ORIGINAL ARTICLE

DEVELOPMENT OF APPROPRIATE DEFLUORIDATION TECHNOLOGIES FOR ETHIOPIAN COMMUNITIES

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ABSTRACT

BACKGROUND: ***In the world, about 25 countries are affected by fluorosis. Such health problems related to consumption of water with excessive fluoride are a general public and governmental concern. In this case different investigations have been done on how to remove the excess fluoride in the water supply system. Despite these investigations, low cost defluoridation techniques that can be used by all the communities at household level are hardly available. This study has investigated the fluoride removal efficiency of local materials like clay pot filters, crushed brick filters in a pot and crushed brick filter with homemade sand filter.***

METHODS: ***The aim of this study was to see the fluoride removal efficiency of local clay pots and crushed bricks made with clay materials around Jimma. The preparation of fluoride filtration apparatuses was divided in to three: a) conically designed clay pot filters from local potters around Jimma town, made with different sand to clay ratio; b) crushed brick fluoride filters made by putting five liters of crushed bricks in a local clay pot having delivery pipe at the bottom; and c) crushed brick fluoride filters made with homemade sand filter.***

In these filters, after initial fluoride concentrations are measured, fluoridated water samples having different concentrations were poured and filtered through the media. The filtrates were collected and analyzed for fluoride content using standard methods.

RESULTS: ***Appreciable fluoride removal has been observed in both filters. In case of clay pot filters, as the ratio of sand to clay increase the percent removal of fluoride increase but the amount of filtrate decrease. Application of these technologies is cost effective, applicable to household label and can be adjusted with other contaminant removal methods like homemade sand filter and large scale water treatment plants.***

CONCLUSION AND RECOMMENDATIONS: ***These technologies can be easily adapted at household level in the majority of Ethiopian communities because they are cheap and easy to construct. Conical clay pot fluoride filters and crushed brick fluoride filter in clay pot and with homemade sand filter can be built with a simple demonstration. In addition local potters can produce such conical clay pot fluoride filters and can provide with low cost to the communities whose water supply system is fluoridated above the recommended limit. Further studies need to be done to know the filtration duration of these fluoride filtration media.***

KEY WORDS: C*lay pot, fluoride filters, defluoridation techniques*

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INTRODUCTION

Fluoride is a common element of the most rock formations and other mineral compounds of the earth's crust (1). Highest prevalence and intensity of dental and skeletal fluorosis, are found around intercontinental hot spots, aborted rift zones and Andean type magmatic belts. Fluoride ion is released in to the ground water sources in geologically unstable areas and has been associated with rifting and rise of fluorine from the lower crust or upper mantle (2).

In rural areas of Ethiopia people are still consuming untreated water from rivers, springs, wells, surface impoundments and other sources which often contain biological and chemical agents detrimental to health (3).

Fluoride is a chemical, which can be found in many ground waters as natural constituents. High fluoride concentration occurrence in such water sources and the risk of fluorosis associated with consumption of such water is a problem faced by many countries, notably Rift Valley countries in East Africa, India, Turkey, Sri Lanka, and China (4). As the latest information showed by UNICEF, fluorosis is also endemic in at least 25 countries one of which is Ethiopia (5).

For a better health, the world health organization (WHO) recommends the fluoride content to remain below 1mg/l in warm climates, and in cold climates it could go up to 1.2 mg/l (5). In Jimma and other rift valley areas large proportion of drinking water sources have fluoride content much higher than the recommended limit (3, 6). For example study done by Teklehaimanot R. have showed that fluoride level of drinking water collected from wells rift valley areas of Ethiopia ranged from 1.2 mg/L to 36.0 mg/L. As the same time 80% of the sampled children resident in this same area birth have been found to have dental fluorosis, and 32% of the children showed sever dental mottling (7).

Kloos H. and Teklehaimanot R. (2) have reported that the fluoride concentration above the recommended limit, 1.5 mg/L, have been found in all parts of Ethiopia.

Galagan and Vermillion (8) indicated the fact that water requirement increases in hot climate as a result of which if fluoride is available in excess of the recommended limit the effect will be worsen than cold climate areas. In such climate the health effect could be adverse due to high consumption of water with relatively lesser fluoride concentration.

In third world countries dental and skeletal fluorosis is endemic because of the presence of this chemical in excess concentration and the absence of inexpensive defluoridation methods (9).

By principle this excessive fluoride in drinking water should be removed; but simple inexpensive methods of fluoride removal are not readily available (3). Some of the methods used to defluoridate are ion exchange using activated alumna, bone char, which needs a furnace to be burnt by higher degree heat, reverse osmosis, and flocculation (3, 5).

Treatment by large scale and advanced defluoridation has the disadvantage of being expensive both in plant construction and high operation and maintenance cost. In addition it is difficult to be utilized by the majority of rural and semi urban communities. The procedure is also complicated which makes it difficult to be operated by locally available human power. A case in point is Wonji sugar factory, which uses automatic defluoridators.

Such problems encourage and enforce scientists to search for simple, available, and economically affordable defluoridation techniques to protect the community from fluoride related problems.

Different researchers have tried simple way of defluoridating water by the country's available material. For example Zovenbergen, C. (9) have used local Kenyan soil derived from volcanic ashes as a fluoride sorbent, and have affirmed that the method is more economical and efficient for defluoridation. Likewise this researcher has found that clay wares fired at 600 ^{o}C have showed fluoride reduction from drinking water.

Fluoride removal by adsorption into burnt clay resins has been studied using countries' clay soil (4).

The main aim of this study was to develop defluoridation technology, which is cost effective and available to the general public at household level. The other main objective was to see the fluoride removal efficiency of these equipments. The treatment methods used in this study are expected to solve the problem of communities who are dependent on the consumption of ground water. Hence, they will be able to defluoridate water at household level using locally available material. Moreover, the study will help teaching institutions to disseminate information and gives a baseline data for researchers.

MATERIALS AND METHODS

An Experimental Study was Conducted in School of Environmental Health and Technology Faculty, Jimma University.

Sample preparation:
Water samples with different concentrations of fluoride were prepared using tap water and fluoride salt. Each water sample was initially tested for knowing initial concentration of fluoride before filtration. Five liters of fluoridated water sample was filtered through each of different clay pot filters, crushed bricks in clay pot and slaw sand filter.

Filter media preparation
Filtering media needed for this study were divided into three. These are the conical clay pot filter, crushed brick fluoride filter made in clay pot, and crushed brick fluoride filter made with homemade sand filter.

1. Conical clay pot fluoride filter preparation
Local potters from Jiren Kebele, near Jimma town, together with investigators have prepared six pots, which have thick and conical shape at the bottom (fig. 1). The pots were fired or glazed as the clay materials are prepared for marketing. Refiring of the clay materials as domestic purposes was not done because it will hinder the filtration.

These apparatuses have a capacity to hold about 10 liters. The filtrate was collected from the bottom. The pot bottom used for filtration was made from pure clay soil with out adding sand and clay soil mixed with sand. Adding sand was to make the filtering media more porous so that it helps to get better quantity of filtrate. In addition, it avoids complete elimination of the fluoride from the drinking water. The sand to clay ratio used was 1:1 and 1:3.

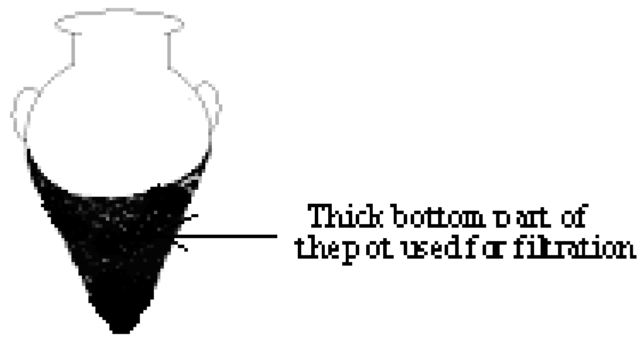

Figure 1 Conical clay pot fluoride filter made with different sand to clay ratios

2. Crushed brick fluoride filter in clay pot

Three Ordinary clay pots were prepared with special order from local potters from Jiren, which has an outlet at the bottom (Fig. 2). These claypots were filled with 5 liters of crushed brick after the brick is crushed and washed. This was made to show how this technology could be fit to the local materials that we have at hand.

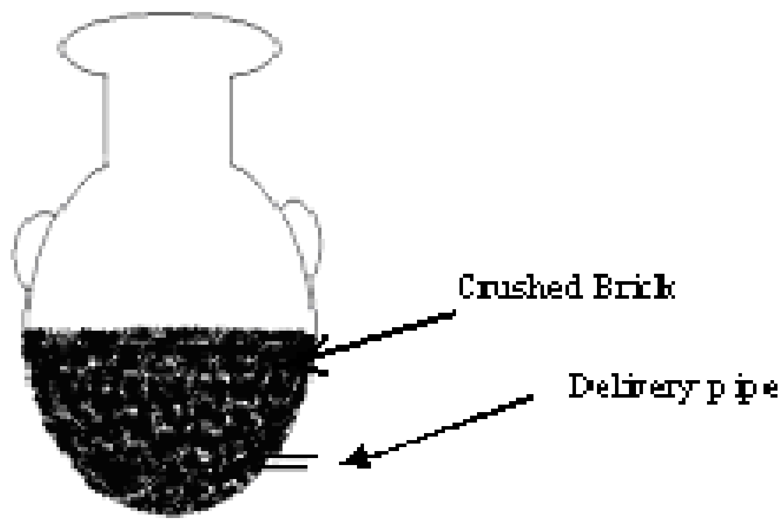

Figure 2. Crushed brick fluoride filter made in clay pot

3. Crushed brick fluoride filter made with homemade sand filter

Home made sand filters are known in the removal of physical, chemical and biological impurities from raw waters. In this case to see the effect of crushed brick in the removal of fluoride, crushed brick was used as filtering media together with sand gravel and charcoal. This is to show how fluoride removal can be use together with homemade sand filters, crushed bricks were used with other filtration media.

For the storage of filter media an oil barrel was used. The barrel has 55 and 86 cm of internal diameter and height respectively. The barrel was filled with ¼th part sand, ¼th part crushed brick, 1/8th part charcoal, 1/8th part sand and 1/8th part gravel. The top 1/8th part of the tank was left for holding raw water for treatment. The sequence of filling the media is as clearly presented in figure 3. The volume of crushed brick used in this filter is about 51 liters.

The crushed brick used in the clay pot with homemade sand filter has effective size of 0.15 – 0.35mm and uniformity coefficient of 1.5 – 3.

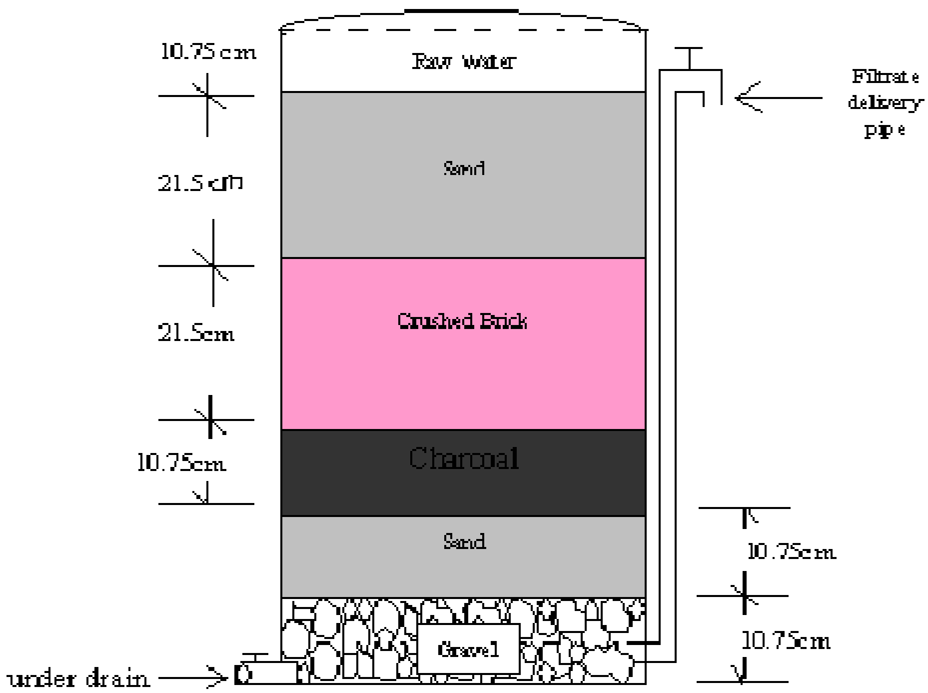

Figure 3. Crushed brick fluoride filter made with homemade sand filter

The top sand layer is expected to filter other biological and physical impurities. The next crushed brick layer is for the removal of fluoride. The charcoal bedded under the crushed brick is expected to adsorb the color, smell and other organic contaminants. The bottom sand and gravel are used to further purify the water under treatment.

Sampling Techniques

Samples were collected from filtrates that are coming out through the delivery pipes of the clay pot and homemade sand filter using clean dry beaker.

The filtrate from clay pot filters was collected by putting the pot filter on filtrate collection device, which is an ordinary clay pot (Fig 4).

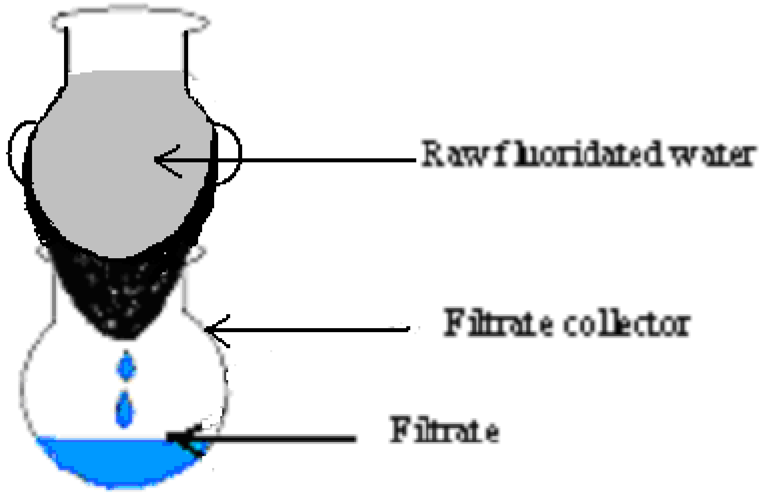

Figure 4. Conical clay pot fluoride filter with the filtrate collection apparatus

Method of determination and data collection

SPADNS methods using HACH model DREL/1c colorimeter and alizarin methods using spectrophotometer were used to analyze the samples. Experimental results were collected on the data collection format.

Reproducibility was determined by triplicate measurement of each sample. The standard deviation ranged less than 9% for clay pot filters and crushed bricks made with homemade sand filter. For crushed brick filters in clay pot, the standard deviation has reached up to 15%.

RESULTS

Filtration of water as a treatment method has been used for a long period of time as contaminant removal and even nowadays modern treatment plants incorporate this method as a unit treatment operation.

This study has showed how defluoridation can be done together with the removal of other contaminants. Homemade sand filters are mostly known in the removal of biological and physical contaminants like coliform organisms, turbidity and color. The crushed brick was added as a filtering media for the removal of fluoride. When water sample containing 4 and 8mg/L fluoride concentration is filtered through crushed brick fluoride filter made with homemade sand filter, an average of 0.4mg/L of fluoride was measured in the filtrate, which is 90 percent of fluoride removal.

Pilot test was conducted to see if homemade sand filter has the effect of fluoride removal, but there was no appreciable removal.

Filtration of the fluoridated water sample through conical clay pot fluoride filters and crushed brick in fluoride filters has eliminated significant fluoride concentration.

Water samples whose initial fluoride concentrations are 12, 10, 7, and 3 mg/L are filtered, all have showed considerable fluoride removal efficiency (Table 1).

Regarding the conical clay pot filter, when the ratio of sand add to clay, to make the conical bottom, is reduced, the efficiency of fluoride removal increases. This has an advantage to adapt the technology to different areas. In areas where exaggerated fluoride concentration in the water supply systems is available, like rift valley groundwaters, which have above 8 mg/L concentration (2), clay pot filters made with out adding sand, can be used. But the main draw back of using such clay pot filter made without sand is the inadequate filtrate output. The amount of filtrate measured immediately after 5 liter of fluoridated water sample is filled in the clay pot filter was about 33 mL/min.

Table 1. Fluoride concentration of the aliquots after filtration of samples having different initial fluoride concentration. Jimma, 2004

Filtration Media	Average fluoride concentration before and after filtration (mg/L)			
	12 mg/L (initial concentration)	10 mg/L (initial concentration)	7 mg/L (initial concentration)	3 mg/L (initial concentration)
Clay pot filter 1*	0.20	0.20	0.16	0.13
Clay pot filter 2**	1.00	0.98	0.51	0.15
Clay pot filter 3***	2.20	2.03	0.90	0.15
Crushed brick filter in clay pot	2.80	2.80	2.40	2.15

**Clay pot filter made without sand*

***Clay pot filter made with sand clay ratio of 1:3*

****Clay pot filter made with sand clay ratio of 1:1*

Other clay pot filters having 1:3 and 1:1 sand to clay ratio showed 75mL/min and 105mL/min filtrate delivery respectively. The flow rate reduces when the volume of the sample added in the filter pot is decreased.

The removal efficiencies by these fluoride filters are presented in table 2.

Table 2. Fluoride reduction efficiency of different clay pot filters and crushed brick in clay pot, Jimma, 2004

Filtration media	Percent reduction of fluoride after filtration			
	12 mg/L (initial concentration)	10 mg/L (initial concentration)	7 mg/L (initial concentration)	3 mg/L (initial concentration)
Clay pot filter 1*	96.3	98.0	97.7	95.7
Clay pot filter 2**	91.7	90.2	92.7	95.0
Clay pot filter 3***	81.1	79.7	87.1	95.0
Crushed brick filter in clay pot	76.7	72	65.7	28.3

**Clay pot filter made without sand*

***Clay pot filter made with sand clay ratio of 1:3*

****Clay pot filter made with sand clay ratio of 1:1*

DISCUSSION

Among the developed fluoride filters the conical clay pot fluoride filters have showed best removal efficiency (79 – 95 %). This is better than the South African clay materials, which is 80 % as investigated by Coetzee P. and coworkers (4). But some clay materials in this study have also showed zero efficiency. This indicates that it is important to check the removal efficiency of the different clay materials of different areas of Ethiopia. Conical clay pots made with 1:3 of sand to clay ratio and those made without sand have showed magnificent fluoride removal. The study has revealed that when the ratio of sand is increasing, the removal efficiency decreases and flow rate increases. This will be very helpful to adjust the appropriate removal method which will not go below the recommended fluoride limit, since the presence of this chemical also helpful for normal physiological activity of our body.

Lower removal efficiency is registered from crushed brick fluoride filters in clay pot which is 28 – 76.7 %. This may be due to the small volume of crushed brick used as filtering medium and low contact time between the fluoridated water and the crushed bricks. Clay materials made from processed bauxite, which consists of amorphous aluminum oxide, have also showed low fluoride removal efficiency in similar study done in South Africa (4).

The main draw back of the crushed brick fluoride filter in clay pot is not only low fluoride removal efficiency but also the demand of high volume of water for washing the crushed brick until it gives clean filtrate. In this case the application of this technology may not be feasible to the communities with shortage of adequate water supply.

Filtration of fluoridated water through the crushed brick fluoride filter made with homemade sand filter has showed considerable fluoride removal. The removal efficiency is almost similar with a conical clay pot fluoride filter made with 1:3 of sand to clay ratio. Such fluoride concentration removal was possible most probably due to the common the effect of other filtration media together with the adsorption effect of crushed brick. This is because the under lied and over lied sand bed can make the fluoridated water to get much contact time with the crushed brick.

Too little of fluoride concentration (less than 0.5 PPM) may not be recommended. In this case some adjustments have to be made on crushed brick fluoride filter made with homemade sand filter to decrease high removal efficiency below the recommended (10). Some of these methods can be: a) to increase the firing temperature when the clay materials are made because increasing the firing temperature can decrease the fluoride adsorption b) to decrease the contact time between the fluoridated water and the adsorbents by increasing the flow rate, and c) to decrease the volume of crushed brick used for filtration. By doing so unnecessary elimination will be tackled.

Removal of fluoride using clay materials has been studied by Moges G. and coworkers who have achieved elimination of fluoride below 1.5 mg/L from 10 mg/L fluoride concentration of water using fired brick and clay materials (12). But this study does not indicate the type of clay material used or the place where these clay materials are located.

Investigators of this study believe that other physical, chemical, and biological contaminants can be removed using these filtration apparatuses. For the sec of curiosity, a preliminary test was done on conical clay pot filters and crushed brick fluoride filter with homemade sand filter to see if there is removal of some other contaminants. The result has showed appreciable removal of turbidity and coliform organisms. But the results are not presented in this paper since it was not the aim of the study.

The defluoridation process made by the three methods has showed satisfactory elimination of fluoride. In this case, these technologies can be used in Ethiopian communities as such technologies done and effectively used in Sri Lanka (11).

Looking the way of fluoride elimination, defluoridation can be basically done by two approaches, which are *flocculation (Nalgonda technique)* and *adsorption* (5). Adding alum, which is commonly known coagulant, makes fluoride removal by flocculation. In this study there were no any additive used. As described by Coetzee P and coworkers (4), the defluoridation mechanism undertaken during filtration in the clay pot and crushed brick fluoride filters is most probably adsorption. Though every solid earth material is potentially adsorbent, the degree of adsorption varies from material to material (1). The solid earth materials used in this study are the local clay material. These clay materials can provide a number of fluoride binding sites such as Ca^{2+}, Mg^{2+}, Al^{3+}, etc. Moreover, exchangeable anions such as OH^- are present and would serve as one of the principal contributing factors for defluoridation due to similar charge so that ion exchange is possible.

The cost needed to prepare and use these technologies is very cost effective and can be used by most of the Ethiopian communities. The cost of clay pot filter with the filtrate collector, crushed brick filter in clay pot, and crushed brick with homemade sand filter are an average of 3.26, 1.75 and 26.75 US dollar respectively. Since defluoridation is needed for waters that are used for drinking and cooking, the clay material may be used for long period before it is saturated. This will make these technologies very cheap and cost effective.

Regarding maintenance of these technologies, though the duration of the filters for how long they can serve without any maintenance is not studied, it is known that after some time the fluoride filters will be saturated with fluoride ion (9). In this case, it is possible to buy and replace new clay pot filter and crushed brick filter. Other possible option is to recharge the adsorbent (clay material) by washing with a mild acid or alkali solution to clean and regenerate it (5).

The important feature of these fluoride filter apparatuses are:

- easily available almost in all part of Ethiopia;
- cheap for the general public;
- adoptable to domestic use;
- simplicity of the design, construction, operation and maintenance; and
- other biological and physical contaminants can be removed.

Conclusion and Recommendation

The study has showed the possibility of removing fluoride from water samples using low cost equipments. These technologies can be easily adapted at household level in the majority of Ethiopian communities where the concentration of fluoride is above the recommended.

Clay pot filters and crushed brick filter in clay pot and with homemade sand filter can be built with a simple demonstration. In addition local potters can produce such clay pot filters and can provide with low cost to the concerned communities.

With further studies, these technologies may be adopted as a unit operation in conventional treatment systems.

In the future adsorption efficiency of the clay materials in the removal of fluoride per unit weight (mg F^-/gm of clay material) and the duration of those clay materials to remove fluoride from drinking water up to the recommended limit needs to be studied. In addition, the composition of the clay materials has to be studied to identify the specific active ingredient of the resins and clay types.

ACKNOWLEDGEMENTS

The investigators are very thankful to research and publication office of Jimma University for financing this project. We also extend our acknowledgement to local potters of Jiren Kebel who have helped us in making the desired pots.

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