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**WATER, SANITATION AND HYGIENE:
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Operational experiences on small-scale community defluoridation systems

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Excessive levels of fluoride in drinking water supplies is a major problem in the Rift Valley of Ethiopia.. The methods of fluoride removal used by industrialized countries require more technical support for operation and maintenance than is possible in the rural areas of developing countries. There is a need for low cost defluoridation systems in areas with no alternative water sources. This paper describes three low cost water defluoridation methods that have been evaluated at pilot scale. Three villages with ground water with high fluoride content and relatively hot climate were considered. Techniques used are chemical precipitation by aluminium sulphate and lime, adsorption by bone char, and adsorption by clay minerals. Community support mechanisms that are useful to make such defluoridation systems sustainable and practical in the Ethiopian context were assessed. We recommend the aluminum sulfate and lime method to other fluoride-affected areas, while developing further alternative techniques.

Introduction

Excessive and undesirable levels of fluoride in drinking water supplies are common problems in the Rift Valley of Ethiopia. The major source of fluoride in the Rift valley water is considered to be the dissolution of acid volcanic rocks, which are rich in fluoride. The water in the Ethiopian rift valley has fluoride concentration between 1-33 mg/l with an average value of about 5 mg/l (Haimanot et al., 1987, Ashley and Bureley, 1995). Over 14 million live within rift valley and therefore adequate measures are necessarily important.

The maximum amount of fluoride in drinking water is regulated at 1.5 mg/l (WHO, 1970). Higher fluoride concentration in drinking water than 1.5 mg/l is linked to dental and skeletal fluorosis.

Possible control options to protect the fluorosis problem may include provision of alternative source of water, blending with low fluoride containing water, provision of bottled water, at least for young persons, treatment of the water supply at source and at the point-of-use.

Catholic Relief Services Ethiopia (CRS/Ethiopia) program in collaboration with , Meki Catholic Secretariat, and Ormoia (regional, zonal and Woreda water offices) developed community managed defluoridation system.

The major objective of the project is:

- Test three low cost water defluoridation methods under field conditions to determine the technical and economic feasibility in rural communities
- Develop community support systems to make defluoridation sustainable in the Ethiopian context.

Feasibility/sustainability: Prospects and challenges

In relation to feasibility/sustainability of defluoridation methods, justifying the technical, cost and social sustainability in the context of rural communities is very essential. The technical feasibility may focus on factors such as availability of materials, cost for initial construction and for operation and maintenance,

treatment efficiency, simplicity of the method, and the quality of treated water. From these perspectives, potentially applicable methods can be selected based on literature review and tested at the pilot scale.

Although strengthening target communities would be useful to make the systems sustainable, other major challenges that need to be addressed during this pilot study in particular and to implement the fluoride removal techniques at community levels in general were identified:

- *Lack of experiences: by the communities* regarding the proposed methods or any other defluoridation systems.
- *Cultural and religious attachments:* The bone char treatment system is less -favored by communities. Some community members raised concern on the bone char system - regarding its source, type, affordability and quality to serve its purpose. The target communities attached the bone char system to religion and culture, which needs further investigation and analysis.
- *Doubtfulness of communities:* Community members are doubtful about the proposed defluoridation systems, and they want to see the feasibility and/or sustainability of each system jointly with the project staff during the piloting period.
- *Inadequate information:* There is no adequate information on the income/expense scenario of households, which makes difficult to determine the O&M requirements of the boreholes at this point.

The above and other issues have been critically considered during the piloting period using different participatory techniques and conventional method such as: Checklists preparation; Semi-structured interview; Focus Group Discussions (men and women).

Design considerations

The chemical requirements

Laboratory treatability test

The aluminium sulfate used in this study was purchased from Awash Melkassa Aluminum Sulfate and Sulfuric Acid Factory. The alum is 17 % Al_2O_3 (about 54 % aluminum sulfate). The sample was used for defluoridation studies with out any further pretreatment. Lime was obtained from the Addis Ababa Water Supply and Sewerage Authority. The lime is locally produced at Dire Dawa Lime Factory. Detail information about the quality of lime used is not available. Water samples were collected from deep bore holes located in very high fluorotic area, which is the central part of the Main Ethiopian Rift.

The fluoride retention capacity of locally produced aluminium sulfate was investigated by means of batch testing. This test is conceptually simple and involves the addition of different amount of alum to the raw water with predetermined initial fluoride concentration. To determine the optimum dose and reaction time, batch experimental investigations were carried out at different dosages of 130, 150, 170 and 200 mg alum/mg F- for each water sample. The range was selected based on the values reported in the literature and our initial preliminary screening experiments.

Experiments were conducted using raw water with different initial fluoride concentrations using a jar or floc tester. The experimental procedure involves addition of weighed amount of alum to the beakers containing 400 ml of sample water, mixing for 15 minutes at 40 rpm, and then the solution was allowed to settle for about 2 hours. Settling time up to 24 hrs was also considered for the evaluation of effective settling.

Fluoride measurement

Standard fluoride solutions were prepared from a reagent grade anhydrous sodium fluoride (NaF) in distilled water. Before measurement, the standard, or the sample solution (10 ml), was mixed with 5 ml of total ionic strength adjusting buffer (TISAB) to prevent interference by other ions and to adjust the solution pH and ionic strength.

TISAB was prepared by dissolving 58 ml of glacial acetic acid, 58 g of sodium chloride, 7 g of sodium citrate and 2 g of EDTA in 500 ml distilled water. The pH was adjusted with five N sodium hydroxide and diluted to 100 ml with distilled water. The TISAB solution contains a decomplexing agent, which releases complexed fluorides in the form of free fluorides, which are then measurable by the ion selective electrode.

The liquid phase was measured for free fluoride using a combination fluoride ion selective electrode (Orion, Model 96-09) connected with pH/ ISE meter (ORION, Model 230A).

Batch experimental results

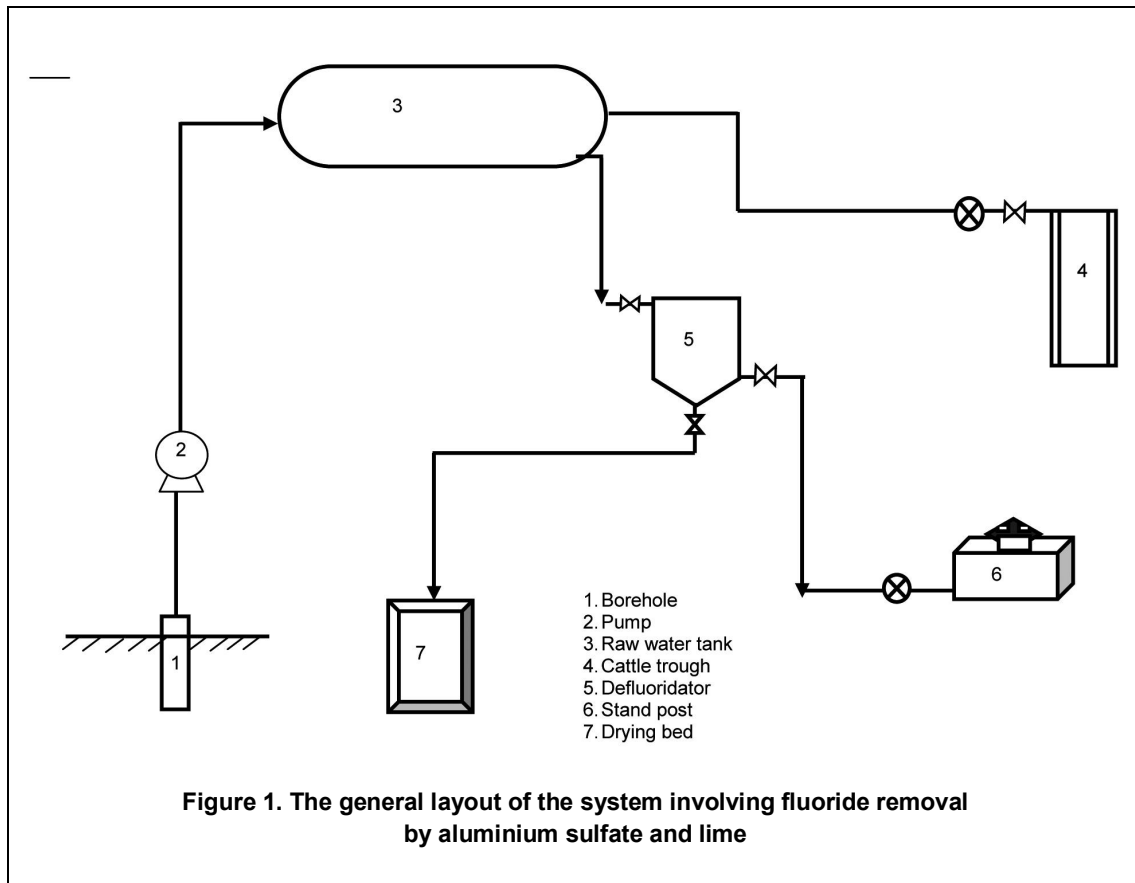
Aluminium sulfate can effectively reduce the fluoride content of most water samples below 1.5 mg/l if the applied dose is larger than 150 mg alum/mg F⁻. The removal efficiency exceeds 70 % in most cases and higher removal efficiency was observed for water samples with high initial fluoride concentration.

The turbidity of treated water is higher compared with that of raw water in all cases with in the settling time of 2 hours due to the presence of unsettled flocs.

The maximum alum dose required for the raw water containing 7.5 mg/l fluoride and alkalinity of 400 mg/l as CaCO₃ is 130 mg alum/mg for the water samples from the study area , according to the laboratory treatability studies and based on literature survey.

The water is pumped from a deep borehole to raw water tank positioned at 6 m above the ground. The raw water is distributed to the treatment unit (only for drinking purpose) and to the cattle trough by gravity flow. The treated water is supplied through the stand post, which is located near to the treatment unit.

Table 1. Raw water fluoride concentration and water quality parameters of the three villages			
Parameters	Concentration (mg/l)		
	DeKo	Langano	Dalota
NH ₄ ⁺	ND*	ND	ND
Na ⁺	207.4	190.4	190.4
K ⁺	11.2	6.6	8.6
Ca ²⁺	16.0	6.4	16.0
Mg ²⁺	2.9	1.9	1.9
Fe, total	0.04	ND	0.12
Mn ²⁺	ND	ND	ND
Cl ⁻	12.0	16.0	36.0
NO ₂ ⁻	0.01	0.01	0.01
NO ₃ ⁻	1.45	ND	ND
F⁻	7.5	8.5	7.5
HCO ₃ ⁻	585.6	488.0	488.0
CO ₃ ²⁻	ND	ND	ND
SO ₄ ²⁻	ND	ND	ND
PO ₄ ³⁻	0.11	0.22	0.02
PH	7.6	7.8	7.4
Conductivity (μS/cm)	918.5	785.5	846.8
Bicarbonate Alkalinity	480.0	400.0	400.0
Total Hardness as CaCO ₃	52.0	24.0	48.0



Based on the observed fluoride concentration, and water demand of the Dalota and Langanu villages, detailed design was prepared. The water is pumped from a deep borehole to raw water tank positioned at 6 m above the ground. The raw water is distributed to the treatment unit (only for drinking purpose) and to the cattle trough by gravity flow. The treated water is supplied through the stand post, which is located near to the treatment unit.

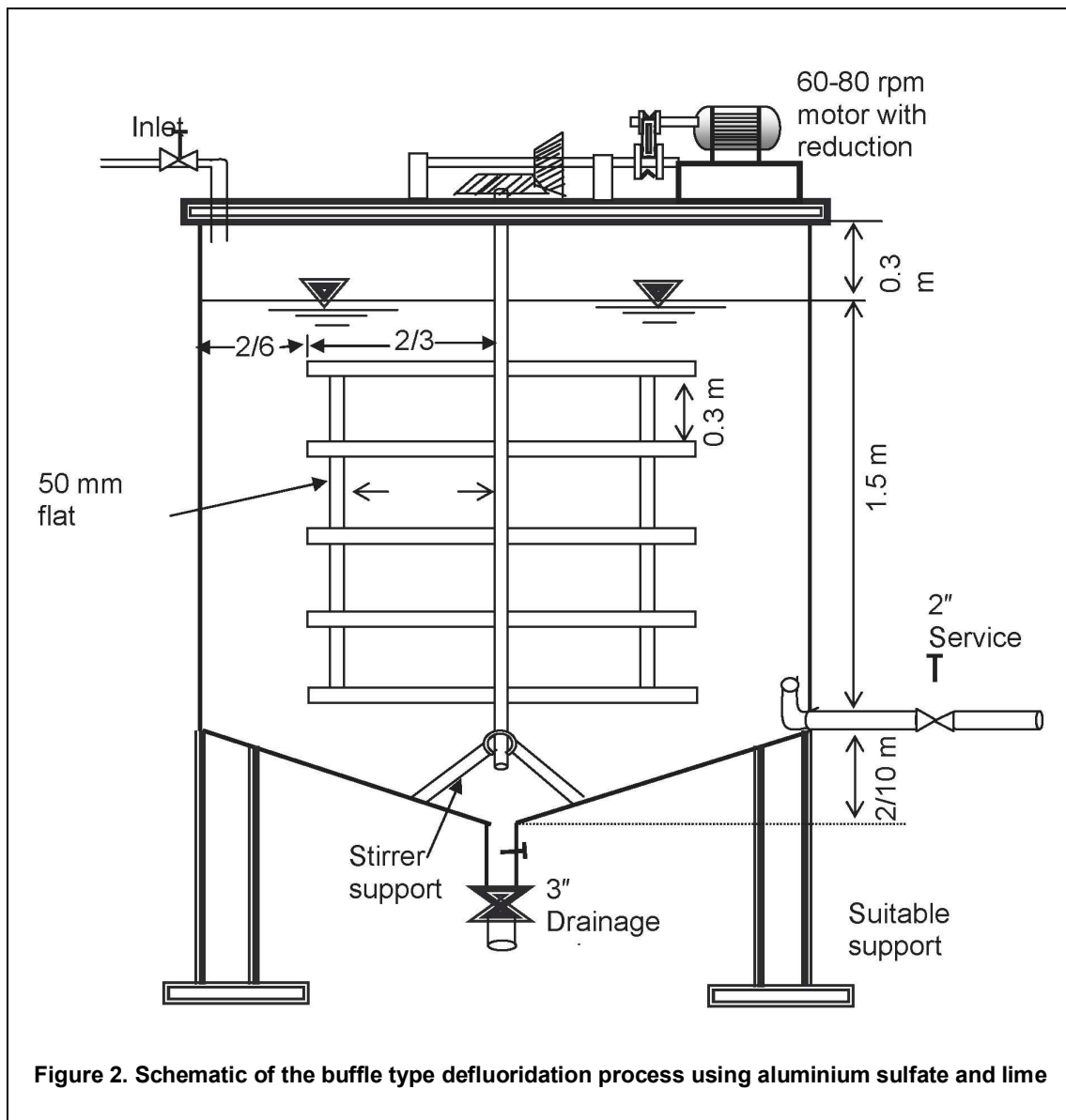
The pilot system

Noting the problem of water scarcity in the area under consideration, the water demand for drinking purpose cannot exceed 5 liters/capita/day. Batch processing of drinking water can be carried out twice a day. The number of cycles of operation for the batch treatment system was decided based on factors such as energy consumption, daily water demand, the availability of operator during the day, and the cost of the reactor.

The reactor is made up of cylindrical steel tank, mounted on reinforced concrete. The tank is conical shaped bottom in order to facilitate settling and equipped with an agitator assembly consisting of 3 HP; 3 phase; 50 Hz; about 1500 rpm; drip proof motor; a gearbox with input 3 HP and maximum output speed of 60-80 rpm. Baffle type mixing system is considered during the pilot study. It is designed to maintain a uniform and relatively slow mixing condition.

The power source for running the mixer assembly is the generator, which is already installed for pumping the ground water. Since the horsepower requirement of the motor for mixing is low, any generator that can produce the required voltage input can be used.

Predetermined amount of the reactants (lime and aluminum sulfate) were first dissolved in a plastic bucket and then charged in to a reactor filled with the required amount of fluoride containing water. The contents were mixed at a rate of about 60 rpm for 15 minutes (reaction time), and were allowed to settle for about 2 hours. The performance of this batch reactor under these specific operating conditions showed the raw water fluoride concentration was reduced from about 8 mg/l to about 2 mg/l which corresponds to 75 % removal efficiency as expected from the batch experimental study.



The sludge, which is composed of aluminium hydroxide flocs and other calcium and magnesium compounds can be discharged through the 3-inch gate valve at the bottom of the reactor. The sludge can be directed to the sludge-drying bed where the water is evaporated. The possibility of using the solid residue for other purposes will also be investigated.

Adsorption processes

Adsorption by bone char

Animal bones, grounded and charred in order to remove the organic materials has been used as a defluoridating media. The bone meal was purchased from the local slaughterhouse (Kera) in Addis Ababa. The material should have been burned in a furnace at temperature of about 500-600 oC. However, it is very difficult to obtain such expensive furnace for the rural community. Therefore, we have used an waste incinerator that partially fulfills the required degree of burning at the site of the project.

Design of the adsorption bed

The most important parameters of design, for the calculation of defluoridation bed, using bone char as exchange media are the water flow rate, bone media height, and exchange capacity. Calculation based on the

exchange capacity shown in Table 1, indicate that about 24.6 m³ of water containing 8.5 mg/l can be treated by assuming that all the fluoride can be retained by the media. However, since the fluoride concentration in the treated water should be about 1.5 mg/l the volume of treated water should be larger. The water flow rate depends mainly on the maximum daily water demand.

Adsorption by clay

Low temperature burnt brick purchased from Gullele Brick Factory was used as a representative clay material for defluoridation. The material was crushed by the local community and sieved to obtain particle size range from about 0.5 to 1.5 mm. The material was chosen mainly because, laboratory tests with this material from the same location showed that its fluoride exchange capacity is comparable with that of clay soil (Moges et al., 1996). In addition, the burnt brick may have good hydraulic permeability as compared with raw clay soil.

In general the experiment indicated that clay has low capacity as compared to bone char and therefore, the lifetime of the adsorption bed is very short. Nonetheless, since clay mineral is widely available in Ethiopia, and adsorption by clay may be cost effective and easier to use in many situations.

The basic design parameters and the size of the exchange bed are similar to that of bone char exchange bed. The main difference is the total fluoride exchange capacity and the rate of fluoride exchange of the two media.

Results of the three methods

The results of the performance of the three methods and the problems observed are summarized in Table 7. The aluminum sulfate and lime process reduce the fluoride content to about 2 mg/l or less with out any observable treated water quality problem. However, in the case of bone char treated water becomes yellowish in color although the color disappeared gradually.

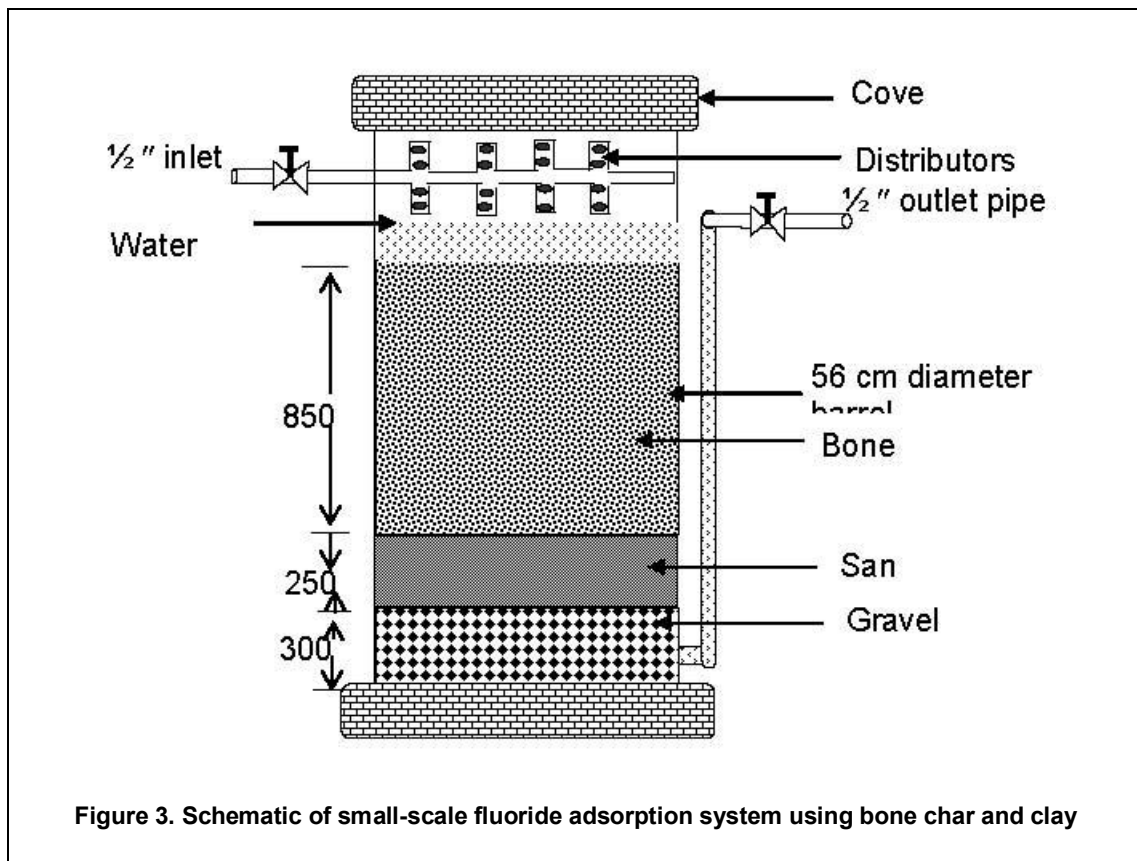


Figure 3. Schematic of small-scale fluoride adsorption system using bone char and clay

Village	Method	Capacity (L/D)	Initial fluoride (mg/l)	Final fluoride (mg/l)	Problem encountered
Dalota	Alum+ Lime	8000	7.8	2.1	No problem, accepted by community
Langano	Bone Char	1000	9.0	0.9	Colour problem, not accepted by community
	Clay	500	9.0	0.5	Slightly turbid not preferred by the community

Village	Alum (Kg)	Dose (mg/mg)	Lime (kg)	Mixing time (min)	Capacity (L/D)	Initial fluoride (mg/l)	Final fluoride (mg/l)	Problem encountered
Dalota	4.2	150	2.1	20	8000	7.8	2.2	No problem
	5.0	180	2.5	20			1.4	
	5.0	180	2.5	15			2.4	
	3.6	130	1.8	20			3.8	
Langano	4.2	130	2.1	20	5000	9.0	2.9	
				10			3.4	
	3.6	100	1.8	20			3.07	
	3.12	90	1.56	20			2.97	-

As can be seen from the above table, the alum dose may vary in the range between 130 mg alum/mg fluoride as far as the mixing time is maintained at 20 minutes. The alum dose applied is about 1 g/l, which may reduce the pH to about 5. The amount of lime that is added is sufficient to correct the slight decrease in pH. Comparison of the results of the pilot plant performance (Table 3) with the laboratory experimental results in Table 1 shows that they are close agreement.

Project cost benefit analysis

Capital cost

Capital cost is generally expensive mainly for that of Aluminum sulfate method, as the establishment of the plant requires more technical and scientific inputs. The estimated capital cost for establishing one Aluminum sulfate defluoridation system is about \$2,000, in the year of piloting and about \$5,000 this time. The cost may be even higher depending on the selection of materials used to build the defluoridation unit. On the other hand, the capital cost for methods based on adsorption on to bone char and clay is relatively lower. Because the defluoridation units can be built using locally available low cost materials.

Running cost

The most important consideration in this particular case is that the community should generate income that is required at least to cover the expenses. Based on the preliminary assessment, one approach to raise income is to sale water for human as well as livestock consumption. The minimum requirement was used for cost estimation and the range of requirement is presented in.

On the other hand, the expenses to keep the system running include chemical cost, material transportation and travel cost, and fuel and lubricants cost. From the pilot it is learned that the cost of using different

methodologies (alum+lime, clay and bone) is different. The cost for alum+lime is generally more expensive than the price of clay and bone. However, the processing of preparing clay and bone as treatment media is labor intensive.

Conclusions and recommendations

- Aluminum sulfate and lime addition, the results obtained so far indicate that the developed defluoridation unit could remove the fluoride concentration to the level below 3 mg/l at the optimum operating conditions chosen.
- Laboratory physico-chemical analysis results indicate that the treated water is suitable for drinking purpose. Existence of aluminum ion may not be a problem if proper amount of lime is used to raise the pH.
- Assessment of the affordability of running cost by the community indicated that the amount required can be generated from the community, however initial capital cost may require subsidy from concerned organizations.
- Operation and maintenance can be carried out by semi-skilled manpower provided that proper training and guidance is given.

The study team recommends further dissemination of the aluminum sulfate and lime method to other fluoride-affected area and at the same to develop alternative techniques and approaches to alleviate the fluoride problem in the Rift Valley Region.

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