA visited non functional Nalgonda Scheme		OSHO functional bone char scheme not visited
	CRS Nalgonda functional scheme visited		OSHO functional bone char scheme visited
	CRS Nalgonda non functional scheme not visited		Single water supply scheme visited
	CRS Nalgonda functional scheme not visited		Multiple water supply scheme visited

Figure 3: Study area: Deflouridation schemes and MWSS visited in Ethiopian Central Rift Valley.

various ways to reduce the F^- concentration in drinking water. At present, a wide range of techniques exists for F^- removal (Tekle-Haimanot et al. 1987).

The most common defluoridation techniques are absorption, precipitation, coagulation, membrane processes, distillation and electrolysis. Ion exchange and/or adsorption are widely accepted technologies used on a full-scale basis and are used in various countries worldwide (Farewell et al. 2006; Feenstra et al. 2007).

In developing countries the logistical challenges and the high cost associated with defluoridation technology, including the cost of power supply, chemicals, regeneration, and consumables can be a constraint to the implementation and sustainability of schemes. In addition local issues including acceptance of the technology by the community may result in rejection or incorrect usage of the scheme (Huber and Mosler 2013).

Several technologies have been developed, though it is primarily the Nalgonda and bone char techniques that have been implemented at large scale at the local level for instance in Kenya and India (Ayoob et al. 2008). These techniques are also the most commonly used in Ethiopia (Osterwalder et al. 2014).

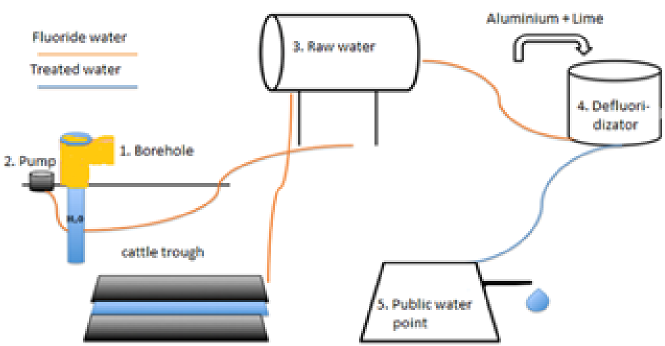


Figure 3: Nalgonda deflouridation scheme (own source).

5.1 Nalgonda

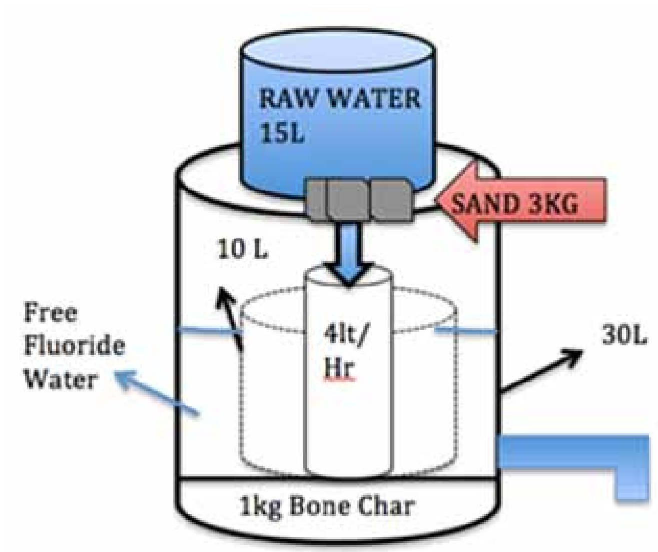
The Nalgonda technique was developed and adapted in India by the National Environmental Engineering Research Institute (NEERI) to be used at either community or household level. It uses the process of aluminium sulphate based coagulation-flocculation-sedimentation, where the dosage is designed to ensure F^- removal from the water. In Ethiopia, under the fluorosis mitigation project promoted by UNICEF and the Federal Water and Energy Ministry, the Nalgonda technique has been piloted in several rural communities. Furthermore, CRS has been implementing this technique in communities in the ECRV since 2005.

Over the last 10 years, 20 of such systems have been installed in the ECRV. Of these 20, half are no longer functional with some of them never having been used. The Nalgonda schemes still functioning are the ones implemented by CRS (in cooperation with the National Fluoride Steering Committee-NFSC). Some NGOs who tried to establish Nalgonda systems were faced with several constraints.

In the following section, an account of the Nalgonda implementation experience of CRS is presented. Dodo (Bora woreda) 85 meters deep borehole, pumps F^- rich water into an 10 m^3 untreated water tank. This raw water is then diverted into the de-fluoridizator (Figure 4, point 4), where the technician treats it with aluminium sulphate and lime. This tank has a steer root to mix the chemicals: this process takes five minutes. After the mixing, flocculation occurs over three to four hours. This treated water is then released towards the common water point. On the other side, a cattle trough is attached to the raw water tank.

5.2 Bone char

The bone char technique uses a locally produced filter media of activated carbon and hydroxyl apatite (using bones collected from local butcheries, mainly from cows). In Ethiopia the technique has been implemented by the local NGO Oromia Self Help Organization (OSHO). The community-level projects were financed by British and



The household bone char filter is made of two blue plastic baskets. The raw water basket is of 15 L capacity. Filtered through a layer of bone sand (3 kg), the water drips into the second tank. This process takes about 30 minutes. The users can keep the process going if they keep refilling the first tank with raw water.

Figure 5: Household bone char.

Swiss funds and supported with technical, economic and social expertise of Eawag and Swiss Inter-church Aid (HEKS) (Osterwalder et al. 2014).

Bone char filters are made of powdered cow bones. The factory processing the filters is based in Mojo (15 km north of Adama) and is being established through a project fund established by the Swiss Federal Institute for Aquatic Science and Technology (Eawag). OSHO's first experience with defluoridation technology involved introducing this filter to 200 household units, an approach that was not embraced by the target communities. The main reasons are the necessity to manage the filter (always relaying on external help for water quality test) and incapacity to realize when the filter needs to be regenerated. Figure 5 depicts a household bone char filter unit and its legend explains how the structure works.

The lessons learned were integrated in a new design for bone-char filters at the community level.

There are seven community bone char schemes implemented by OSHO in cooperation with Eawag benefitting over 3,000 households. Eawag, OSHO and Nakaru Catholic Foundation (NCF) highlight that this is the most sustainable setup in a rural context in developing countries, as it is fairly low-tech and can be assembled using

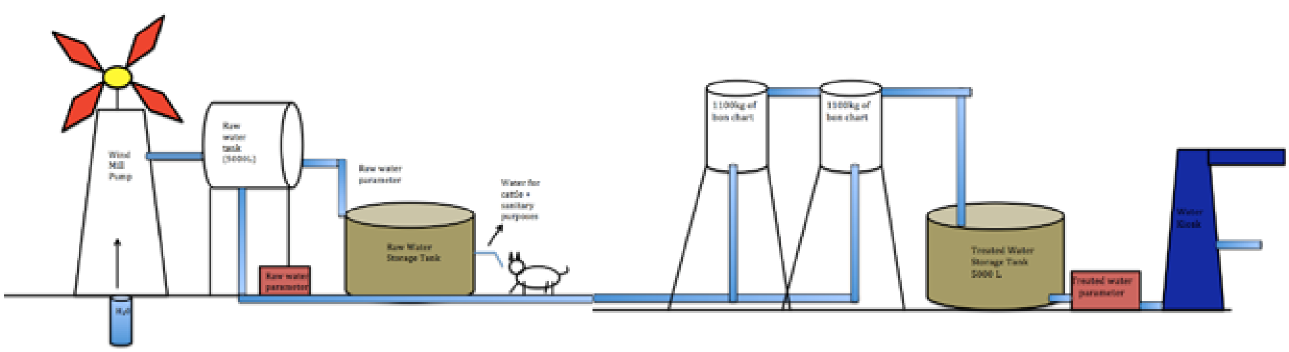


Figure 6: Community bon char defluoridation scheme.

locally available material (see figure 6). This brings down the need for external assistance.

5.3 Multiple-village Water Supply Schemes

Besides defluoridation, the Ethiopian government is currently investing in expanding multiple-village water supply schemes (MWSS) aimed at delivering low F^- water throughout the ECRV. In fact, in the last decade the Ethiopia Federal Government enacted several water policies and programs to ensure safe drinking water supply to its population. Important strategies are: the Hygiene and Sanitation Strategic Action Plan 2011 - 2015, Drinking Water Quality Monitoring and Surveillance Strategy, Water Sector Policy, One WASH Programme, National Policy Guideline for Self-Supply and the Universal Access Plan (for water supply). All of these strategies state the necessity to enhance safe drinking-water supply to all Ethiopian citizens. However, in Ethiopia, there is no standard specification on maximum acceptable levels of fluoride in water, though in the last ten years several organizations have adopted the WHO guidelines and in practice have refrained from commissioning wells that have fluoride levels above this threshold. The Ethiopian government recommends raising the threshold to 3.5 mg/l, thus accepting the inevitability of a certain degree of dental fluorosis (Ethiopian Ministry of Water Resources, 2002).

At present, five MWSS are in operation in the study area of the ECRV Ethiopian Rift: Adama, Ziway, Bulbula, Arsi Negelle/Siraro and Shashamane. Adama, Ziway and Shashamane are urban water supply scheme, which according to their design have the aim to supply mainly urban dwellers, but currently they are also serving rural kebeles (Ethiopian word for neighbourhoods). Bulbula, Arsi Negelle/Siraro are rural water supply schemes. Bulbula Rural Water supply project aims to supply rural communities in 13 villages including Bulbula town with a fluoride-free water supply system. Arsi Negelle/Siraro water supply project supplies free supply rural communities in three weredas (Ethiopian word for district) a fluoride-free water supply system (Arsi Negelle, Shahsemene, Siraro Weredas). Siraro is now under the new Wereda called Shalla Wereda. A new MWSS, “Oromia Lakes Region Water Supply Project” is currently under construction and it has the aim to supply safe drinking water to Arsi Negelle, Shala, Shashamane and Siraro Weredas through 170 km of distribution network (57 water points and 23 cattle troughs).

These MWSS’s are supported at the regional level by the Water, Mines and Energy Bureaus of Oromia and SNNPR, which have invested in safe sourcing strategies to deal with the high fluoride concentrations and extend the safe water supply coverage to remote rural communities.

Table 1, given in the next chapter, shows the main features of the five MWSS. The practice is for the MWSS to be constructed over a number of years, having been extended and renovated. For instance, since 2006, the Adama water supply line has extended to reach Wonji/Shoa villages (5 km South of Adama). It initially reached only Adama town and four rural kebeles (neighbourhoods). In Adama there is a supply-demand gap up to 30 %. In fact, as it is possible to see in table 1 , Adama MWSS was constructed and design considering a population of 200,000 inhabitants, which now is 350,000 plus 72,000 of Wonji/Shoa area (CSA, 2008). The same applies for Shashamane where on a population of 300,000 inhabitants, the percentage of persons covered by the system reach only 53.22 %.

Three of the five MWSS schemes use low fluoride water from lakes or rivers and are equipped with a treatment facility. Bulbula and Arsi Negelle/Siraro on the other hand schemes rely on groundwater derived from springs and boreholes. The number of connections differs from scheme to scheme. All water offices reported that water users have to pay for a private connection, while users of public water points are not charged.

6. Cost, Benefit and Vulnerability Analysis

60 Randomly selected water users were interviewed. An average of seven beneficiaries at each water defluoridation scheme and MWSS were interviewed, among them three were women. Data on the reasons of failure, water consumer patterns and perception of fluoride problem were collected.

Six parameters were used to calculate the costs for both types of schemes. The initial investment (i), total operational costs (ii), investment costs per m^3 (iii); operational costs per m^3 (iv), profit per m^3 (v) and water tariff (vi).

The benefits were calculated by identifying the number of beneficiaries per Fluoride Treatment Scheme and MWSS. The number of beneficiaries includes daily water users from the communities as well as irregular users from external kebeles (local Ethiopian territorial legal entity). This indicator estimates the population having access to low-fluoride water.

The vulnerability of the schemes was measured by calculating the reliability of water supply. The local community expressed that a waiting time of more than 15 minutes was not reliable. Furthermore, different NGOs implementing defluoridation plans were visited such as CRS, OSHO and LVIA. Data on the reasons of failure, water users' habit and perception of fluoride problems were collected.

7. Results

7.1 Multiple-villages Water Supply Scheme

7.1.1 Costs

- Collection of data on the costs (initial investment, operational costs and water tariff) of individual MWSS proved difficult because of the absence of systematic and standardized financial reports;

Table 1: Main characteristics of the Multiple Water Supply Schemes

Multiple Water Supply Scheme	Year of implementation	Source of water	Current total length of pipes including branches to each water points	Treatment plant	Designed number of users benefiting from MWSS	Number of water users benefiting from MWSS
Adama Extension to Wonji/Shoa	2002	Awash River	NA	YES	200	295 on a total population of 422
Ziway	2002	Ziway Lake	85	YES	20	41,42 on a total population of 43,610
Bulbula WS	2008	Tufa Spring + 3 springs	111	NO	-	73
Arsi Negelle/Siraro WS	1995 - 1998	13 wells drilled; 10 are productive	153	NO	120	257
Shashamane WS	2010 boreholes 1999 Wesh river	Wesh river + 2 boreholes	NA	YES		160,000 On a population of 300,000
					Total Water users benefiting from MWSS	**826,42**

- Table 2 presents an estimation of the total operation costs, based upon which the profit and monthly return on investments could be estimated;
- The higher investment costs per m3 are in Arsi Negelle/Siraro (15.22 Birr/m^3), probably because of the high cost of drilling 10 wells (180 - 200 meters depth) as main source of water;
- Operational costs ranges typically between 0.43 and 23.44 Birr/m^3 (they become higher in case of power cuts because of the use of generators);
- In Arsi Negelle and Shashamane, there are frequent power cuts reflected in their high operational costs;
- The highest total operational costs are in Shashamane MWSS, due to the high costs for chemicals used to treat water from Wondo River, which are all imported apart of aluminum sulphate;
- Water tariffs have been also raised to increase the high operational costs (i.e. in Arsi Negelle/Siraro the water tariff of 14 Birr/m^3 is in place);
- The higher operational costs are not calculated in the water tariff in Shashamane (4.5 Birr/m^3). This explains the loss made by the Shashamane water utility.

7.1.2 Benefits

- The number of persons served by MWSS is large (ranging from 41,420 to 295,000) per system (table 1);
- In each of the six MWSS, water users from rural kebeles come to fetch water from the public water points (i.e in Adama next to serving urban water users, MWSS is also used by four rural kebeles);
- Walking distance have become shorter over time (from one hour to 30 minutes);
- Villages that before were relying on drinking water with high fluoride concentrations, have now access to clean low fluoride water (i.e Wonji/Shoa);
- During fieldwork, it was observed that the youth who consumes water from these water points did not suffer from undesirable effects on their appearance related to dental fluorosis. This observation needs to be validated with further researches and epidemiological studies.

Table 2: Investment and Operational costs per each MWSS (Birr/m^3)

Water Supply Scheme	Initial investments (Birr)	Total operational costs m^3 (Birr)[2]	Investment cost per m^3 (Birr)[3]	Operational cost per m^3 (Birr)	Profit per m^3 (Birr)[4]	Water tariff (Birr/m^3)
Adama Wonji/Shoa	110,000,000	5,450,000	1.63	1.61	2.44	4.05
Ziway	29,500,000	4,474,203	1.17	3.55	2.45	6
Bulbula	26,000,000	3,000,000	0.19	0.43	9.57	10
Arsi Negelle/Siraro	48,000,000	3,696,000	15.22	23.44	-9.44	14
Shashamane	60,000,000	8,622,185	3.40	9.77	-5.27	4.50

1) (CSA, 2008).
2) Maintenance, chemical and electricity costs sum together give the total Operational Costs. The total Operational costs were calculated by using the data available. Not all schemes had the available data for electric, maintenance, chemicals and management costs divided. In these cases, estimation was made.
3) The return of the investment cost is calculated on the entire life span of the system (20 years).
4) Profit may not represent the actual reality on the ground: management issues such as illegal connection and revenues water are not shown in the actual calculation.

7.1.3 Vulnerabilities

- The main problems reported are water shortage, leakages and issues related to daily operational and maintenance costs;
- According to table 3, Adama (3 to 5), Bulbula (3 to 4) and Ziway (3 to 4) have faced the most instance of water shortages days per week for the longest period of time;
- All water schemes were designed without taking in consideration the population growth in twenty years

Table 3: Vulnerabilities of MWSS (Own source)

Name of the MWSS	Frequency of water shortage per week (no presence of water for two hours onward)	Main problems reported
Adama	3 - 5	• Leakages, from 30 to 40% • Old pipes in the line • Daily maintenance due to road and other construction • Increase in cost of chemicals • All chemical additives except for alum are imported
Ziway	3 - 4	• O&M costs increase of 30 to 50%. (over the last five years) • Old pipes and increase of leakages along the main line • Increase in pollution • Increase in cost of chemicals • All chemical additives except for alum are imported
Bulbula	3 - 4	• The system's maintenance structure is unstable • Frequent bursts • Daily maintenance needed due to frequent breakdown • The structure is of low quality (the system is quite new; a lifecycle of 20 years was guaranteed) • Pipes and lines need to be changed, but at the moment there are not enough funds to do that • Leakages
Arsi Negelle/ Siraro	2	• Breaking pipes (3 to 4 times per week) • Leakages • Old pipes (13 years old) • Water pollution • Dirty pumps, water gets stuck • Interruptions in power supply • Water users complaining about the high costs of supply
Shashamane	1	• All chemical additives except for alum are imported • Not enough water for the whole community • People use Wondo river when they face water shortage; this is a health risk • Illegal connections • Power interruptions (at least once a week) • Lack of transportation facilities • People tend to emigrate

length. This lead to an increase of water demands in particular in Adama where on a population of 350,000 plus 72,000 in Wonji/Shoa the coverage of water supply is only 70 % (295,000 inhabitants covered by the MWSS in total). This situation is also present in Shashamane where on a current population of 300,000, the actual number of persons covered by MWSS is 160,000[1]);

- Exceptional conditions applied in Adama city for road construction interfered with the water line system;
- In Ziway, Adama and Shashamane, more chemicals are needed to treat the increasing pollution of rivers and lakes;
- In Bulbula, daily maintenance is needed due to frequent breakdown of the new water pipeline structure although a life cycle of twenty years was guaranteed.

7.2 Defluoridation schemes

7.2.1 Costs

- Table 4 shows the costs divided according to initial investment, total operational and per m^3 costs, treated water tariff (Birr/m^3), profit and profit per month;
- In the initial investment costs, cost of developing a water source is considered. For all schemes visited, a shallow motorized or windmill well was in place. However, for a clear vision of the costs per each water source development see table 5;
- In a community defluoridation scheme, the installment of a water source is the major part of the initial investment and it has direct consequences on the operational costs;
- Household bone char filters units cost the least to the community members, but are not in use anymore (low

Table 4: Investment, operational costs and profit for each defluoridation scheme.

Type of Defluoridation Schemes	Initial Investment (Birr)[5]	Investment Cost (Birr/ m^3)[6]	Total Operational Costs (Birr/ month)[7]	Operational Costs (Birr/ m^3)	Treated Water Tariff (Birr/m^3)	Profit (Birr/m^3)	Profit per Month (Birr)
Nalgonda[8]	560	8.52	8,449	15	11	-0,65	-349
Bone char Community with fuel[9]	543,418	7.44	7,852	13	22	9.91	5,948
Bone char Community wind-powered[7]	543,418	7.44	2,852	4	20	15.24	9,148
Household Bone chart[10]	5,71	0.62	816	10	20	NA	NA

[5]) *For all three-community defluoridation schemes, the initial investments have included the costs to develop a shallow well-motorized water source. Furthermore, these data were reported considering the initial investment to set up the entire scheme (water tanks, pipe line, kiosk and water storage).*

[6]) *The value is calculated considering a life span of Nalgonda and bone char of ten years.*

[7]) *The total of operational costs for Nalgonda are the sum of water caretaker salary, fuel, guard salary and chemicals. For the community bone char are the sum of water caretaker salary, maintenance, regeneration and sampling. Per HH bone char are the sum of only regeneration and sampling costs.*

[8]) *As implemented by CRS and LVIA experience, data collected from their reports and during the interviews, calculations were made by making an average between the two schemes' costs.*

[9]) *As implemented by OSHO: data collected during interviews.*

[10]) *Household Bone Char is not in use anymore. Profit per m^3 and Profit per month could be calculated.*

Table 5: Costs of developing a water source.

Hand dug wells	From 10 to 30 thousands Birr
Motorized shallow well (100 m depth)	Up to 500 thousands Birr
Deep well of 250 m depth	From 1.2 to 1.5 million
Spring Protection	Up to 50 thousands Birr

treatment capacity and not able to be sustain by the household in the long term);

- The initial investments required by Nalgonda systems are higher than those of bone char systems and their treatment capacity is also lower (8.52 versus 7.44 Birr/m^3);
- Operational costs of Nalgonda systems are also higher because of the chemicals costs required;
- Fuel costs involved in both community bone char and Nalgonda treatment methods contribute to operational costs. It is for this reason that bone char systems with windmill-powered pumps have lower operation costs;
- Nalgonda systems reviewed have lower water tariffs than the ones of Bone char. However, this price does not cover the total operational cost, as the chemicals were subsidized for CRS by government;
- The community bone char systems, as they are in operation, are able to break-even and even make a small profit, even including costs;
- Nalgonda systems, on the other hand, have operational costs that invariably outweigh income;
- In engine-powered community bone char systems, returns on investment can be expected within seven months. Windmill-powered ones can expect returns within four months.

7.2.2 Benefits

- As table 6 shows, a total of 39,865 people currently have access to low fluoride water (data collected on the field)[11];
- This comprises 3,000 households covered by Nalgonda systems. Including the additional 1,000 households from remote rural kebeles also accessing these systems, this amounts to 20,000 individual water users;
- Community bone char systems currently cover 2,973 households including the approximately 1,000 households from remote rural areas from outside the coverage area that also access them, with a total coverage of 19,865 individual users;
- The kiosks developed by OSHO and through the involvement of *eder* in CRS Nalgonda schemes are an important benefit of community systems[12];
- OSHO developed a kiosk where the water caretaker sells a part of treated water as well other items. In this way, the caretaker's commitment increases because it is in his/her own interest to stay at the kiosk and cater to customers;
- In both experiences (OSHO and CRS), the location was key to the functioning of the system. The water points can also be reached through the main road and in case of technical problems, they do not have to wait too long for repairs;
- However, the location is not 'central' for a person living in remote rural areas, which means they have to walk long distances to get the water. In this case, if they would have to pay the original price of treated water, they would prefer to go to Meki town rather than to get it from NGO-developed water points.

[11]) *This value was calculated considering a rural household characterized by 5.0 people (CSA 2008).*

[12]) Eder *is a traditional social institution established with the mutual agreement of community members, to help out, whenever any members or their family members face adverse situations. People voluntarily choose to be part of it. Membership entails they are also in charge of burial activities or supporting the grieving families economically.*

7.2.3 Vulnerabilities

- The main vulnerabilities of Nalgonda systems pertain to both social and technical issues;
- The water shortage per week is higher in the Nalgonda systems than in the community bone chars ones (two - three times per week compared to one);
- Others vulnerabilities reported are common to both schemes: power outages, leakages in tanks, breaking of the pumps (etc.);
- Specific limitations of Nalgonda systems pertain to technology and management of these systems;

Table 6 Benefits and Vulnerabilities of de-fluoridation schemes (own source).

	Schemes	
	Nalgonda	**Bone char**
Households Coverage (Each rural household has 5.0 people in average, CSA 2008)	• 3,000 Households • 1,000 Households from external kebeles • Total: 4,000 Households	2,973 Households 1,000 Households from external kebeles Total 3,973 Households
Total Coverage (per person) per scheme	Total person: 20,000	Total person: 19,865
Total Coverage per person of the two schemes	39,865 persons covered by Nalgonda and bone char defluoridation schemes	
Management arrangement	A good water committee needs to follow all the steps • Technicians need to be trained to know the chemicals quantity to add • Caretaker should live near the treatment scheme to control the process • Costs of chemicals are high if not subsidize, the system will hardly be sustainable in the long term	• Constant monitoring and water quality tests need to be done by external organizations • Necessity of training, awareness and social operators
Actual reduction of F	Average of 30 - 40 % of the original F content reduced 0.7 - 3.7 (mg/g)	Average of 40 - 50 % of the original F content reduced 2.3 - 4.7 (mg/g)
Number of water shortage per week	2 - 3	1
Other Vulnerabilities	• Sludge disposal: during the rainy season, the tank collecting the wastewater needs to be controlled to manage the risk of flooding • At the beginning of the treatment, the water can taste a bit salty • The treatment takes 4 hours, the location needs to be chosen carefully • Power outages • Breakdown of pump • Leakage from the tanks	• Windmill breakdown • Leakages from the tanks • Power outages • Scarcity of fuel needed for the generator
Side Benefits	Involving Eder can be a good strategy to enhance the involvement of the community	Dual function kiosks, selling not only water but also other necessary items -Availability of raw materials

- They include the inevitable saline taste in the treated water, the long time required to treat water and the necessity of employing a well-trained caretaker who could manage the administration of chemicals to the high-fluoride water during the treatment process;
- The main limitations of bone char systems include the need to replenish the bone char every six months, the value of choosing an appropriate site and involving people, and the need for constant monitoring (monthly) of the quality of treated water.

8. Discussion and conclusions

- This cost-benefit-vulnerability analysis of defluoridation and safe sourcing systems provides several insights in the efficacy of current programs and projects to mitigate fluorosis. It identifies frequent (common) failures, socio-technical vulnerabilities and profitability status of the schemes (see table 7);
- Cost benefit analyses shows that MWSS is less costly than community defluoridation method regarding investment and operational costs per m3 and water price's affordability;
- On scale of vulnerability both methods are facing daily operational problems, but MWSS are more likely to be fixed. For defluoridation schemes the engagement of the community is fundamental for their long-term functionality, although full economic-managerial independence is not yet in place in the schemes visited;
- On scale of benefit, MWSS are able to reach more people than community defluoridation schemes (95.40 % versus 4.60 %). However, community defluoridation schemes are vital in areas where not other safe sourcing are available because they allow people to have access to low fluoride water.
- Nevertheless we need to investigate the opportunities around finding safe source of water for permanent sourcing or as a backup for the multi community scheme approaches;
- Considering an average of drinking/cooking water consumption in Ethiopia of 3,650 litres per year (UNDP, 2006), and taking the average of the water tariff for the community defluoridation scheme and MVWSS, it is possible to conclude that the cost per person per year is much lower for safe sourcing (see Figure 7).

Further lessons learned

Lesson 1: Developing a large Multiple Villages Water Supply Scheme when low fluoride sources are available is more cost-efficient and sustainable in the long term.

Lesson 2: Community defluoridation systems can be developed within isolated communities, which cannot be connected to the large water supply schemes, but certain criteria need to be taken into consideration (i.e. type of filter, location, engagement of the community).

Lesson 3: The capacity of NGOs to connect with local institutions, codes and needs is decisive for the long-term sustainability of community level defluoridation schemes.

Lesson 4: Community level defluoridation schemes are

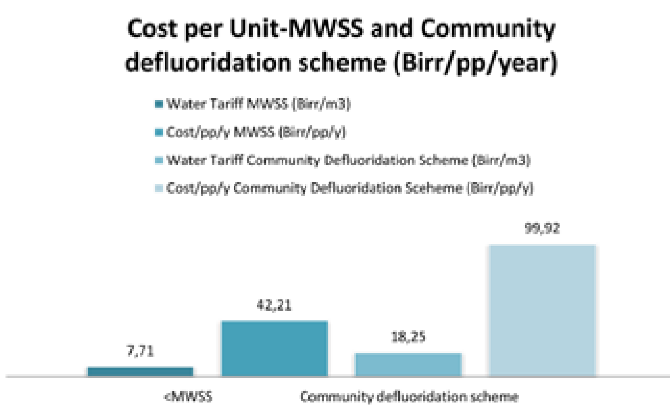


Figure 7: Cost per units of water per person per one year (Birr/m^3) at the MWSS and defluoridation schemes.

not profitable and that running costs for the purchase of expensive chemicals (in the case of Nalgonda systems, for example) and water sampling and replacement of filters (bone char) still have to be subsidized by external agencies such as NGOs.

Lesson 5: Understanding the current strategies in place to deal with high fluoride concentration is as important as understanding the distribution of fluoride in groundwater.

Lesson 6: Communication between governmental, regional, local and NGO stakeholders need to be improved.

Table 7: Benefit and vulnerabilities of MWSS and Defluoridation schemes.

Scheme	MWSS	Nalgonda	Bone Char
Investment cost m³/Birr	4.32	8.52	7.44
Operational Cost per m³ / Birr	7.76	15	8.5
Water Tariff (unsubsidized price) Birr/m³	7.71	11	20
Effects on fluoride reduction	F is either absent or lower 1.5 mg/l	Average of 30 - 40 % of the original F content reduced 0.7 - 3.7 (mg/g)	Average of 40 - 50 % of the original F content reduced 2.3 - 4.7 (mg/g)
Main Vulnerabilities	• Leakages • Old pipes in the line • Increase in cost of chemicals • Pollution • Dirty pumps, water gets stuck • Interruptions in power supply • Water users complaining about the high costs of supply	• Electricity breakdown • Breaks in the pumps • Sludge disposal • Long time for filtering • Salty taste of the water	• Windmill breakdown • Leakages from the tanks • Electricity cuts • Not enough fuel for the generator
Management Arrangements	• Good management of the scheme is required • Local water officers need to be constantly active in solving the O&M issues • Problem between authorities might occur • Involvement of NGO's in the managment	• A good water committee needs to follow all the steps • Involde Eder can be a good strategy to enhance the involvement of the community • Technicians need to be trained to know the chemicals quantity to add • Caretaker should live near the treatment scheme to control the process • Costs of chemicals are high if are not subsidized, the scheme will be hardly sustainable in the long term	• ·Good to introduce Kiosk with double function, not only selling water but also material • Constant monitoring and water quality tests need to be done by external organization • Necessity of training, awareness and social operators
People covered by each scheme	826,42	20	19,865
Percentage of people covered by all schemes	95.40 %	2.31 %	2.29 %

References

Ayoob, S., Gupta, A.K., and Venugopal, T.B. (2008). A Conceptual Overview on Sustainable Technologies for the Defluoridation of Drinking Water, Critical Reviews in Environmental Science and Technology 38, no. 6: 401 - 470.

Central Statistical Agency (CSA) (2008). Federal Democratic Republic of Ethiopia Statistical Abstract December, Addis Ababa.

Dace, O., Wiatrowski, E., Samachson, J., and H. Spencer (2002). Fluoride Analysis of the Human Diet and of Biological Samples, Clinica Chimica Acta 51: 211 - 216.

Dessalegne, M., and F. Zewge. (2013). Daily Dietary Fluoride Intake in Rural Villages of the Ethiopian Rift Valley, Toxicological & Environmental Chemistry: 1 - 13.

Farewell, J et al. (2006). Fluoride in Drinking-Water. World Health Organization with IWA publishing: 1 - 144.

Feenstra, L.V., Griffioen, J. (2007). International groundwater resource assessment center, Fluoride in Groundwater: Overview and Evaluation of Removal Methods: 1 - 25.

Hengsdijk, H., Jansen, H. (2006). Ecosystems for water, food and economic development in the Ethiopian central rift valley, BO-10-006-22, Report of inception mission to Ethiopia and Workplan. Plant Research International.

Huber, A.C., Mosler, H.J. (2013). Determining Behavioral Factors for Interventions to Increase Safe Water Consumption: a Cross-Sectional Field Study in Rural Ethiopia. International Journal of Environmental Health Research 23, no. 2: 96 - 107.

Kaseva, M.E. (2005). Contribution of Trona (Magadi) Into Excessive Fluorosis. A Case Study in Maji Ya Chai Ward, Northern Tanzania: 1 - 9.

Kravchenko, J., Rango, T., Akushevich, I., Atlaw, B., McCornick, P., Merola, R.B., Paul, C., Weinthal, E., Harrison, C., Vengosh A., and M. Jeuland (2014). The Effect of Non-Fluoride Factors on Risk of Dental Fluorosis: Evidence From Rural Populations of the Main Ethiopian Rift. Science of the Total Environment: 1 - 12.

Malde, M.K., Scheidegger, R., Julshamn, K., Bader, H.P. (2010). Substance Flow Analysis: a Case Study of Fluoride Exposure Through Food and Beverages in Young Children Living in Ethiopia. Environmental Health Perspectives 119, no. 4: 579 - 584.

McKnight, C.B., Levy, S.M., Cooper, S.E., Jakobsen, J.R. (1998). A pilot study of aesthetic perceptions of dental fluorosis vs. selected other dental conditions. ASDC J. Dent. Child, 65, 233 - 238.

Melaku, Z. Shabbir, I. (2002). Perception on Fluoride Related Health Problems in an Area of Endemic Fluorosis in Ethiopia: an Exploratory Qualitative Study: 1 - 9.

Meseret, D. and F. Zewge (2013). Toxicological & Environmental Chemistry, Daily dietary fluoride intake in rural villages of the Ethiopian Rift Valley, Toxicological & Environmental Chemistry, DOI: 10.1080/02772248.2013.827685.

Ministry of Water Resources (MoWR). (1999). Ethiopia Water Resources Management Policy, Review of Rural Water Supply UAP Implementation and Reformulation of Plans and Strategies for Accelerated Implementation, Addis Ababa, Ethiopia.

Ministry of Water Resources (MoWR). (2002). Ethiopian Guidelines: specification for drinking water quality. Federal Democratic Republic of Ethiopia. Addis Ababa, Ethiopia.

Ministry of Water Resources. (2009). Rift Valley Lakes Basin Integrated Resources. Development Master Plan Study Project. Federal Democratic Republic of Ethiopia. Addis Ababa, Ethiopia.

Ministry of Water Resources. (2011). Revised Rural Water Supplies Universal Access Plan. Federal Democratic Republic of Ethiopia. Addis Ababa, Ethiopia.

Ministry of Water Resources. (2012). National Water and Sanitation Inventory. Federal Democratic Republic of Ethiopia. Addis Ababa, Ethiopia.

Ministry of Water Resources.(2013). Spatial Distribution of Fluoride in the Ethiopian and its Adjacent Highlands. Water Supply and Sanitation Directorate National Fluorosis Mitigation Project Office. The Federal Democratic Republic of Ethiopia 1 - 149.

Oromia Water, Mines, Energy Bureau. (2014).Water Access in rural Areas. The Federal Democratic Republic of Ethiopia.

Osterwalder, L., Johnson, C.A., Yang, H., Johnston, R.B. (2014). Multi-criteria assessment of community-based fluoride-removal technologies for rural Ethiopia, The Science of the Total Environment., 488 - 489, 532 - 8.

Rango, T., Kravchenko, J., Atlaw, B., McCornick, P.G., Jeuland, M., Merola, B., and A. Vengosh (2010). Groundwater Quality and Its Health Impact: an Assessment of Dental Fluorosis in Rural Inhabitants of the Main Ethiopian Rift, Environment International 43: 37 - 47.

Rango ,T., Vengosh, A., Dwyer, G., and G. Bianchini. (2013). Mobilization of arsenic and other naturally occurring contaminants in groundwater of the Main Ethiopian Rift aquifers, Water Research, http://dx.doi.org/10.1016/j.watres.2013.07.002.

Rodd, H.D., and Davidson, L.E. (1997). The aestethic management of severe dental fluorosis in the young patient. Dental Update, 24, 408 - 811

Susheela, A.K., Bhatnagar, M. (2002). Fluoride Induced Cell Injury Through Elimination of Fluoride and Consumption, Molecular and Cellular Biochemistry, 1 - 6.

Tekle-Haimanot, R. (2005a). Study of Fluoride and Fluorosis in Ethiopia with Recommendations on Appropriate Defluoridation Technologies: a Unicef Sponsored Consultancy, Ed. Addis Ababa.

Tekle-Haimanot, R, Melaku, Z., Kloos, H, Reimann, C., Fantaye, W., and L. Zerihun. (2005b). The Geographical Distribution of Florid Surface and Groundwater in Ethiopia with an Emphasis on the Rift Valley, Science of the Total Environment, Vol. 367, No. 1, 2005, 182 - 190.

Tekle-Haimanot, R., Haile, G. (2014). Chronic Alcohol Consumption and the Development of Skeletal Fluorosis in a Fluoride Endemic Area of the Ethiopian Rift Valley, Journal of Water Resource and Protection, Vol. 6 No. 2: 149 - 155.

United Nations Development Programme. (2006). Human Development Report 2006: Beyond Scarcity–Power, Poverty and the Global Water Crisis, Basingstoke, United Kingdom, Palgrave Macmillan.

UN Entity for the Gender Equality and the Empowerment of Women, UNIFEM Fact Sheet: At a Glance – Women and Water UN Women. http://www.unifem.org/materials/fact_sheets.php?StoryID=289 .

WHO. (2008). Guidelines for Drinking-water Quality: Third Edition Incorporating the First and Second Agenda, Volume 1 Recommendations, Geneva, Switzerland.

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