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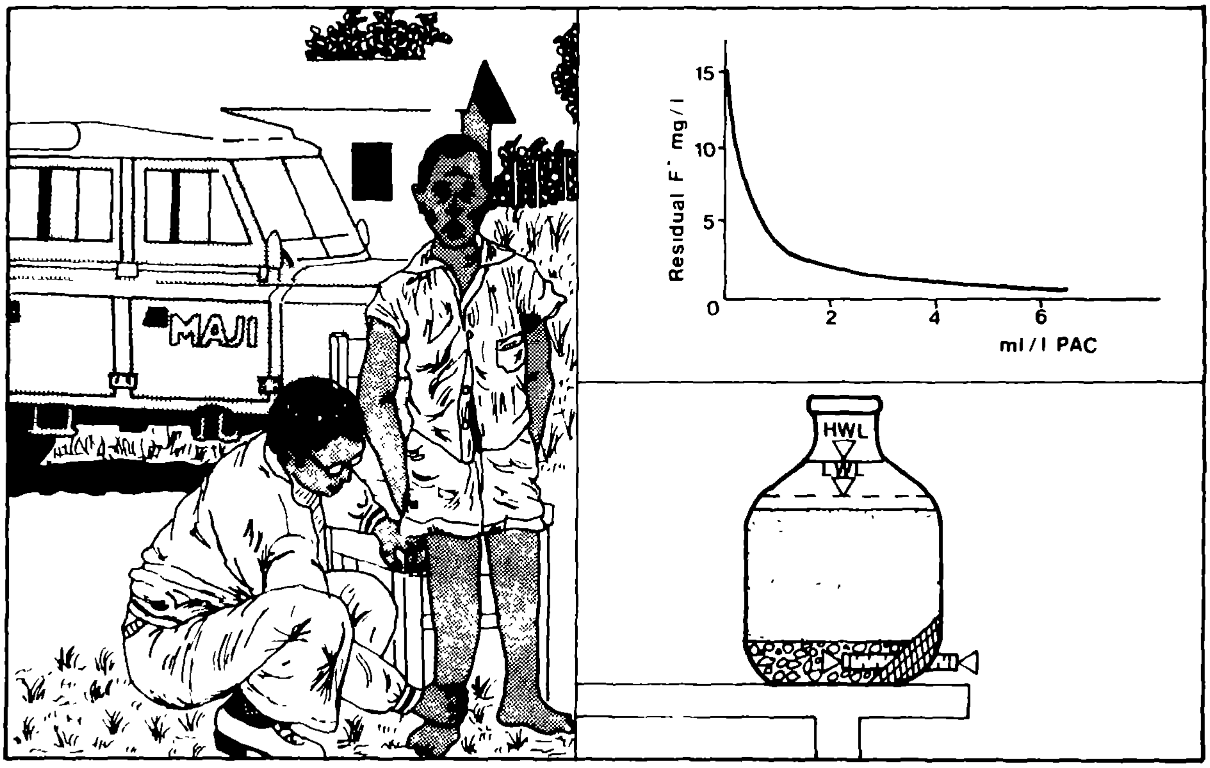
Excess Fluoride in Potable Water in Tanzania and the Defluoridation Technology with Emphasis on the Use of Polyaluminium Chloride and Magnesite



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EXCESS FLUORIDE IN POTABLE WATER IN TANZANIA AND THE DEFLUORIDATION TECHNOLOGY WITH EMPHASIS ON THE USE OF POLYALUMINIUM CHLORIDE AND MAGNESITE

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ABSTRACT

Fluorosis is a public health problem in some parts of Northern Tanzania. Field and clinical studies carried out by some medical experts have indicated that fluorosis has taken a new look in the form of knocked knee deformity among young adults and children. The prevention of fluorosis should be by developing simple and moderately cheap methods of fluoride reduction. This could be defluoridation at point of use or at home using a defluoridation device.

In Tanzania steps have already been taken to prevent the problem of fluorosis. The steps taken include the investigation of several methods of removing fluoride. The methods investigated include use of polyaluminium chloride, filtration through magnesite, use of clay pot chips, filtration through granulated bone and bone char.

In spite of the fact that polyaluminium chloride will have to be imported from abroad, the chemical has a very high fluoride removal capacity up to 95 % at an optimum dosage of 8.0 ml/1 litre raw water.

Magnesite has shown a removal efficiency up to 81 % with bigger particle sizes 3 - 6 mm depending upon contact time allowed to take place. With smaller sizes 0.5 mm diameter, 74 % removal efficiency was achieved after 30 minutes.

Clay pot chips also showed a fluoride reduction between 16 % to 76 % depending upon the contact time allowed to take place.

Two devices developed in Thailand were also tried in the experiments conducted in Arusha. One unit was filled with granulated bone of 1.0 mm and 2.0 mm particle sizes and the other with charred bone. The two media in the units were able to reduce fluoride to the lowest possible level.

The tests made during this research work at the laboratory scale were repeated several times to confirm the results obtained.

1 INTRODUCTION

Fluoride is now one of the recognized essential elements with recommended daily intake levels. The element is useful healthwise when taken in optimum levels, at the rate of 1.0 - 1.5 mg/l (World Health Organization, 1984), this being a guideline for drinking water quality. The total daily intake of fluoride by individuals including other sources varies from country to country. This may vary from 0.2 mg of fluoride per day in infants to 5.0 mg of fluoride per day in adults (Murray, 1986).

The quality of water is determined by the amount of soluble minerals and by it's physical and biological characteristics. The amount of soluble minerals represents the chemical characteristic of water. Different treatment methods and processes have been devised and developed to remove or reduce the amount of salts present to maximum permissible contaminant level. Amongst them, these include high total soluble salts, hardness, iron and manganese, high fluoride concentration and nitrate content. All the parameters mentioned including heavy metals cause different water use problems, in different countries of the world. To overcome this, guidelines have been set by the international body, the World Health Organization, besides those set by individual countries.

High fluoride concentration in drinking water is a problem known in a number of countries including Tanzania. Ever since the publication of certain medical and dental reports on the effects of fluoride on health particularly concerning enamel of the teeth and bone structure, more attention has been given to the concentration of naturally occurring fluoride especially in drinking water. Consumption of too much fluoride leads to the destruction of the enamel and causes a number of endemic conditions referred to collectively as fluorosis. To mention a few these include dental malformation, stained enamel, mineralisation of tendons, digestive disorder etc. Furthermore excess fluoride can also cause a clinical syndrome referred to as skeletal and crippling fluorosis. These health hazards are prevalent in some parts of Tanzania mainly in severely hit regions. These conditions occur in different people at very different fluoride contents. Looking at the water quality guidelines issued by the World Health Organization, water containing fluoride over 1.0 - 1.5 mg/l content must be rejected or treated.

As water passes through a fluoride bearing mineral it dissolves some of it, thus the water is said to contain fluoride. Most water schemes contain a proper concentration to inhibit dental decay, others have too little thus addition of the nutritionally important fluoride in drinking water becomes necessary. But a large number of water sources contain excessive amounts which need to be removed and brought down to acceptable levels.

Tanzania faces this problem of high fluoride concentration in some of its regions. In spite the fact that the country has adopted a temporary standard for rural areas of 8 mg/l, this is far too high compared to 1.0 - 1.5 mg/l, guideline set by the World Health Organization. If the guideline set by the World Health Organization was adopted, then Tanzania would have 30 % of its water sources as unsuitable for domestic use (Bardecki, 1974). Since the temporary value of 8 mg/l fluoride is high, and to utilize the 30 % water source as per WHO guideline, treatment of the water has to be done in order to reduce fluoride to the acceptable level. To do this a method or methods have to be developed to meet the conditions of Tanzania. The technology of removing excess fluoride has been well studied, developed and tested and equipment is readily available from engineering firms. But the defluoridation technology has no practical field experience, thus no further news on the development is available in the literature besides experiments and some pilot plants and trials based mainly on artificial test water.

Tanzania is currently studying the different treatment methods available in order to develop a method for the removal of excess fluoride from drinking water which would suit the country's conditions and natural resources. This thesis work is also part of the efforts being made in Tanzania for getting a defluoridation technique.

2 OCCURRENCE OF FLUORIDE

Fluorine is the most electronegative of all the chemical elements and it is never found in the nature in the elemental form. It is normally found in the form of fluorides in a chemically combined form. Fluorine represents about 0.06 - 0.09 % of the earth's crust (World Health Organization, 1970).

In the periodic table fluorine falls in the same group with chlorine, bromine, iodine etc. It therefore tends to have similar chemical and physical properties. One of the most common property of these elements is their ability to form salts, thus getting the name halogen, salt formers. In the environment fluoride occurs in soils, rocks and water, and to lesser extent in the air.

2.1 Fluoride in Soils and Rocks

The geochemistry of fluoride ion is much influenced by its being diadohic with hydroxyl ion in many silicates and phosphates. Fluoride occurs notably as fluorspar, cryolite, fluorapatite etc. As fluorspar it is found in sedimentary rocks - limestone and sandstone, and as cryolite in igneous rocks. When these rocks undergo weathering thus forming soil the fluoride goes with it. The process of leaching also helps to deposit fluoride ions in the soil. Table 1 illustrates some of the known fluoride bearing minerals in the world. Some of these mineral compounds are also found in Tanzania hence influencing the high fluoride concentration. These minerals are fluorite, fluorapatite, topaz, phlogopite and lepidolite.

Table 1. Fluoride bearing mineral compounds found in India (Teotia et al, 1981).

Name of mineral compound	Chemical formula
A. Fluorides	
Fluorite	CaF_2
Fluorecite	$(Ca, La, Dy)F_2$
Chryolite	$NaA1F_6$
B. Phosphate	
Fluorapatite	$3Ca_3(PO_4)_2Ca\ F:cl)_2$
Magnerite	$Mg_2(PO_4)F$
Triplite	$(Mn, Fe, Mg, Ca)_2FPO_4$
C. Silicate	
Topaz	$(Al(FOH)_2)SiO_4$
D. Mica Groups	
Phlogopite	Magnesium Mica
Lepidolite	Lithium Mica

The above mentioned fluoride bearing minerals are nearly insoluble in water. It therefore means that fluoride ions will be present in ground and surface water sources only when conditions favour their solubility.

2.2 Fluoride in Ground and Surface Water Sources

The water normally available to man is involved in the hydrological cycle. The average dissolved fluoride content of the major rivers of the world is well defined at 0.01 to 0.02 mg/l (World Health Organization, 1970). The fluoride content of water obtained from lakes or artesian wells is for most part below 0.5 mg/l. But in Tanzania higher concentrations have been recorded from lakes and rivers. Fluoride in surface and ground waters arise from the following processes (Aswathanarayana et al, 1986):

- Leaching of the rocks of the area where volcanic ash, exhalations and sublimates have very high leachable fluoride contents.

- Rain water which may acquire a small amount of fluoride from marine aerosols and continental dust.
- Industrial emissions such as freons and organofluoride compounds produced by burning of fossil fuels, dust in the cryolite factories.
- Industrial effluents from industries that use fluoride bearing compounds.
- Fluoride in the run - off from farms that use phosphatic fertilizers.

Of all the factors described and explained above leaching of rocks is applicable to Tanzania. Thus the very high fluoride concentration in the water sources of Northern Tanzania is the main cause of endemic fluorosis.

Groundwater generally contains easily soluble fluorides which are easily and almost fully absorbed. In surface water sources, part of the fluorides are in a state of suspension, so that a more or less large proportion is not absorbed by the body.

One of the main problems facing the potability of ground water and in some cases surface waters found in some parts of Tanzania are however not the occurrence of highly saline waters in boreholes, wells, water holes etc., but the presence of high fluoride concentration. This normally is in the form of sodium fluoride among the dissolved salts in all groundwaters.

The high fluoride concentration in Tanzanian water sources is to some extent known. This is the result of geological and hydrological condition and process as earlier explained.

2.3 Fluoride in the Atmosphere

The presence of fluoride ions in rainwater collected in remote areas suggests that an atmosphere which has not been contaminated by human activities contains some fluoride (Rose and Marier, 1977). However the quantity is in the level of detection. This can roughly be defined as less than 0.05 $\mu g/m^3$ of air. This fluoride is acquired by rainwater from small amount of fluoride from marine aerosols and continental dust, this being a natural phenomena. As earlier mentioned, industrial emissions, such as freons, organofluoride compounds produced by burning of fossil fuels and dust in cryolite factories, phosphatic fertilizer factories etc., can contribute to small amounts of soluble fluoride to the atmosphere. The fluoride concentration in the air in some factory areas can reach levels as high as 1.4 mg/m^3 of air. Gaseous industrial waste, burning of coal and gases emitted from volcanic areas increase the amount of fluorides in the air (Murray, 1986).

2.4 Correlation between Fluoride Ion and Other Water Quality Parameters

No clear correlation between the occurrence of fluoride in water and other quality parameters has been noted. Higher concentrations of fluoride most often are found in waters with high electrical conductivity as illustrated in Table 2 showing results of one borehole in Basuto, Arusha Region (see also Figure 2 on page 9).

But high conductivity does not necessarily mean high fluoride concentration.

Table 2. Water quality of a borehole in Arusha Region at different depths.

Parameter		Water struck at different depths in meters 6	15	24	33	42	51	54.9
pH		8.8	8.8	8.8	8.8	8.8	8.4	8.4
Electrical Conductivity at 25°C	μs	3700	3500	3600	3500	3700	3600	3750
Alkalinity as $CaCo_3$	mg/l	-	-	-	-	-	-	-
Hardness as $CaCo_3$	mg/l	ND	ND	ND	ND	70	84	80
Calcium	mg/l	ND	ND	ND	ND	7.2	7.4	18.4
Magnesium	mg/l	ND	ND	ND	ND	13.0	16.5	8.5
Sodium	mg/l	-	-	-	-	-	-	-
Fluoride	mg/l	18.0	18.0	18.0	18.0	18.0	18.4	17.6

ND - not determined

As can be seen in Table 2 dissolved salts and fluoride concentrations are too high. The content of calcium and magnesium is very low thus the waters are normally soft. But the levels of sodium and chloride are moderate.

The results in Table 2 do not agree with the hypothesis that the deeper you go the higher the fluoride content becomes (Dobos, 1979). The most important aspect with fluoride concentration in groundwater sources is the geological formation and its mineral content rather than the depth.

3 FLUORIDE DISTRIBUTION IN TANZANIAN WATER SOURCES

The problem of excess fluoride in water sources of Tanzania has well been established. Besides the work done in earlier years, from the period of September 1969 to June 1972, the Soil and Water Laboratory Ubungo, Dar es Salaam carried out a statistical analysis of several water samples analysed for fluoride. The results obtained are summarized in Table 7 which clearly elaborates that the problem is most severe in Arusha, Kilimanjaro, Mwanza, Shinyanga and Singida (Figure 3). The fact that the mentioned regions are severely hit by high fluoride concentration has also been confirmed by Brokonsult AB, a Swedish firm, which was commissioned in 1978 to undertake a study of the Rural Water Quality Programme in Tanzania. Furthermore during the Water Master Plan Programmes more water samples were collected and analysed for physical and chemical characteristics, fluoride being one of them. More work is still going on to analyse water samples in order to collect enough data that would be used for laying the strategy of solving the fluoride problem in Tanzania.

3.1 Northern Tanzania

The northern part of Tanzania is mainly Arusha and Kilimanjaro Regions (Figure 3 on page 12). This could also include Mara, Mwanza and Shinyanga Regions. The most important volcanic rocks and ash contributing to the high fluoride concentration of ground and surface waters are in the east and south - east of Mount Meru area. This area includes some parts of the Sanya Corridor that is the area between Mount Meru and Kilimanjaro (Figure 1). The author tries to go into details some of those regions where the problem is severe as follows:

Arusha Region:

Several studies have been conducted in Arusha Region concerning fluoride problems. Besides those done by the Soil and Water Laboratory Ubungo Dar es Salaam, Nanyaro et al (1984), Mungure (1984), Aswathanarayana et al (1986) and Mcharo (1986) did a very good job in identifying the magnitude of the problem. Table 3 shows some of the results obtained when analyzing some of the water sources in the region. Maji ya Chai area has been well covered, which is illustrated in Figure 2 on page 9.

Table 3. Some water sources in Arusha Region with high fluoride concentration.

Name of Source	Fluoride content mg/l		
Maji ya Chai River	12	-	23
Pond waters of Kitefu	61	-	65
Jekukumia Spring	63		
Mommella Lakes	up	to	690
Erement Spring	40		
Water hole 01 Balbal	up	to	140
Mbulu area Springs	up	to	99
Engare Nanyuki River	21	-	26

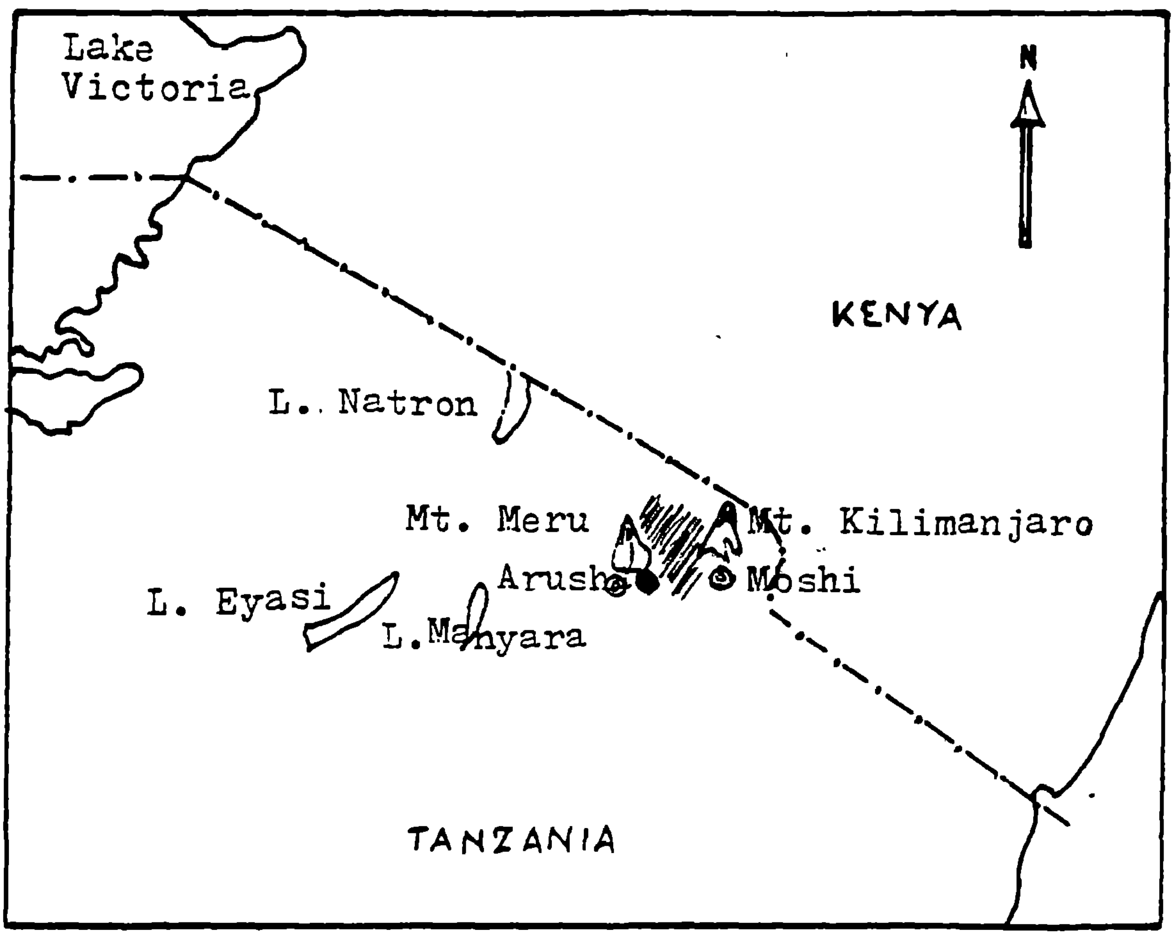


Figure 1. A map of Northern Tanzania showing the Sanya Corridor-shaded part. The black dot is the project area.

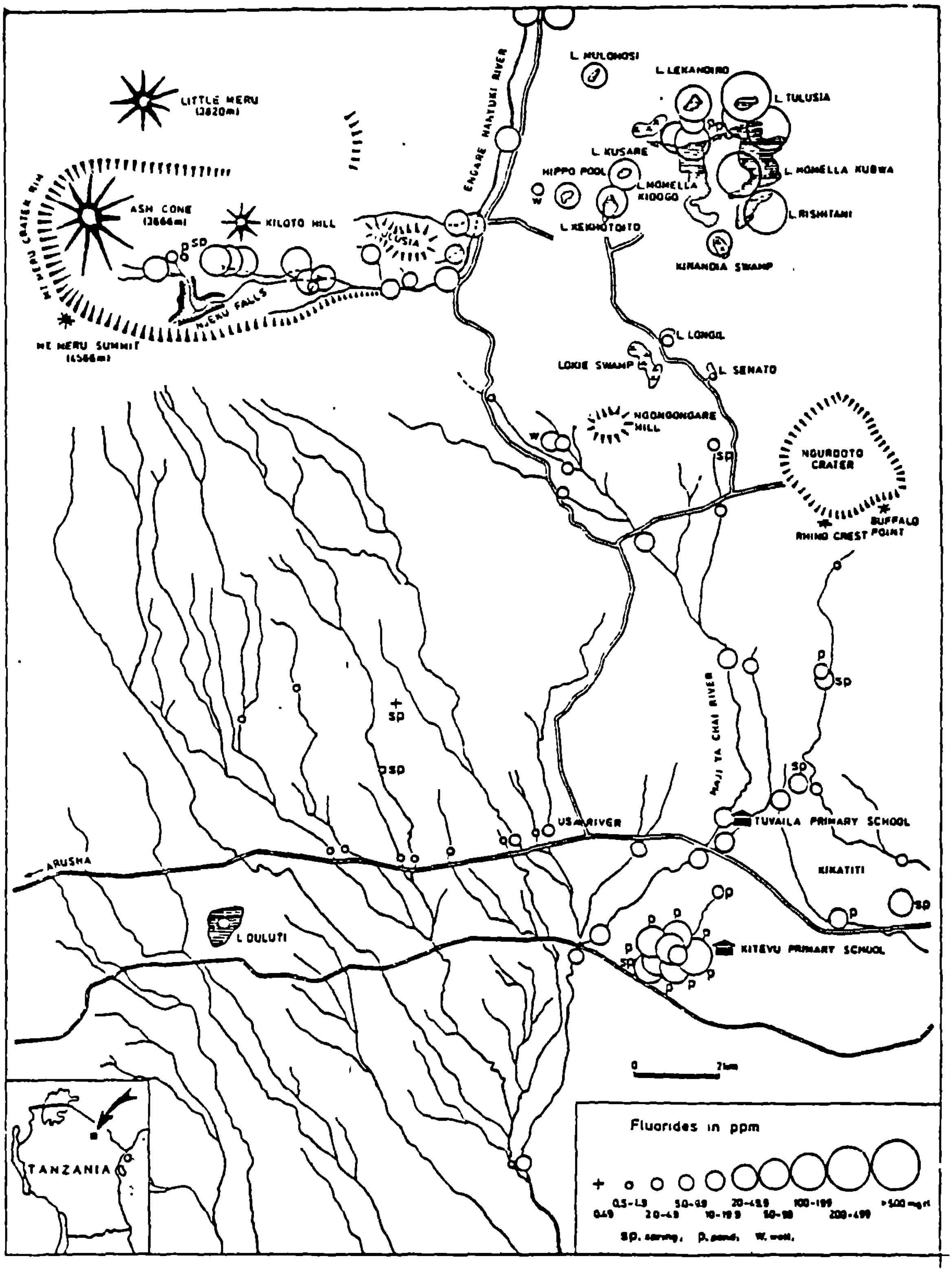


Figure 2. A map showing the fluoride concentration of rivers and lake waters in the Maji ya Chai area (Aswathanarayana et al, 1986).

Mwanza Region:

The work done by the Soil and Water Laboratory Ubungo Dar es Salaam showed a maximum value of fluoride being 18.0 mg/l. This figure was based on a few water samples analysed for fluoride. But during the National Water Master Plans more water samples have been analysed and a higher value of 45.0 mg/l has been recorded. Table 4 illustrates the fluoride situation in Mwanza Region.

Table 4. Fluoride concentration in some water sources of Mwanza Region.

Name of District	Number of boreholes	Fluoride concentration mg/l
Magu	7	1.1 - 5.0
Geita	14	0.1 - 1.8
Sengerema	2	0 - 1.7
Kwimba	30	0 - 9.2
Mwanza	19	0.8 - 45.0

Besides the boreholes, the water from lake Victoria is also used for domestic purposes. The fluoride concentration of the lake water varies from 0 to 1.5 mg/l. This difference could be due to the variation of the geological formation in the lake.

Shinyanga Region:

The previous work showed a maximum value of 14.8 mg/l of fluoride for Shinyanga. This figure was based on a few water samples analysed for fluoride. Ever since more has been done during the Water Quality Surveillance Programmes and the Water Master Plans. Many water samples have been collected and analysed, Jinamo shallow wells in Meatu sub-district indicated a concentration greater than 100 mg/l.

Table 5 illustrates the fluoride situation in the districts of Shinyanga Region.

Table 5. Fluoride concentration in some shallow wells and boreholes in Shinyanga Region (Rutagemwa and Koyi, 1982).

Name of District	Number of shallow wells in use	Fluoride mg/l	Number of boreholes	Fluoride mg/l
Shinyanga	380	1 - 60	35	0.5 - 49
Bariadi	230	2 - 16	13	2 - 10
Maswa	160	2 - 25	4	3 - 10
Meatu	120	2 - 60	-	-
Kahama	150	1.5	4	1.5

From the results compiled above it can be seen that in Shinyanga Region, only Kahama district has water supplies with optimum levels of fluoride.

Singida Region:

The fluoride situation in water sources in Singida Region is summarised in Table 6. These sources are shallow wells and boreholes.

Table 6. Fluoride concentration in some shallow wells and boreholes in Singida Region (Zakayo, 1982).

Name of District	Number of samples analysed	Fluoride concentration mg/l
Iramba	54	0.7 - 67
Singida	128	0.3 - 24
Manyoni	53	0.1 - 19

3.2 Southern Tanzania

In the southern part, there is a much smaller area of volcanic rocks situated in the southern highlands regions. The southern volcanic area, is mainly situated in Mbeya, Tukuyu and Njombe Districts (Figure 3). These areas receive relatively high annual rainfall. As regards to fluoride concentration in these areas, this is clearly illustrated in Table 7. The values are not as high as those found in the northern part of the country. Based on the work done it shows that the waters there yield a fluoride content of up to 10 mg/l, in spite of the volcanic activities taking place. More work is still going on for a clear picture of the situation. Though the problem of fluoride is not prevailing, a different problem has surfaced. This is the deficiency of iodine in water sources, hence goitre is a health problem in some parts of Iringa and Mbeya Regions.

Figure 3. A map of Tanzania showing the fluoride belt.

3.3 The Rest of the Country

The fluoride situation for the whole country is summarized in Table 7. As discussed while some regions are severely affected others like Dar es Salaam have very low concentrations of fluoride in their water sources, that is about 0.2 mg/l. Hence dental caries is a problem (Shaba, 1982).

Table 7. Fluoride concentrations in Tanzanian water sources mg/l (Bardecki, 1974).

Name of Region	Number of Water Samples	Mean Value	Minimum Value	Maximum Value
Arusha	124	7.11	0.10	78.00
Coast	204	0.56	0.00	20.40
Dodoma	391	1.45	0.00	92.00
Kigoma	30	0.61	0.00	6.10
Iringa	68	0.52	0.00	3.21
Kilimanjaro	98	1.91	0.00	25.00
Mara	58	2.02	0.20	9.60
Mbeya	79	0.74	0.00	10.00
Morogoro	93	0.60	0.00	4.00
Mtwara, Ruvuma & Lindi	90	0.55	0.00	7.00
Mwanza	52	3.43	0.20	18.00
Shinyanga	38	3.22	0.28	14.00
Singida	78	5.85	0.00	67.00
Tabora	44	1.20	0.00	7.60
Tanga	116	0.94	0.00	20.00
West Lake (Kagera)	27	0.93	0.00	4.40
Tanzania (Mainland)		1.91	0.00	92.00

In the table above Mtwara, Ruvuma and Lindi Regions are represented together. The reason behind was due to a small number of water samples collected when the task was accomplished.

4 FLUORIDE INGESTION

Owing to the presence of fluoride in water, soil and the environment human beings are exposed to various levels of fluoride uptake. This is achieved through food, water, industrial and pharmaceutical products etc. Although waterborne fluoride is said to present the largest single source of daily uptake of this ion, in some parts of the world, staple food may be the main contributor. This is particularly so in areas with high fluoride content, for example in the northern part of Tanzania. Ingestion of excess fluoride causes a clinical syndrome referred to as fluorosis. Figure 4 shows the hydrogeochemical basis of endemic fluorosis.

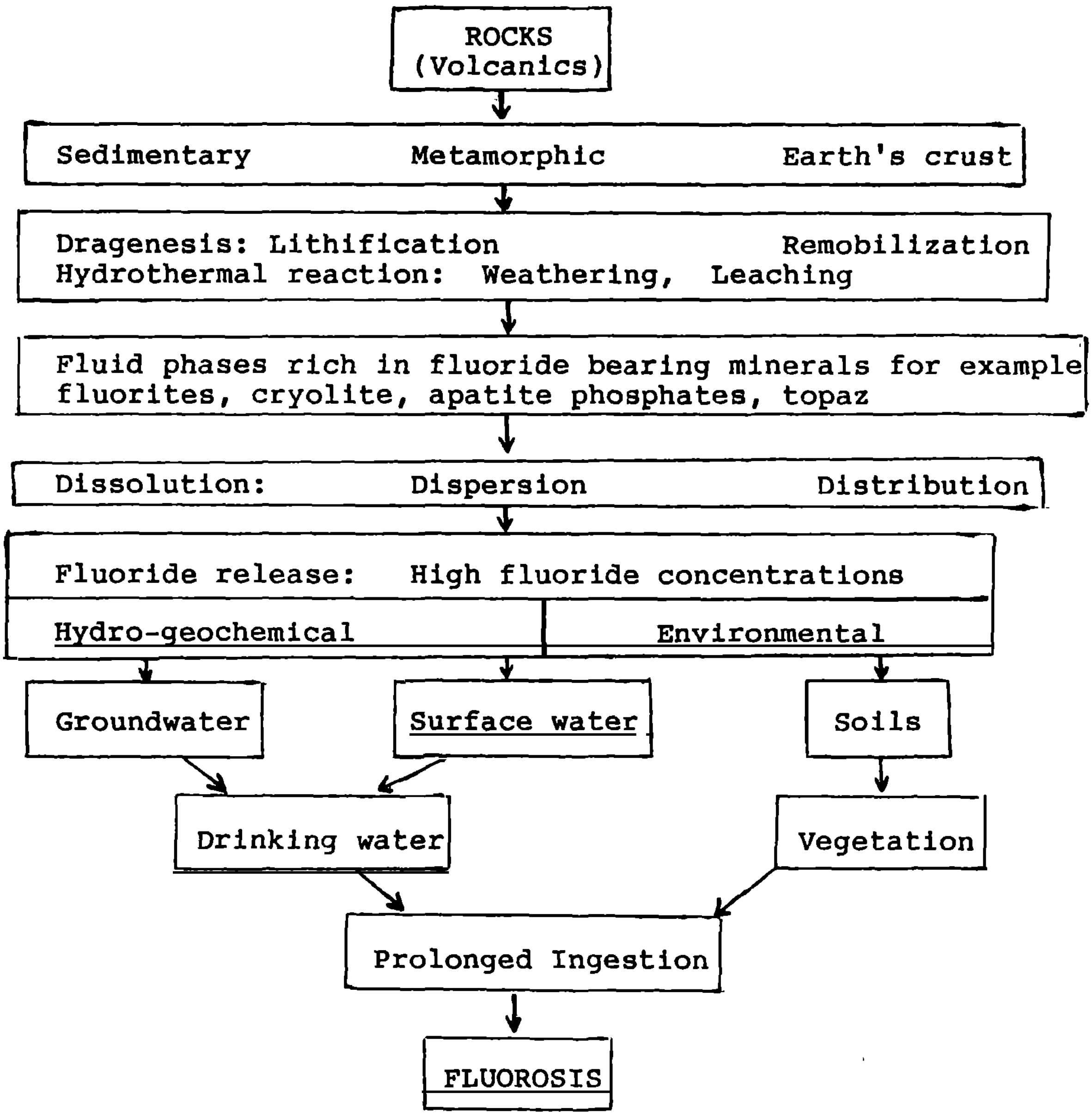


Figure 4. Hydrogeochemical basis of endemic fluorosis (Teotia et al, 1981).

4.1 Fluoride Ingestion from Water

The fluoride contained in drinking water is the largest single contributor to the daily fluoride intake (Murray, 1986). The fluoride ingestion from water depends on:

- the concentration of fluoride content in the water to be used
- dietary habits
- climatic conditions.

Due to climatic conditions and nature of work accomplished people drink different quantities of water. For example an agricultural worker in a hot country like Tanzania may drink 5 - 10 litres per day of water and is therefore more susceptible to fluorosis than an office worker in temperate country who may not drink more water than 1 - 2 litres per day (Aswathanarayana et al, 1986). The most important factor for determining the amount of water consumed per day is the maximum daily temperature of the country in question. Other factors influencing on the water to be consumed are humidity and rainfall. Table 8 gives a comparison of the ingestion of fluoride in northern Tanzania with temperate areas of the world.

Table 8. Comparison of fluoride ingestion in Northern Tanzania with temperate areas (Aswathanarayana et al, 1986).

Name of sources	Ingestion of fluoride in Northern Tanzania mg/day/capital	Normal levels of ingestion of fluoride in temperate areas mg/day/capital
Water	3 litres with 8 mg/l of fluoride ingested 24 mg	2 litres with 0.2 mg/l fluoride ingested 0.4 mg
Tea	10 grams with 100 - 200 mg dry weight fluoride ingested fluoride 1-2 mg	Ingested fluoride about 1.0 mg
Magadi	5 grams of magadi [1] with 1000 mg of fluoride ingested fluoride 5 mg	NIL
Miscellaneous mainly food	Ingested fluoride about 1 mg	Ingested fluoride about 0.6 mg
Total ingested	32 mg/d/capital	2 mg/d/capital

1) Magadi - swahili word meaning sodium carbonate, sodium bicarbonete. In this situation the magadi is highly contaminated with fluoride.

As can be seen in Table 8 above the amount of fluoride ingested in northern Tanzania is about 16 times the amount ingested in temperate areas: it therefore means that much more fluoride is consumed in northern Tanzania, in some cases this range can be even higher. But what remains to be answered is how much fluoride is actually being utilized by the body. Table 9 shows the fluoride balance in human body as compiled by the WHO (1970).

Table 9. Fluoride balance in the human body (WHO, 1970).

Fluoride in Water Supply, mg/l		2	5.5	6.1	8	20
Age, Years		35	55	57	57	30
Length of Residence, Years		10	29	34	19	8
Time of Observation, Days		96	60	133	140	45
Fluoride ingested daily, mg	Fluid	2.4	3.8	6.7	11.3	20.8
	Food	1.2	1.3	1.0	2.5	1.5
	Total	3.6	5.1	7.7	13.8	22.3
Fluoride excreted daily, mg	Faece	0.4	0.6	0.4	1.4	1.4
	Urine	2.9	4.5	8.1	10.4	12.3
	Total	3.3	5.1	8.5	11.8	13.7
Balance, mg/day		+0.3	0.0	-0.8	+2.0	+8.6

Manji et al (1986) reported the prevalence of dental fluorosis in relation to altitude in children aged 11 - 15 years from three low fluoride zones and two high fluoride zones of drinking water. The results obtained during the study in Kenya are summarized in Table 10.

Table 10. Percentage of children suffering from dental fluorosis as reported by Manji et al (1986).

Fluoride concentration in drinking water mg/l		Percentage of children with dental fluorosis at different altitudes		
		at sea level	at 1500 m	at 2500 m
Low	0.5	36.4	78.0	100.0
High	0.5 - 1.0	71.2	93.8	-

Based on the results, the study has established that populations living at high altitudes may be more susceptible to dental fluorosis than those at low altitude. Furthermore, it is reported that certain physiological changes may occur in humans living at high altitudes whereby the effects of fluoride on mineralizing tissue causes the pains to increase.

Tanzania is currently doing some studies on the effects of fluoride. Hence it is the belief of the author that some studies with respect to altitude would be conducted in order to confirm or modify those results reported by the Kenyan researchers.

4.2 Fluoride Ingestion from Food

Among the major factors thought to be contributing to the increase in human exposure to fluoride and consequently fluorosis is the increasing fluoride content in food. Such an increase can arise from the following factors (WHO,1970):

- Use of water containing excess fluoride concentration in food processing.
- Exposure of crops to both air and water borne fluoride in areas irrigated with water containing high fluoride concentration.
- Use of fluoride containing fertilizers.

In case of Tanzania, especially the northern part of the country people use trona - sodium carbonate - sodium bicarbonate as an agent for speeding up the cooking of legumes. The trona used by the inhabitants has been found to be highly contaminated with fluoride. Hence the compound may contain 20 to 14 900 mg/l fluoride.

The ingestion of foods containing high fluoride levels results in higher concentration of fluoride beyond the safe level. Table 11 gives an indication for the range of fluoride concentration in some food types. The table has been prepared by picking the lowest and highest value leaving the intermediates. Efforts have been made to compare those figures given by the World Health Organization and some figures worked out in Tanzania. It can be seen in Table 11 that the fluoride content in some foodstuffs is a little bit higher than those figures given by the World Health Organization.

Table 11. Fluoride concentration in some types of foodstuffs (WHO, 1970).

Type of food	Fluoride concentration mg/l
Meat, Chicken, Beef, Pork, Mutton	0.2 - 1.4
Eggs	0.6 - 1.5
Milk	0.07 - 0.22
Fish: - sardine, salmons	4.5 - 19.3
- mackerels	27.0 - 85.0
- oysters	0.7 - 3.5
Fruits: - lemon, orange	0.03 - 0.36
- banana, apple	0.22 - 1.32
Cereals:- corn, wheat, rice	0.10 - 4.0
Beer	0.20
Tea	3.2 - 178.8
Coffee	0.2 - 1.6

Table 12. Fluoride concentration in some foodstuffs in Northern Tanzania (Mungure, 1984).

Food type	Fluoride content mg/l
Banana	2.5 - 5.20
Beans	2.5 - 10.90
Pumpkin	2.5 - 7.50
Cassava	3.0 - 8.25
Fingermillet	2.5 - 13.75
Sorghum	2.5 - 11.30
Maize	2.5 - 5.80
Pegion peas	2.5 - 5.30
Potatoes	2.5 - 5.80
Tomatoes	2.5 - 11.20

Generally speaking it should be noted that not all the fluoride ingested through food or water is taken by the body. Some of it is excreted through urine, sweat, saliva and faeces (see Table 9 on page 16).

4.3 Ingestion of Fluoride from the Atmosphere

Inhaled fluorides, whether in gaseous or in other form are almost completely absorbed into the blood stream (Rose and Marier, 1977). However, under extreme environmental conditions such as dust pollution from industries, human, being can receive a considerable amount of fluoride from airborne sources (Rose and Marier, 1977). This type of fluoride ingestion is not common in Tanzania; because such industries which emit fluorides are not in existence.

5 FLUOROSIS IN HUMAN BEINGS

Fluoride is nutritionally essential element. However health problems may arise either from deficiency or excess of fluoride. Thus the presence of fluoride in water, food and atmosphere may be beneficial or detrimental to public health depending on the concentration. If the ion is taken in optimum levels of 1.0 - 1.5 mg/l, fluoride helps in preventing dental caries. But taken in higher concentrations it may result in endemic conditions referred to as fluorosis. Recommended daily intake of fluoride is 1.5 - 4.0 mg/d, of this 99 % in man and and animals is in bones and teeth (Aswathanarayana et al, 1986). Fluoride concentration of about 1 mg/l is beneficial because it prevents dental caries in children during the period when teeth enamel is formed (Shaba, 1982; Malentlema, 1982). Higher concentration would cause severe mottling of the teeth in children. Ingestion of very high amounts of fluoride more than 20 mg/day for a very long period may cause skeletal and even crippling fluorosis (Aswathanarayana et al, 1986).

Variability in the incidence of fluorosis among people who draw their water from the fluoride containing sources, arises from any one or combination of the following aspects:

- Diet inadequate in nutrients such as protein, ascorbic acid, calcium, vitamins etc. This nutrition imbalance tends to aggravate the fluorosis problem.
- Type and the amount of staple foods consumed, these contribute to the retention of fluoride in the body. This is influenced upon the content of trace elements such as molybdenum and zinc.
- Use of soft and alkaline waters for cooking purposes, thus increased water consumption which is influenced by body size, habits climate etc.
- Age, children are more affected than adults.
- Sex, males are more affected than females. (Aswathanarayana et al, 1986)

5.1 Benefits of Fluoride Consumption

As discussed fluoride is a nutritionally essential elements found in the enamel of the teeth, bones and other body tissues. As the international guidelines of the World Health Organization recommend a fluoride concentration in drinking water should be at 1.0 - 1.5 mg/l. Thus fluoride at optimum levels ensures good health and protects teeth from dental caries.

As with Tanzania, concentration of fluoride in drinking water of up to 8 mg/l does not produce abnormal effects on bones in man but does benefit the old people from bone decalcification (Rural Water Supply Health Standard Committee, 1974).

5.2 Observation of Detrimental Effects of Fluoride in Man

Fluoride taken above optimum level causes dental fluorosis and persistent ingestion of higher fluoride concentration results in skeletal and crippling fluorosis (WHO, 1970). In Tanzania the problem of fluoride ingestion has been studied mainly in the northern part of the country where people are having dental fluorosis. Some studies have been conducted in Dar es Salaam where concentrations are below 0.2 mg/l (Bardecki, 1974). Most of the studies so far carried out on fluoride intake have been based mainly on the amount of this ion in drinking water.

5.2.1 Dental Fluorosis

Dental fluorosis is due to excessive deposition of fluoride in the enamel leading to mottling and discoloration of the teeth. This could be classified in three grades depending upon the degree of severity.

Grade 1: Loss of translucency, presence of faint yellow lines, few teeth affected

Grade 2: More teeth affected, show yellow to brown stain of the enamel

Grade 3: All teeth are affected, have severe discoloration (Teri, 1982).

The occurrence of dental fluorosis in Northern Tanzania is observed to be very high, Arusha Region 83 % - 95 % (Mosha and Moshi, 1982). In 1977 random samples of children born and brought up in areas with 3 mg/l fluoride in Arusha, 6 mg/l fluoride in Kisongo area and 20 mg/l fluoride concentration in Maji ya Chai village all in Arusha Region were examined. The findings indicated a progressive increase in the severity in dental fluorosis with the increase in fluoride concentration in drinking water (Bruun et al, 1977 cited by Mosha and Moshi, 1982). These findings confirm the statement that human beings from infancy to 16 years of age whose teeth are under mineralization suffer from dental fluorosis (WHO, 1970). Table 13 shows the different fluoride concentrations and the rate of dental fluorosis.

Table 13. Different fluoride concentrations and the dental fluorosis (Labovics et al, 1968 cited by Kljacsko and Apelcin, 1976).

Fluoride content mg/l	Dental health effects
Less than 0.3	Dental caries
0.3 - 0.7	Dental caries
0.7 - 1.1	A small number of the population can suffer from dental caries.
0.9 - 1.1	Optimum levels where hot climates prevail.
1.1 - 1.5	Minimum dental caries in the population if any. A minimum number of population starts to show dental fluorosis.
1.5 - 2.0	Normally 30 - 40 % of the population suffer from dental fluorosis.
2.0 - 6.0	Dental fluorosis suffered by about 30 - 100 % of the population. With children, bone development is weak and abnormal.
6.0 - 15.0	Dental fluorosis, sufferers very many, normally about 80 - 100 % of the population are affected.

The above classification was suggested by Lobovics et al (1968) cited by Kljacsko and Apelcin (1976). Through discussions with some people the classification seems to be applicable in Tanzania.

5.2.2 Skeletal Fluorosis

Skeletal fluorosis is the gross appearance of the bones which have been induced due to early calcification of tendons, ligaments and joint capsules of all over the body especially in the vertebral (WHO, 1970). The clinical symptoms resulting from skeletal fluorosis include among others the following:

- joint pains, i.e. at the knees, ankles, shin cervical spine, hip and joints of the arm
- backache
- bow legs and knocked knees
- stiffness of the trunk and hampered movement of the limbs (Teri, 1982).

Skeletal fluorosis has been observed in some of severely hit areas. One of these known areas is Maji ya Chai village in Arusha Region. Other areas are yet to be identified.

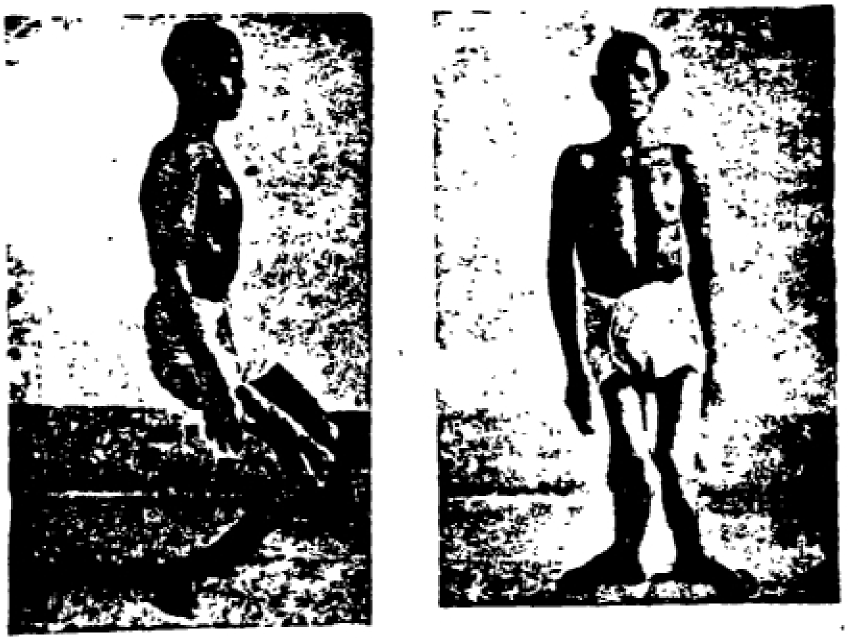


Figure 5. A picture showing young men suffering from crippling skeletal deformities showing distortion of the legs (Krishnamachari, 1974).

5.2.3 Crippling Fluorosis

Crippling fluorosis is the later stage of fluorosis which is characterized by fixed kyphosis and severe joint contractures. Kyphosis means forward bending of the spine (Krishnamachari, 1974; Teri, 1982). An affected person has difficulties in walking due to partial stiffness and limitation of movement of various joints. The problem predominated in adults beyond 40 years. Children exposed to high doses of fluoride could suffer from crippling fluorosis. In a study conducted in some districts in India, crippling fluorosis in the form of knocked knees (Figure 5), has occurred in young adults and even in children under 10 years old among communities exposed to high levels of fluoride (4 - 13 mg/l) (Krishnamachari, 1974).

Agreeing with Krishnamachari, the author saw a case of a young child suffering from crippling fluorosis during a visit to Maji ya Chai Village in Arusha Region. This case was observed during the first National Fluoride Workshop held in Arusha in 1982. During the visit at the village medical doctors got a chance of examining some of the affected persons as seen in Figure 6. As the excercise was taking place a case was noticed of a 2 1/2 years old boy who started to show signs of knocked knees. Table 14 illustrates the effects of the different fluoride dose in the human body including their duration of ingestion.

Figure 6. a) A picture showing some of the Maji ya Chai villagers who are suffering from crippling fluorosis.

Figure 6. b) A doctor examining a young school boy who is showing distortion of the legs.

Table 14. Different fluoride doses and their effects in the human body (Nguvumali, 1987).

Fluoride	Source	Time duration of ingestion	Biological effects
1 mg/l	Water	Life time	Prevention of dental caries. Helps bone and tooth formation.
2 or more mg/l	Water	During tooth formation	Dental fluorosis
5 mg/l	Water or Air	Years	No osteosolerosis
8 mg/l	Water	Years	10 % osteosolerosis
20 - 80 mg/l or more	Water or Air	Years	Crippling fluorosis
50 mg/l	Food or Water	Years	Thyroid changes
100 mg/l	Food or Water	Months	Growth retardation
125 mg/l	Water	Months	Kidney changes
25 - 5 g	Acute dose	2 - 4 hours	Death

6 REVIEW OF SOME FLUORIDE REMOVAL METHODS

Removal is hereby defined to refer to the total effects of all possible mechanisms which remove or reduce fluoride in treated water, as known it is difficult to separate experimentally the effect of adsorption or precipitation. The removal of fluoride in one word is defluoridation.

The technology of defluoridation has been to some extent well developed and tested. Research on the technology, experimental work and application of the techniques for excess fluoride removal have been carried out in Argentina, India, Mexico and the United States of America (Murray, 1986). But there has been no further news on the development, and the literature does not indicate much activity on the subject. This could be due to the fact that the methods are too sophisticated and expensive.

Developing countries are trying to develop methods that could suit climatic condition and human resources of their respective countries. This is being done using the available removal technologies. Kenya has been trying the use of lime and alum popularly known as Nalgonga technique developed in India. Tanzania is currently planning to follow the Kenyan example by trying a few methods by using also the locally available materials wherever possible. Thailand has experimented on bone charred with success (Mosha, 1987). Many researchers in the world have studied the several developed methods for excess fluoride removal from potable water (Choi and Chen, 1979; Rubel and Woosely, 1979 etc.).

There are so many methods for excess fluoride removal including lime and alum, lime precipitation, alum, Defluoron 2, Andco Process, tricalcium phosphate, activated alumina, bone charred, granulated bone, clay pot etc.

Of all the methods a review has been done on the following:

- lime and alum method
- lime as a fluoride remover
- Defluoron 2 process
- Andco process
- filtration through activated alumina
- filtration through bone media
- use of clay chips in fluoride reduction
- blending of two or more water sources as a means of fluoride reduction.

The main reasons of reviewing the above mentioned methods and processes are:

- to make them known to those who do not know their existence
- to study the possibility of experimenting on some of them taking into consideration the natural conditions of Tanzania
- to study the possibility of using locally available materials amongst the methods.

6.1 Lime and Alum Method

Excess fluoride removal from potable water has been an important project in India since 1960. The research project included contact beds using bone charred, activated alumina, ion exchange resins serpentine, a family of minerals and activated magnesia. Due to the setbacks encountered in the mentioned methods, the lime and alum was developed popularly known as Nalgonda Technique (Bulusu and Pathak, 1980). The method comprises addition of commercial aluminium sulphate and lime to fluoride containing water followed by coagulation and flocculation, sedimentation, filtration and disinfection as illustrated in Figure 7.

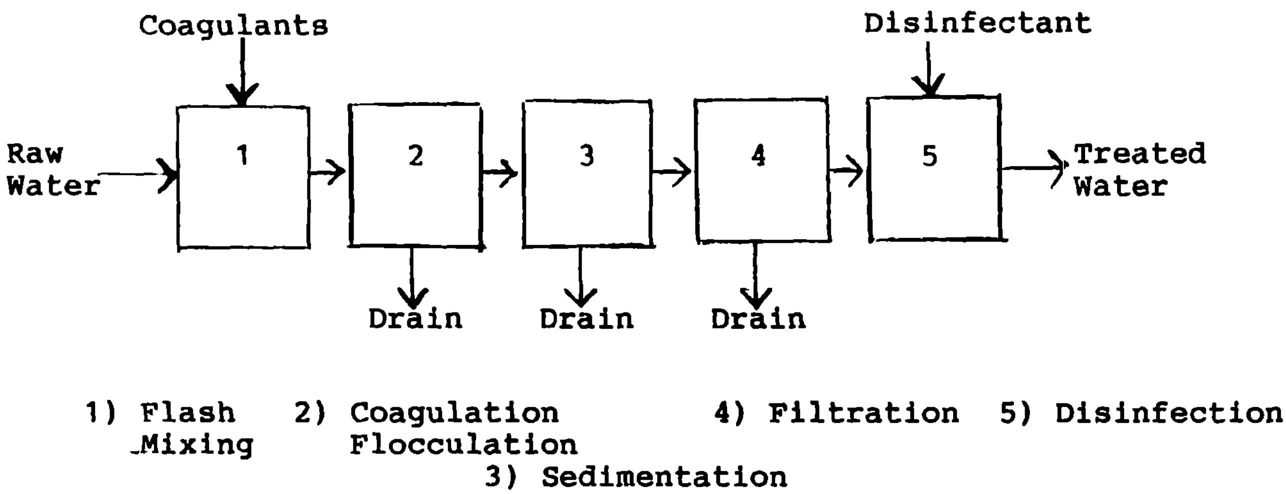


Figure 7. Flow diagram on the Nalgonda Technique.

The method is said to reduce fluoride concentrations down to 1.0 mg/l with high alkalinity playing a very important role. The high alkalinity value is obtained by adding lime in order to raise pH before the addition of alum.

The method has been tried in Kenya at a pilot level. Jar test experiments were conducted in order to determine the optimum dosage of alum required to reduce fluoride concentration from various levels to 1.0 mg/l. From the experiments and field trials the results indicated that 260 mg/l of alum was required to reduce the fluoride concentration from 2.05 mg/l to 1.10 mg/l while 1170 mg/l of alum was required to reduce the ion from 14.20 mg/l to 2.0 mg/l (Gitonga, 1985). No figures were given on the amount of lime required for raising the pH. The Indian experience says that 1/20th the amount of alum would be the amount of lime required for raising the pH (Nawlakhe et al, 1975). Furthermore Gitonga did not give the pH range at which the optimum fluoride removal was obtained.

Aluminium ion in excess is also a health problem. Results obtained from field trials in Kenya gave a high value of residual aluminium ion in the treated water. This depended on the amount of alum added. An addition of 1 200 mg/l alum gave a residual aluminium ion of 6.0 mg/l (Gitonga, 1985).

6.2 Lime as a Fluoride Remover

Lime is used to supply the divalent calcium ion necessary to combine with fluoride to form calcium fluoride precipitate. The concept is illustrated by the following chemical equation.

$$CaO + H_2O = Ca(OH)_2 \qquad (1)$$

$$Ca(OH)_2 + 2F^- = CaF_2 + 2(OH) \qquad (2)$$

As suggested in the literature, the use of lime is more effective if the concentration of fluoride is greater than 20 mg/l which could result to the subsequent precipitation of calcium fluoride as illustrated in equation (2). The precipitation could result in a fluoride reduction to about 8 mg/l (Rabosky and Miller, 1974). The pH range for lime precipitation is 11.5 - 12.0 and that of coagulation is 6.0 - 7.0 (Rabosky and Miller, 1974). The pH 6.0 - 7.0 is good when alum is being used. This range does not allow aluminium to dissolve in water thus not causing excess residue aluminium ions in the treated water.

6.3 Defluoron 2 Process

Defluoron 2 is made up of sulphonated carbonaceous material which is loaded with aluminium ions in a cylindrical shell, Figure 8. In principle the method is an ion exchange process passed through resin. The aluminium ions combine with fluoride ions from the water to be treated forming a compound of aluminium fluoride. Regeneration happens with the use of commercial aluminium sulphate solution with a pH value between 2.6 and 2.8, and a contact period with medium being 30 to 40 minutes. The capacity and efficiency of the process is dependent on alkalinity and the initial fluoride concentration of the raw water to be treated. The pH range and contact time at which fluoride removal is optimum has not been mentioned. The method was developed by the Central Public Health Engineering Research Institute Nagpur India (Majumder, 1973).

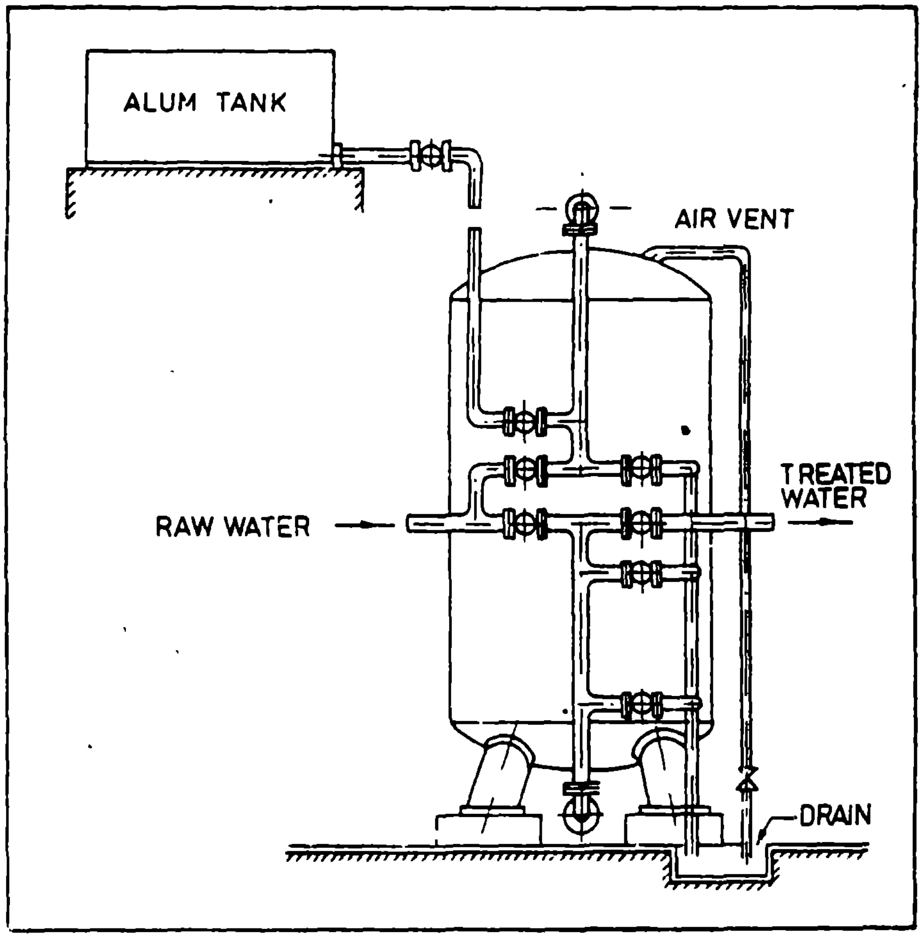


Figure 8. Defluoron 2 plant for fluoride removal (Majumder, 1973)

6.4 Andco Process

Andco is an american developed method. The process is sophisticated but the chemical consumption is low (O'Brien, 1983). In the process, fluoride is removed as a high insoluble fluorapatite compound. In the process pH plays a very significant role in excess fluoride removal to optimum level. Acidic condition tends to increase the solubility of fluorapatite while upwards adjustment of the pH completes the precipitation of fluoride. Andco process involves the addition of phosphate-calcium mixture, adjusting the pH to 6.2 - 7.0 as illustrated in Figure 9. Then fluorapatite is added and mixed, waiting for seven minutes in the holding tank for the reaction to take place.

The chemical reaction is:

$$2NaF + 6H_3PO + CaCl_2 + 9Ca(OH)_2 = 2Ca_5(PO_4)_3F + 2NaCl + 18H_2O \quad (3)$$

After the time of holding in tank has passed the pH is readjusted to 7.5 - 9.5 with 8.5 being the optimum value for water used for domestic purposes: the water then goes to the clarifier from which it goes to the filters. After which the water goes through disinfection process and then conveyed to a storage tank or consumer.

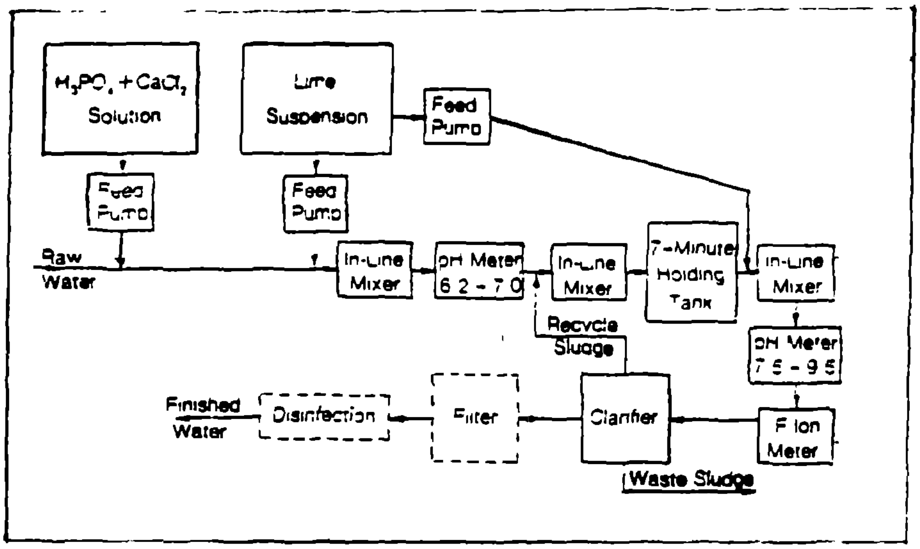


Figure 9. Fluoride removal by Andco Process (O'Brien, 1983).

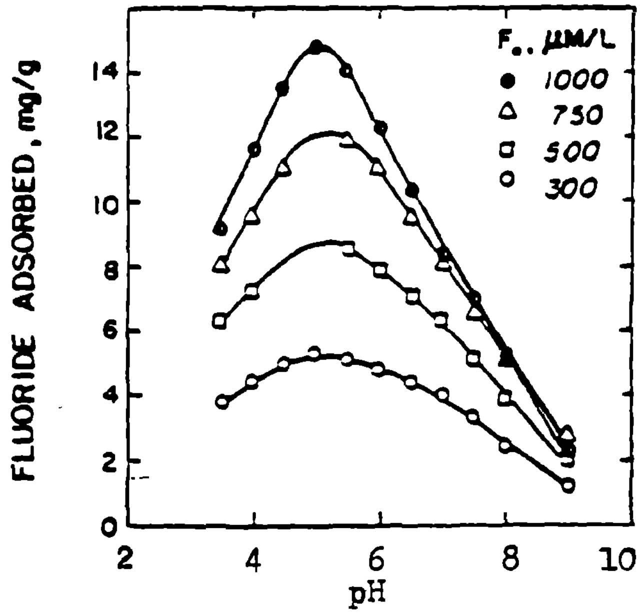
The facilities for using Andco process are supplied by Andco Environmental Process Inc., U.S.A. as package plants (O'Brien, 1983).

6.5 Filtration Through Activated Alumina

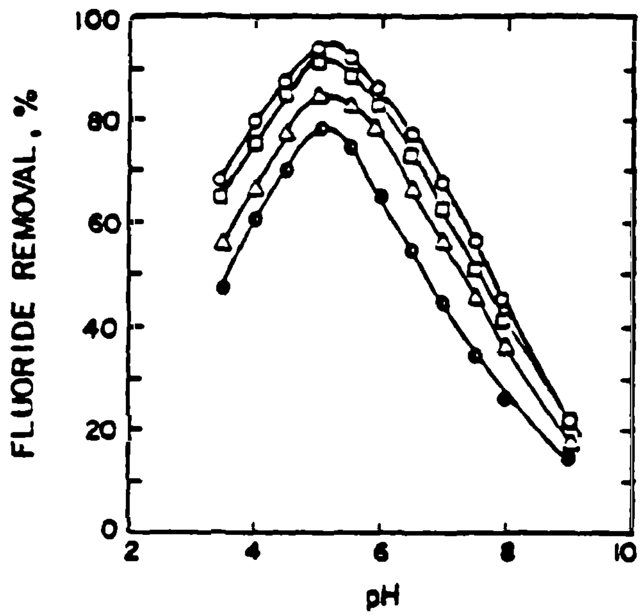
Of all the defluoridation methods and techniques, activated alumina has been well studied and documented. A number of publications on the subject have demonstrated the advantages over other excess fluoride removal methods. The first people to study the fluoride removal properties of activated alumina were Boruff, Fink and Lindsay in 1930's (Barbier and Mazounie, 1984). According to its characteristics, activated alumina can fix both cations and anions. Many factors exist which affect the fixation, one of them is particle size of the filtering material. The fluoride fixation capacity of activated alumina increases when smaller particle size material is used for a given raw water and constant filtration conditions.

Fixation declines with increasing alkalinity because bicarbonates compete with fluorides at the adsorption sites. There is a great retention of fluoride ions under acidic conditions, pH value being 5.5 (Barbier and Mazounie, 1984).

Activated aluminas are generally obtained by heat treatment of hydroxides. Different types exist, for example F-1 which depends primarily on the pH and surface loading (Hao and Huang, 1986). This is clearly illustrated in Figure 10 (a) and (b).



a) Fluoride removal per unit weight of activated alumina.



b) Percentage fluoride removal.

Figure 10. Effects of pH and surface loading on defluoridation by activated alumina (Hao and Huang, 1986).

With activated alumina, optimum removal exists when the pH value of raw water is adjusted to 5.0 - 6.0 by using sulphuric acid (Rubel and Woosely, 1979). Choi and Chen (1979) reported an optimum pH value of 6 on activated alumina while Wu and Nitya (1979) reported an optimum value of 5. All these values are well illustrated in Figure 10 (a) and (b). A plant layout using activated alumina for fluoride reduction to maximum contaminant levels is shown in Figure 11. After achieving the fluoride removal to accepted level, the pH has to be readjusted to accepted values hence rendering the water treated fit for domestic use.

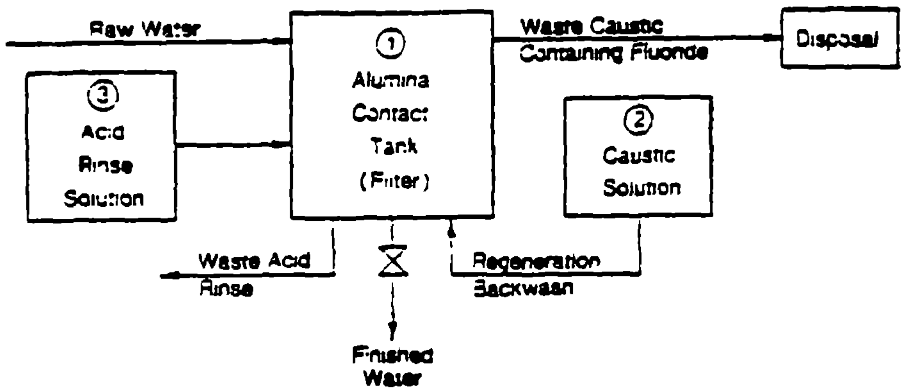


Figure 11. Fluoride reduction using activated alumina (O'Brien, 1983).

The release of free aluminium ions may also exhibit toxic effects to human health. But there is no evidence of carcinogenesis in a series of studies, only that aluminium has been associated with certain neurological disorder (Murray, 1986). To avoid the problem of excess aluminium in the treated water, great care must be taken when using activated alumina. Due to the formation of alumina fluoro complexes, it may be desirable to operate the fluoride adsorption process at pH values slightly higher than 6 in order to prevent alumina from dissolving. Even though this is not the optimum pH for fluoride reduction.

Activated alumina has been experimented for household defluoridation and has also been successful in several modern plants (Rubel and Woosely, 1979).

The defluoridation unit in Figure 12 was used in Sweden in 1983. Two units were connected to taps from which the raw water had fluoride concentration of 6.9 to 7.7 mg/l. After passing the water through the units, the treated water was collected and analysed for fluoride, pH and aluminium. In both cases the parameters were at acceptable levels (Svedberg, 1984).

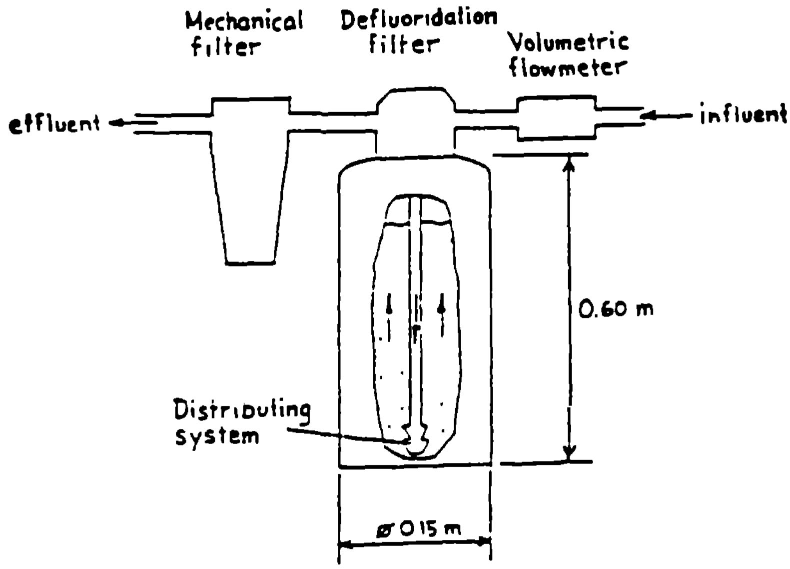


Figure 12. Household defluoridation unit used in Sweden (Svedberg, 1984).

6.6 Use of Bone in Fluoride Removal

Bones can be used in two types for defluoridation, these being granulated bone media and bone charred. Granulated bone media has been successfully used for fluoride reduction in Argentina (Cardero, 1985). Advantage of the method is that bones are locally and easily available at low cost or even free of charge from slaughterhouses. Preparation is simple: the bone must be cleaned, all flesh and blood removed and furthermore degreased. This can be achieved by soaking the material in a strong alkaline solution. Then the bones are to be washed, sundried and crushed into smaller particle size. This process does not need sophisticated means to do the job but can be accomplished manually. Care should be taken to ensure that the media is free of contamination. In principle the granulated bones react with fluoride as the teeth and the bones of the human body. The removal of fluoride is achieved by means of ion exchange properties of the granular which consists of hydroxyapatite. A contact time of half an hour is allowed which is enough to allow the fluoride to chemically combine with bones. At a production of 20 litres per day and a concentration of 10 mg/l fluoride in the raw water, the media will need to be replaced after every three months (Cardero, 1985). This type of media could be appropriate for household defluoridation unit as indicated in Figure 13.

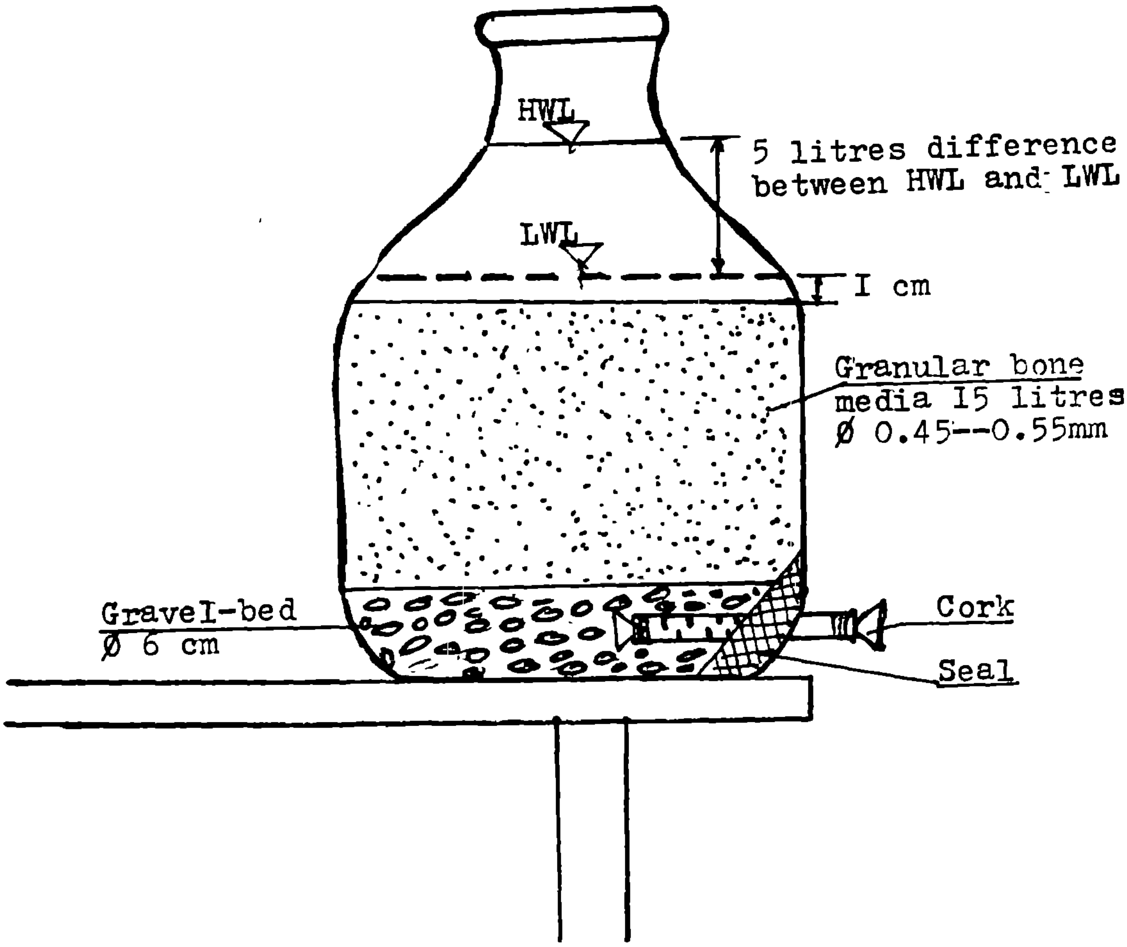


Figure 13. Household defluoridation device (Cardero, 1985).

Bones can also be used as bone char. This is ground animal bones charred in order to remove the organic materials. Bone char was used to reduce fluoride in Britton, South Dakota USA from 1953 to 1971. But the fluoride capacity of bone char was lost during each successive regeneration and was susceptible to attack by low pH. Thus these factors have discouraged further development on the use of bone char (Rubel, 1984).

Taking into consideration one of the objectives of the International Water Supply and Sanitation Decade of improving the peoples health by providing safe drinking water, Dental Faculty University in Bangkok, Intercountry Centre for Oral Health Organization developed a defluoridator (Mosha, 1987). This unit is based on filtration and adsorption as illustrated in Figure 14. The bone char was prepared using purchased bone meal of 40 - 60 mesh size as produced for agricultural and industrial purposes. The bone was activated by heating at temperature of 600° C for 20 minutes. After cooling the bone was weighed in 1 kilogram lots for use in the defluoridation unit (Mosha, 1987). During experimentation the 1000 gram bone char was to have the ability of defluoridating 480 litres of water with fluoride concentration of 5 mg/l to less than 1 mg/l with a flow rate of 4 litres per hour. The filtering material can remain active for 1 - 3 months depending on the amount of water to be treated and the initial fluoride concentration (Mosha, 1987).

The results obtained in Thailand seem to agree with those obtained in Argentina, though the bone treatment was different. The expected time for media replacement is also the same in both cases.

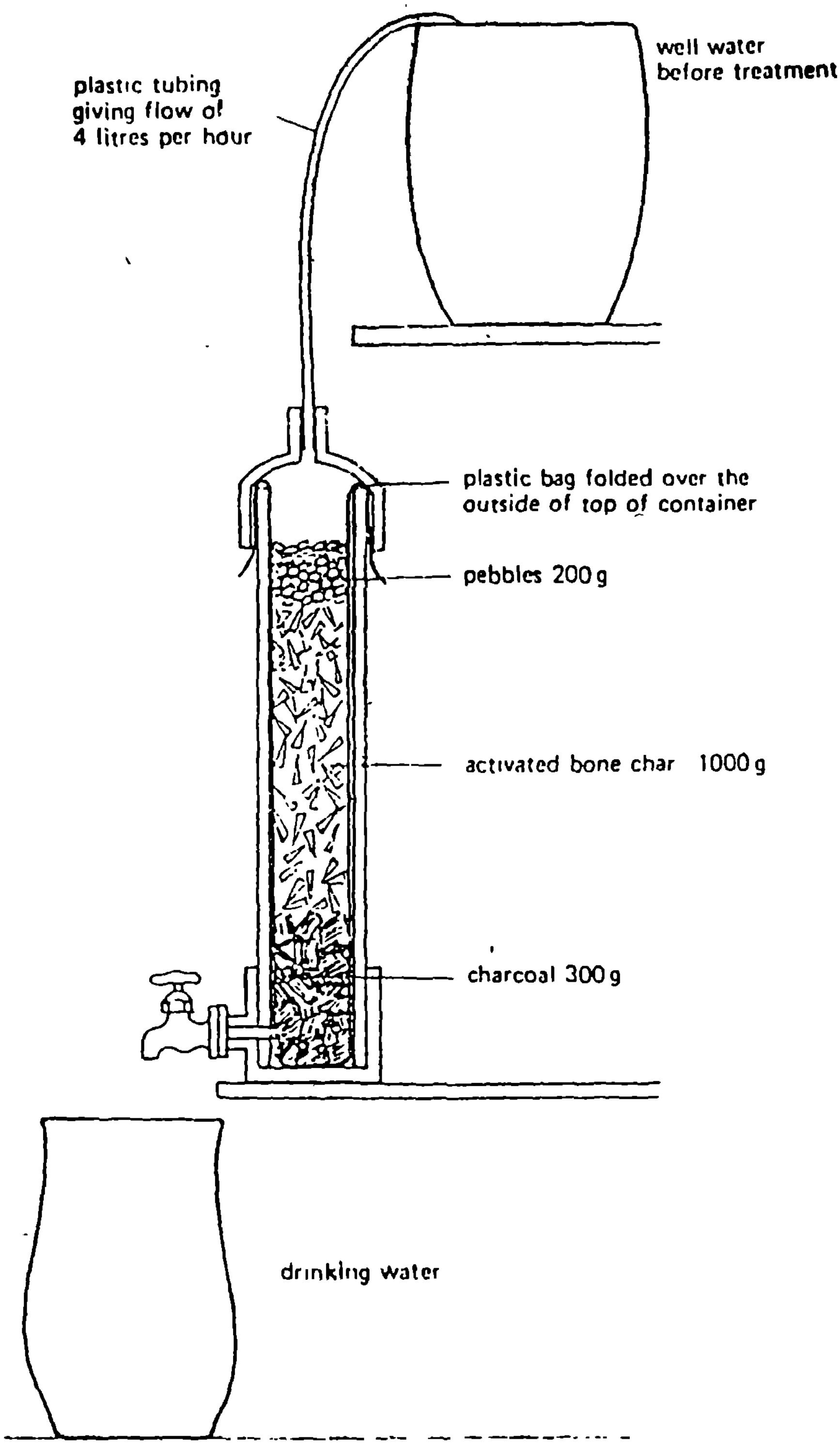


Figure 14. Intercountry Centre for Oral Health Defluoridation Unit (as cited by Mosha, 1987).

6.7 Use of Clay Pot Chips in Fluoride Reduction

Some tests carried out at the University of Nairobi reported that clay pot chips have the ability of reducing fluoride concentration in water. The chips were obtained by breaking the pots bought from the pot makers (Gitonga, 1985). Ever since there has been no further development on the use of the material.

6.8 Blending of Two or More Water Sources

Blending could be done by bringing water of low fluoride concentration and mix it in order to dilute the high fluoride content in a large reservoir. These can be two or more water sources.

Mixing of two or more water sources is being practiced in Arusha town in Tanzania. Arusha town gets its water for domestic purposes from a series of springs which have fluoride concentration ranging from 2.5 to 5.3 mg/l. The water from the several springs is collected in Masama collector which gives fluoride concentration at a range of 2.9 to 4.3 mg/l (Mcharo, 1986). There is some reduction of the fluoride content taking into consideration the maximum value obtained from the springs before mixing. The questions which have to be looked into before one uses the method are the mixing ratios and effects of the different water quality parameters with regards to fluoride reduction.

6.9 Summary of the Literature Review

Inorder to assess the different methods of fluoride removal, their working principles and main features including development possibilities, the methods are summarized in Table 15.

Table 15. Summary of the literature review of some defluoridation methods.

Name of method	Principle involved	Features of the method	Development potential with respect to developing countries	Reference
Lime and Alum	Coagulation and flocculation with lime and alum, sedimentation and filtration.	Large quantities of chemicals required. Adverse effects on water quality.	Good due to simplicity. Alum is a chemical used in water treatment.	Nawlakhe et al, 1975 Gitonga, 1985
Lime	Precipitation	Poor removal with low fluoride content.	Could work fairly with high fluoride concentration above 20 mg/l.	Rabosky and and Miller, 1974
Defluoron 2 Process	Ion exchange achieved by filtering.	Alkalinity is very important.	Difficult to evaluate due to limited information available in the literature.	Majumder, 1973
Andco Process	Addition of phosphate-calcium mixture, precipitation of fluoroapatite.	Sophisticated and expensive, not much is available in the literature.	Difficult to evaluate.	O'Brien, 1983

Table 15. Continued.

Name of method	Principle involved	Features of the method	Development potential with respect to developing countries	Reference
Activated Alumina	Adsorption and filtration of the water through a filterbed.	Relatively complex, expensive. Very effective and has much experience.	Fair. Only that the material will have to be imported from abroad.	Choi and Chen, 1979 Rubel and Woosely, 1979 Bulusu and and Pathak, 1980 Hao and Huang, 1986
Bones -charred -granulated	Ion exchange, bone and fluoride react.	Cheap material, easily available, simple method.	Good but possibility of rejection.	Rubel, 1984 Cardero, 1985 Mosha, 1987
Blending	Dilution by mixing more than one water source.	Not much available in the literature.	Difficult to evaluate.	Mcharo, 1986
Limestone	Adsorption and filtration of the water through a filterbed.	Smaller particle size for filtration material required. Quickly exhausted thus regeneration problems.	Fair considering the availability of limestone locally.	Mcharo, 1986
Clay pot chips	Adsorption and filtration of the water through filterbed.	Long contact time required.	Fair taking into account the cost involved. Material locally available.	Gitonga, 1985

7 EXPERIMENTS ON SOME OF THE TREATMENT METHODS OF FLUORIDE REMOVAL

A few methods, using a variety of chemicals commonly used in water treatment were chosen for testing their fluoride removal ability. These chemicals included among others alum and lime and polyaluminium chloride. Besides the chemicals, a variety of media were also chosen for testing their removal ability. The media included treated magnesite, granular and charred bones and clay pot chips. The choice to try these was based on the literature search, discussions and lectures received in water treatment during my studies at Tampere University of Technology.

After the test were done, the treated water was analysed for fluoride concentration and pH. When enough water was treated samples were collected and sent for full analysis for domestic use. This was done for both raw water as well as treated water after fluoride removal. The analytical results of raw water are as indicated in Table 16. The results show that the water is soft with high fluoride concentration.

Table 16. Physical and chemical characteristics of the intake water of the Engurudoto Pilot Plant under construction.

Description of parameter	Unit	Values obtained
pH		8.5
Turbidity	NTU	1
Conductivity	μs	850.0
Fluoride	mg/l	20.1
Alkalinity	mg/l	302.0
Hardness as $CaCo_3$	mg/l	33.0
Calcium	mg/l	3.6
Magnesium	mg/l	5.8
Chloride	mg/l	not determined
Sodium	mg/l	not determined

The source of water under experiment is a spring from where the river starts. The intake is constructed at the foot of Ngongongare Hill. As the spring water flows downstream with other springs joining, the source acquires the name Maji ya Chai meaning tea water, see map in Figure 2.

The physical and chemical properties of the raw water are within the limits of both the WHO guidelines and the Tanzanian rural temporary water health standards except for fluoride. The value of fluoride concentration varied between 18 - 23 mg/l. These limits of acceptable and allowable concentrations of chemical substances affecting potability as suggested by both WHO, 1984 and Rural Water Health Standards Committee (RWHSC) of Tanzania, 1974, are clearly illustrated in Table 17.

Table 17. Physical and chemical potable water quality parameters (WHO, 1984 and Rural Water Health Standards Committee (RWHSC), 1974).

Description of parameter	Unit	WHO maximum allowable	Tanzanian temporary standard
Substances affecting palatability			
Total dissolved solids	mg/l	1500	2000
Iron	mg/l	0.3	1.0
Manganese	mg/l	0.5	0.5
Copper	mg/l	1.5	3.0
Zinc	mg/l	1.5	15.0
Total hardness	mg/l	500	600
Sulphate	mg/l	400	600
Chloride	mg/l	250	800
Other factors affecting palatability			
Turbidity		5 NTU	
Taste		not offen-sive	not objection-able
Odour		not offen-sive	not objection-able
pH		6.5 - 8.5	6.5 - 9.2
Substance affecting health			
Nitrate	mg/l	10	100
Fluoride	mg/l	1.5	8
Substances which are toxic			
Arsenic	mg/l	0.05	0.05
Cadmium	mg/l	0.05	0.05
Chromium	mg/l	0.05	0.05
Cyanide	mg/l	0.10	0.20
Lead	mg/l	0.10	0.10
Selenium	mg/l	0.01	0.05
Phenolic substances	mg/l	0.002	0.002

When carrying out the experiments two parameters were analysed these being pH and fluoride concentration. The experiments done were in two main groups with appropriate method followed. These were:

1. Coagulation and flocculation, under which the following chemicals were used
   - lime and alum
   - polyaluminium chloride.

2. Filtration and adsorption experiments which included
   - filtration through magnesite
   - filtration through clay pot chips
   - filtration through granulated bone and bone charred.

Then followed a combination of polyaluminium chloride and magnesite.

7.1 Analytical Procedures

a) Fluoride ion

The analysis of fluoride concentration in water samples requires the determination of the amount of fluoride ion present in the sample. Various analytical methods are used in the analysis of this halogen.

Most of these methods are time consuming and inaccurate with interference by other ions causing problem of accuracy. Therefore, the method chosen for analysing fluoride must be of such sensitivity that even small quantities down to less than 1 mg/l can be detected accurately. Thus of all the methods available specific ion electrode is most preferred. This is due to its sensitivity to fluoride at the lowest possible levels encountered in water. Moreover the electrode method is easily performed and convenient and interferences found in water can be minimized or eliminated.

This method requires a specific ion meter, or an expanded scale pH or digital pH meter that is provided with millivolts in addition to pH. Moreover needed is a combined electrode which has both fluoride sensing electrode and a reference electrode. This type of apparatus was used for analysing fluoride in the experiments performed.

Reagents used included a stock solution of 100 mg/l sodium fluoride from which standards were made with appropriate dilutions and total ionic strength adjusting buffer (TISAB). The buffer is meant to neutralise the interfering ions in the water samples. The standard and the tisab solutions can be industrially prepared or prepared by an analyst in the laboratory. All the chemicals were kept in plastic bottles to preserve their stability. During the analytical work plastic beakers were used. The use of the specific ion meter was in line with the manufacturer's instructions.

b) Procedure

25 millilitres of water sample was transferred into 100 millilitre capacity plastic beaker using a 25 millilitre capacity measuring cylinder. A magnetic flower was also put into the beaker. After rinsing the cylinder 25 millilitres of tisab solution was measured and transferred into the beaker containing the water sample. The beaker was put on a magnetic stirrer. The electrode was lowered very slowly until the tip was not touching the magnetic rod. The sample containing the tisab was stirred for some time and finally the concentration of fluoride in the sample taken when the meter reading was steady. The actual figure in mg/l was obtained with the help of standard curve which is prepared whenever the analysis is done.

In this work Electronic Orion Research model 70IA/digital ion analyzer was used.

c) pH value analysis

The pH readings were recorded using pH 91 with electrode type E 50. the meter was all the time standardized using buffer solutions with pH values 6.9 and 9.3. The electrode was rinsed with distilled water and wiped dry with a tissue paper at the end of each water sample reading. The water sample to be tested was put into a 100 millilitre capacity plastic beaker, the electrode was immersed and the pH value recorded when a stable reading was obtained.

7.2 Coagulation and Flocculation

Under this heading two treatment methods would be discussed, these are:

- use of lime and alum
- use of polyaluminium chloride.

In these methods chemicals are applied during the water treatment process. Thus the treatment process can be divided into at least four stages, these include:

- the dosing stage where the determined amounts of chemicals are added
- the mixing stage where the added chemicals are completely mixed
- flocculation stage where the small flocs are encouraged to form into bigger flocs that can settle
- the sedimentation stage where the flocs already formed are allowed to settle to the bottom of a settling tank technically known as clarifier.

The experiments performed and discussed involve the determination of the optimum amounts of chemicals to be applied during the treatment process with the purpose or reducing fluoride to the optimum levels to safeguard the human health. These experiments were jar tests.

7.2.1 Lime and Alum as Fluoride Reducer

Six beakers were prepared, to each a volume of 500 millilitres of raw water was put. Then to each of the beakers now containing raw water with an initial fluoride concentration of 18.0 mg/l, 500 mg of lime was added. The quantity of lime added raised the pH to 9.6. To the six beakers appropriate volumes of alum were added: these were 3.0, 4.0, 5.0, 6.0, 7.0 and 8.0 millilitres respectively. The whole set of beakers was put under a multiple stirrer and slowly stirred for 15 minutes at 30 rounds per minute. The contents were left to settle for half an hour. After settling they were filtered through a filter paper. The filtrate was then analysed for fluoride and pH. The results obtained are summarized on Table 18 and also presented in Figure 15.

Table 18. Results of jar test experiment when using lime and alum in fluoride reduction.
Raw water: fluoride concentration 18.0 mg/l
pH value 8.6

Beaker Number	Lime added g/500 ml	pH	Alum added ml/500 mls	pH	Fluoride content mg/l Residual	Removed	% Removed
1	0.5	9.6	3.0	7.5	7.2	10.8	60.0
2	0.5	9.6	4.0	7.1	5.3	12.7	70.6
3	0.5	9.6	5.0	6.8	4.2	13.8	76.7
4	0.5	9.6	6.0	6.6	4.0	14.0	77.8
5	0.5	9.6	7.0	6.3	4.5	13.5	75.0
6	0.5	9.6	8.0	5.9	5.9	12.1	67.2

Figure 16 shows the pH range at which higher fluoride removal took place. This pH range agrees with the findings of other investigators.

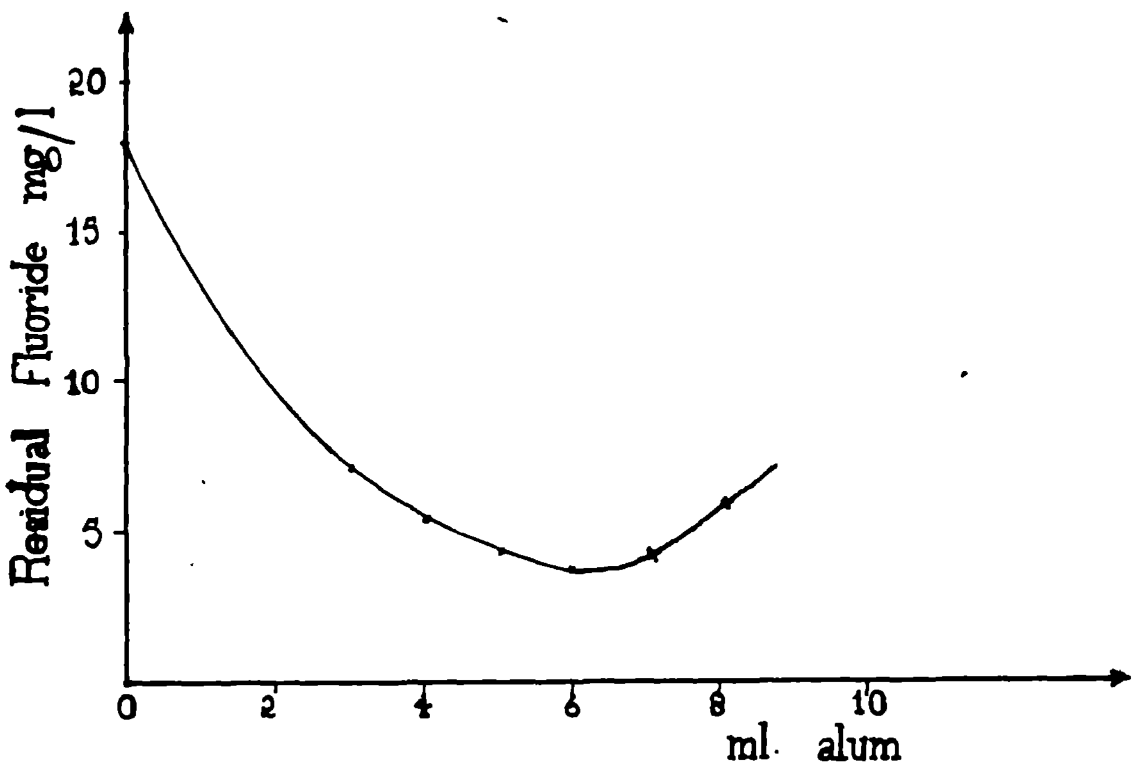


Figure 15. Fluoride reduction using alum.

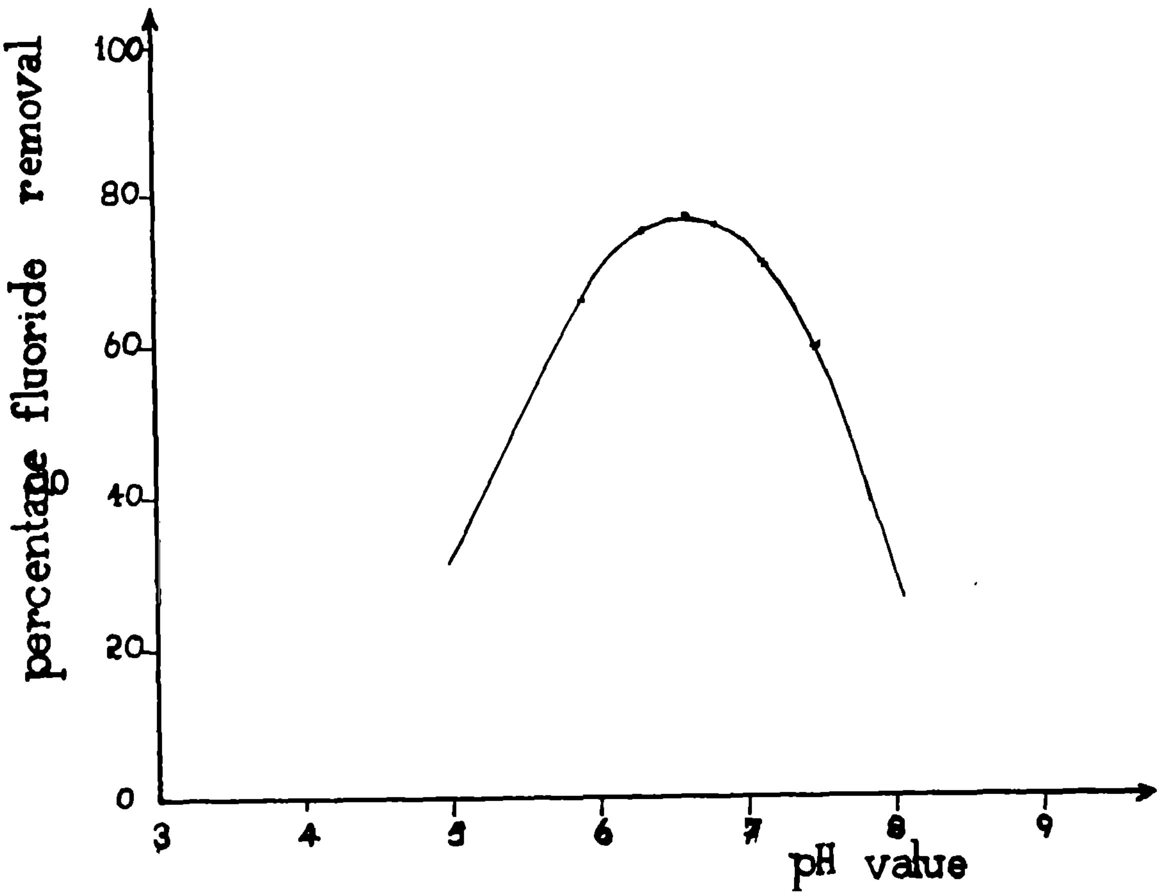


Figure 16. Percentage fluoride removal plotted against pH values.

7.2.2 Use of Polyaluminium Chloride in Fluoride Reduction

Polyaluminium chloride is a new chemical manufactured by Kemira Oy, a Finnish company. The chemical is commercially known as Kempac. Polyaluminium chloride is a polynuclear complex of the polymerized aluminium ion where the chloride forms the anion part. The compound is an inorganic polymer, the general formula for the chemical is $Al_n(OH)_mCl_{3n-m}$ (Kemira Oy, 1987). The chemical is in a liquid form supplied in 800 litre containers, its properties are summarized in Table 19 below.

Table 19. Properties and composition of polyaluminium chloride (Kemira Oy, 1987).

Description of property		Concentration and water values
Aluminium oxide	(Al_2O_3)	10 %
Chloride	(Cl)	9 %
Sulphate	(SO_4)	2 %
Density		1200 kg/m^3
Viscosity		15 mPas at -10^{o} C
		8 mPas at 5^{o} C
		5 mPas at 20^{o} C
Freezing point		-15^{o} C
pH		2.7 $\pm$ 0.3
Colour		colourless or yellowish

Besides the above mentioned properties the product has the following properties as well:

- forms flocs very fast
- flocs are large
- good turbidity remover
- acts in a wider pH range than aluminium sulphate
- less alkali needed for pH adjustment because of low pH values (Kemira Oy, 1987).

a) Jar test experiments with polyaluminium chloride

Six one litre capacity beakers were set each containing 500 millilitres of raw water with an initial fluoride concentration of 19.0 mg/l. To each of the six beakers the following volumes of polyaluminium chloride were added, that is 1.0, 2.0, 3.0, 4.0, 5.0 and 6.0 millilitres. The set of beakers was put under a multiple stirrer and the content was slowly stirred for 15 minutes at a speed of 30 rounds per minute. Flocs were formed in a short time in beakers 1 and 2 containing 1 and 2 millilitres of polyaluminium chloride, followed by the rest of the beakers when stirring. Flocs in beakers 5 and 6 containing 5.0 and 6.0 millilitres respectively were not quite visible, they looked cloudy or milky.

After the stirring process, the content was left to settle for half an hour. Then it was filtered through a filter paper. The filtrate was then analysed for fluoride content and pH reading taken. The results are summarized in Table 20. Beaker 6 gave 0.7 mg/l fluoride concentration and pH value of 4.1. This means 96 % fluoride removal. Beaker 4 gave 1.6 mg/l fluoride and a pH value of 4.2. This means 91 % fluoride removal. This value (1.6 mg/l) is almost meeting the World Health Organization guideline 1984. Beakers 1, 2 and 3 meet the Tanzanian temporary standard as far as fluoride concentration is concerned. But the pH values in all cases do not meet any of the criteria described. This means that there is a need of pH adjustment to make the water acceptable for domestic use.

Table 20. Results obtained after a jar test experiment using polyaluminium chloride (PAC).
Raw water: fluoride concentration 19.0 mg/l
pH 8.5

Beaker Number	PAC added ml/500 ml	pH	Fluoride content mg/l		% - age
			Residual	Removed	Removed
1	1.0	6.0	4.7	14.3	75.3
2	2.0	5.0	5.0	14.0	73.7
3	3.0	4.6	2.6	16.4	86.3
4	4.0	4.2	1.7	17.4	91.3
5	5.0	4.2	1.2	17.8	93.7
6	6.0	4.1	0.7	18.3	96.4

After obtaining the first results, an optimum dose was found to be between 3.0 and 4.0 millilitres of polyaluminium chloride per 500 millilitres of raw water. The residual fluoride of 2.6 and 1.7 mg/l is within the Tanzanian Temporary value of 8.0 mg/l. Furthermore, these values are within the maximum contaminant levels of fluoride depending upon the annual average daily temperatures. Where for 12^{o}C the fluoride level is 2.4 mg/l and 21.5^{o}C to 26.2^{o}C the fluoride level is 1.6 mg/l (Rubel, 1984). From this point the jar test experiment was repeated with the following volumes of polyaluminium chloride, that is 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 millilitres added to the six beakers arranged under the multiple stirrer. The intermediate volumes were taken for accuracy. Slow stirring was performed in the same way as in the previous experiment. Then the contents were left to settle for half an hour. Settling was very fast in the first four beakers. The content in the beaker was filtered and the filtrate was analysed for fluoride and pH. The results are summarized on Table 21. The water in beaker 6 gave a fluoride value of 2.5 mg/l this being 86.8 % removal and a pH value of 4.5. In spite of the fluoride reduction, the pH value was far too low to make the water acceptable for domestic use. Thus this called for pH adjustment to reach acceptable level.

The results obtained are also represented graphically in Figure 17 and those of pH are in Figure 18.

Table 21. Results of the second jar test experiment using polyaluminium chloride (PAC) dosage decreased accordingly.
Raw water: fluoride concentration 19.0 mg/l
pH value 8.5

Beaker Number	PAC added ml/500 ml	pH value	Fluoride content mg/l		% - age
			Residual	Removed	Removed
1	0.5	7.1	8.8	10.2	53.7
2	1.0	6.7	3.8	15.2	80.0
3	1.5	6.3	2.7	16.3	85.8
4	2.0	5.7	3.8	15.2	80.0
5	2.5	4.8	3.3	15.7	82.6
6	3.0	4.5	2.5	16.5	86.8

The experiment was repeated in the same way as previously done. But this time the optimum dosage noted during the first experiment was taken into consideration. The results obtained are summarized in Table 22.

Table 22. Results of the repeated jar test experiment.
Raw water: fluoride concentration 19.0 mg/l
pH 8.5

Beaker Number	PAC added ml/500 ml	pH value	Fluoride content mg/l		% - age
			Residual	Removed	Removed
1	1.0	6.3	4.8	14.2	74.7
2	2.0	5.3	5.6	13.4	70.5
3	2.5	4.8	2.9	16.1	84.7
4	3.0	4.4	2.1	16.9	88.9
5	3.5	4.4	2.0	17.0	89.5
6	4.0	4.3	1.6	17.4	91.6

When the experiment was repeated flocs in beakers 1 and 2 were formed in a very short time from the moment slow stirring started. As agitation continued the flocs were broken down and became small.

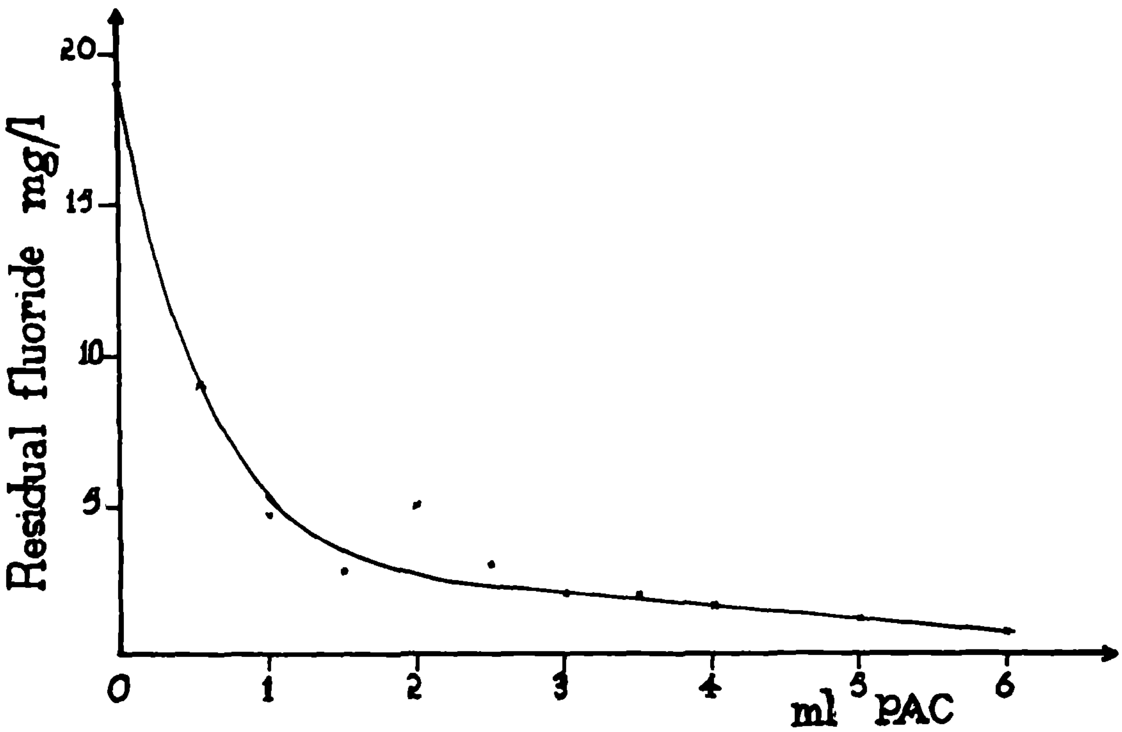


Figure 17. Fluoride removal using polyaluminium chloride.

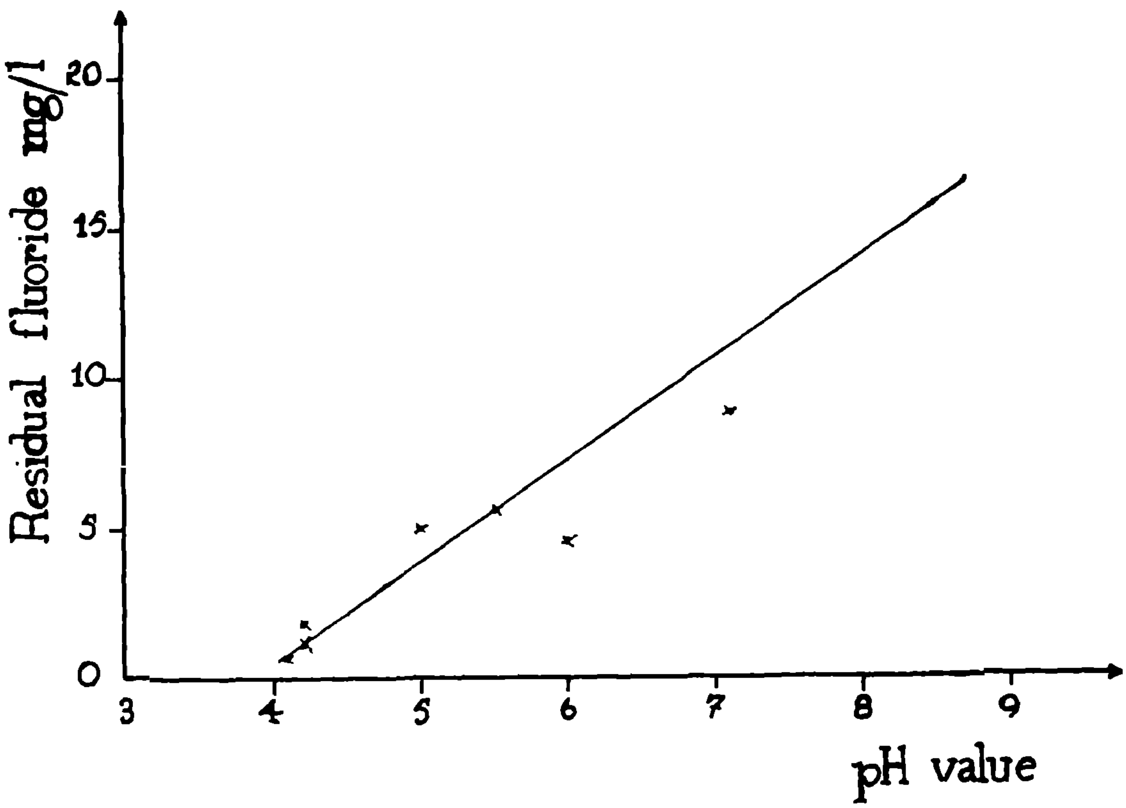


Figure 18. pH values and residual fluoride.

Flocs in beakers 5 and 6 were very small thus difficult to identify them. Generally the content in these beakers looked cloudy. Stirring took 10 minutes at a speed of 30 rounds per minute. After stirring the contents were left to settle for half an hour.

The mixture was then filtered and the filtrate was analysed for fluoride and pH values recorded as seen in Table 22. In spite of the good fluoride removal the pH values were very low thus requiring adjustment to bring them to acceptable levels.

b) Experiment of pH adjustment

For adjusting the pH values, sodium carbonate was used. Furthermore possibilities of using magnesite was also investigated. The same amount of raw water was used in the six beakers. To each of the six beakers the same volumes of polyaluminium chloride were added as before. The volumes were predetermined in the previous experiments. For pH adjustment 0.5 grams of sodium carbonate was added to each of the six beakers. The mixture was put under multiple stirrer and stirred slowly for 10 minutes.

The content was left to settle for half an hour and then filtered through a filter paper. The filtrate was then analysed for fluoride and pH. The results obtained are as indicated in Table 23. From the table it can be noticed that beakers 1, 2, 3, 4 and 5 gave higher fluoride values compared to those without the addition of sodium carbonate. Furthermore beakers 1 and 2 gave higher pH values compared to the rest of the beakers.

Table 23. Results obtained after the addition of sodium carbonate (Na_2Co_3) with the aim of adjusting the pH.
Raw water: fluoride concentration 19.0 mg/l
pH value 8.5

Beaker Number	PAC added ml/500 ml	(Na_2Co_3) added g/500 ml	pH value	Fluoride content mg/l Residual	Removed	% - age Removed
1	0.5	0.5	9.4	10.9	8.1	42.6
2	1.0	0.5	9.1	10.5	8.5	44.7
3	1.5	0.5	8.5	10.0	9.0	47.4
4	2.0	0.5	7.8	5.0	14.0	73.7
5	2.5	0.5	7.1	2.3	16.7	87.9
6	3.0	0.5	6.7	1.5	17.5	92.1

With this experiment the trend in flocs formation was opposite to the first experiments, beaker 6 had heavy good flocs followed by beaker 5, 4, etc. Beaker 1 had the least flocs.

The experiment was repeated, six beakers were prepared in the same way as was already done. To start with 0.5 grams of sodium carbonate were added to each beaker, thus raising the pH. The pH value recorded was 9.9. This was followed by the addition of appropriate amounts of polyaluminium chloride to each of the six beakers, that is 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 millilitres. The beakers were stirred for 10 minutes at slow speed. The content in the beakers was left to settle for half an hour, then filtered. The filtrate was analysed for fluoride and pH. The results obtained are tabulated in Table 24. As can be seen beaker 6 gave a fluoride concentration of 1.5 mg/l and a pH value of 7.2. These values are acceptable for drinking water quality as stipulated by the WHO guidelines.

Table 24. Results obtained when adjusting pH using sodium carbonate before treating with polyaluminium chloride.
Raw water: fluoride concentration 19.0 mg/l
pH value 8.5

Beaker Number	(Na2Co3) added g/500 ml	pH value	PAC added ml/500 ml	pH value	Fluoride content mg/l		% - age Removed
					Residual	Removed	
1	0.5	9.9	0.5	9.5	10.8	8.2	43.2
2	0.5	9.9	1.0	9.0	10.6	8.4	44.2
3	0.5	9.9	1.5	8.4	10.0	9.0	47.4
4	0.5	9.9	2.0	7.5	4.8	14.2	74.7
5	0.5	9.9	2.5	7.2	2.2	16.8	88.4
6	0.5	9.9	3.0	7.1	1.5	17.5	92.1

From the results obtained it was found out that it is appropriate to add sodium carbonate first followed by the addition of the predetermined polyaluminium chloride for good results.

The experiments were repeated taking into consideration the range of the optimum dosage. Results obtained are tabulated in Table 25.

Table 25. Results of the repeated experiments on pH adjustment. The same raw water was used.

Beaker Number	(Na_2Co_3) added g/500 ml	pH value	PAC added ml/500 ml	pH value	Fluoride content mg/l		% - age Removed
					Residual	Removed	
1	0.5	10.0	1.0	9.0	11.0	8.0	42.1
2	0.5	10.0	2.0	7.3	4.6	14.4	75.8
3	0.5	10.0	2.5	7.2	4.1	14.9	78.4
4	0.5	10.0	3.0	7.1	1.9	17.1	90.0
5	0.5	10.0	3.5	6.8	1.0	18.0	94.7
6	0.5	10.0	4.0	6.6	0.9	18.1	95.2

7.3 Filtration and Adsorption Processes

Filtration in water treatment is a process of filtering water in order to remove suspended particles. Adsorption is a process whereby ions are adsorbed on the surface of the material used, and in some cases this is followed by ion exchange process. Under this heading, the following filtering media will be discussed and experimented:

- magnesite
- clay pot chips
- granulated bone and bone charred.

With these materials, besides the ion exchange process, sufficient contact period is also very important. If sufficient time is allowed a reaction takes place thus achieving good fluoride reduction.

7.3.1 Fluoride Removal by Filtration Through Magnesite

Magnesite is found in Chambogo Same and Leborosite Masailand in Tanzania and many other places yet to be identified. The magnesite used in the fluoride reduction experiments was collected from Chambogo Same. Raw magnesite is composed of magnesium carbonate which has a chemical formula of $MgCO_3$.This material was heated at a temperature of 800^o C - 1000^o C. Thus releasing the carbon dioxide and getting the treated magnesite, magnesium oxide. The reaction taking place during the heating process is as indicated in the following equation:

$$MgCO_3 \longrightarrow MgO + \uparrow CO_2 \qquad (4)$$

Based on the information obtained and the discussions held it was found out that in order to get one ton of treated magnesite one needs one ton of firewood. During the experiment the magnesite used was of a diameter of about 3.0 - 6.0 mm. The fluoride concentration of the raw water was 18.0 mg/l and the pH was 8.5. The quantity of water treated was 5 litres. This quantity was put into a 20 litre capacity container fitted with a bib cork, as seen on Figure 19.

About 6.0 kilograms of magnesite was placed into container. Before water to be treated was put into the container, the material was thoroughly washed using tap water. When the washing process was over, 5 litres of raw water was put into the container and left for the reaction to take place. A contact period of half an hour was allowed. Then a sample was collected and analysed for fluoride and pH. The procedure was repeated after an hour has passed.

The experiment was left over night, on the following day 2 litres were collected and analysed for fluoride and pH. The results obtained are summarized in Table 26.

Table 26. Results obtained from filtration - adsorption process with the use of magnesite with a diameter of about 3.0 - 6.0 mm
Raw water: initial fluoride content 18.0 mg/l
pH value 8.5

Contact Time minutes	pH value	Volume collected litres	Fluoride content mg/l Residual	Removed	% - age Removed
30	9.6	0.3	10.0	8.0	44.4
60	9.8	0.3	9.6	8.4	46.7
Over night (about 16 hours)	10.2	2.0	5.4	12.6	70.0

The experiment was repeated with fresh magnesite which was graded to get sizes of about 3.0 mm and below. This time 3.0 kilograms were weighed and placed into the same container. A volume of 8.0 litres fresh raw water was poured into the container, after cleaning the filtering media. A contact period of half an hour was allowed. Then a few millilitres were drawn and analysed for fluoride and pH. After an hour had passed another few millilitres were drawn and analysed for fluoride and pH. Two litres were drawn through the bib cork after 90 minutes had passed, and were also analysed for fluoride and pH.

The whole experiment was left to stay overnight. On the following day two litres were drawn and analysed for fluoride and pH in the same manner. The results obtained are summarized in Table 27.

Table 27. Results of fluoride reduction obtained after filtering the water through magnesite.
Raw water: fluoride concentration 18 mg/l
pH value 8.5
volume 8 litres
Filtration material: magnesite
diameter 2.5 mm
quantity 3 kilograms

Contact Time minutes	pH value	Volume collected litres	Fluoride content mg/l Residual	Removed	% - age Removed
30	9.5	0.3	12.0	6.0	33.3
60	9.6	0.3	10.8	7.2	40.0
90	9.7	2.0	9.5	8.5	47.2
Over night	10.1	2.0	5.6	12.4	68.9

After the second trial, the results were found to be the same despite the fact that the diameter of magnesite was changed. Thus it was decided to repeat the experiment.

On repeating the experiment the original size was used but this time more material was added. It was also made sure that the water to be treated had a really contact with the magnesite with some excess water above magnesite, see Figure 19. After cleaning the material and rinsing, 8 litres were added into the container and 30 minutes contact time was allowed.

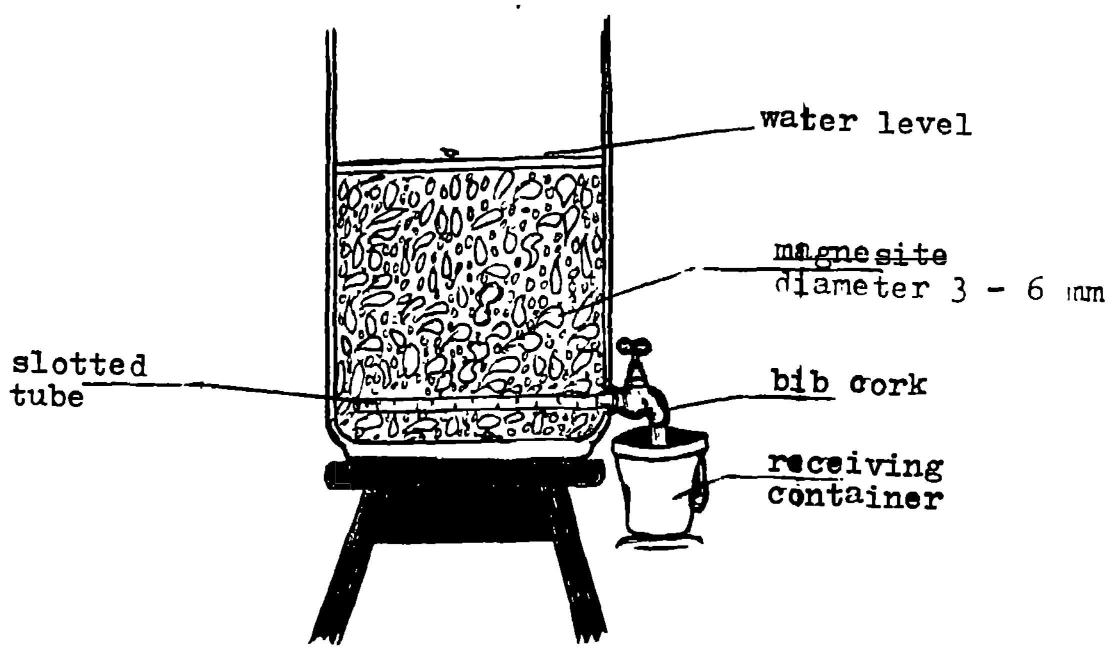


Figure 19. Filtration unit with magnesite as filtering material.

After the contact time had passed a litre was drawn and analysed for fluoride and pH. This was repeated after every 30 minutes and analysis performed in the same way. After 180 minutes the container was completely drained and the water was collected and analysed for fluoride and pH. The results are noted on Table 28.

Table 28. Results obtained after allowing enough contact time and filtering through magnesite.
Raw water: fluoride concentration 19.0 mg/l
pH value 8.5
volume 8 litres
Filtration material: magnesite diameter about 3.0 - 6.0 mm
Quantity: enough to let the 8.0 litres of water be completely in contact with the material.

Contact Time minutes	pH value	Volume collected litres	Fluoride content mg/l		% - age
			Residual	Removed	Removed
30	9.9	1.0	9.6	9.4	49.5
60	10.0	1.0	8.6	10.4	54.7
90	10.0	1.0	8.5	10.5	55.3
120	10.1	1.0	8.6	10.4	54.7
150	10.0	1.0	8.4	10.6	55.9
180	10.1	1.0	8.4	10.6	55.9
Drained	10.1	1.0	7.8	11.2	58.9

A complete draining of the water under experiment was accomplished. This was followed by pouring six litres of fresh raw water into the unit, making sure that all the water was in a complete contact with magnesite, the experiment was left over night. On the following morning all the water was drawn from the unit through a bib cork. Out of it a sample was drawn and analysed for fluoride and pH.

Results obtained showed a residual fluoride concentration of 3.4 mg/l and pH value of 10.3. This means 81.1 % removal efficiency.

7.3.2 Use of Clay Pot Chips in Fluoride Reduction

Clay is commonly used for making pots and other household items. This is achieved by moulding, air drying and followed by heating over fire using firewood.

Clay is found almost everywhere in this planet of ours. The main difference is in the type and quality of the clay in question. For this experiment clay pot chips were used for fluoride removal. These were collected within the town of Arusha from broken pots. These pot chips were further broken manually to a mesh size of about 6.0 mm in diameter.

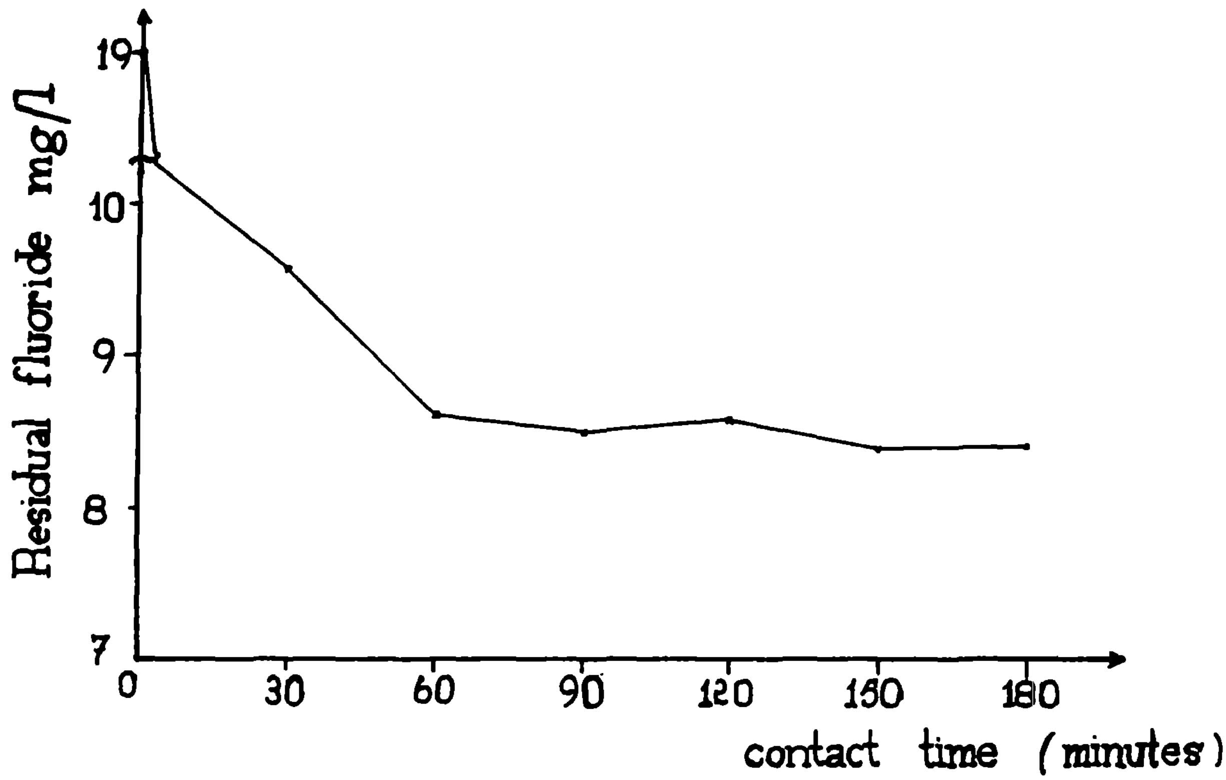


Figure 20. Performance results of fluoride removal by filtration through magnesite.

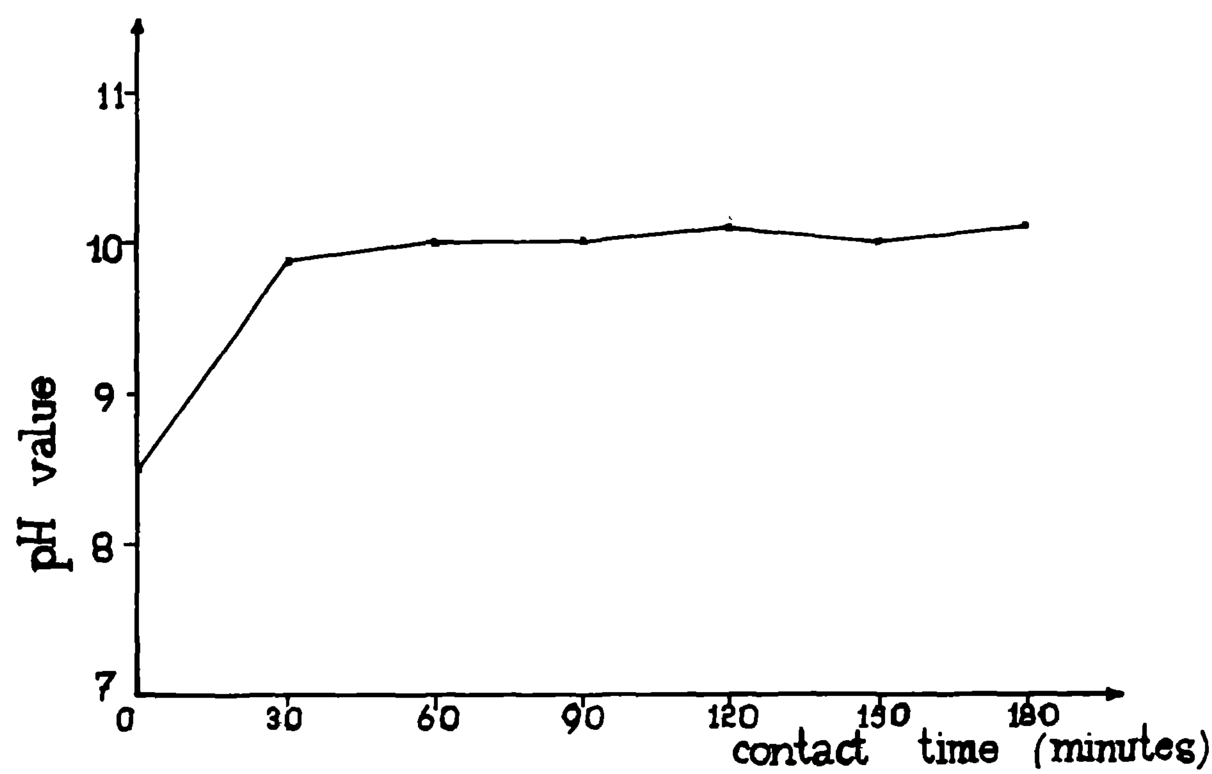


Figure 21. pH values obtained during fluoride removal using magnesite.

A container with a capacity of 20 litres was collected and into it a half an inch bib cork was fixed. The bib cork was fixed in such a way that a volume of about 2 litres was left below which would help in the collection of sludge and any other settleable material.

The container was filled with 4 kilograms of clay pot chips. And after that 12 litres of water which contained fluoride 18 mg/l was added. The pH value of the water was 8.5. But before raw water was put in the container, the chips were thoroughly washed with tap water.

After pouring the raw water into the container, it was left for half an hour so that some reaction could take place between the clay pot chips and the raw water intended for treatment.

A certain amount of water was drawn through the bib cork. Water was then analysed for fluoride and pH value recorded. Results are as seen in Table 29. This procedure was continued in the following morning, that is after 24 hours. In the same way a certain amount of water was drawn through the bib cork and analysed for fluoride and pH.

Table 29. Results of fluoride removed by clay pot chips.
Raw water: initial fluoride concentration 18.0 mg/l
pH value 8.5

Clay pot chips: diameter 6.0 mm

Contact Time minutes	pH value	Fluoride content mg/l		% - age Removed
		Residual	Removed	
30	7.6	6.0	12.0	66.7
1440	6.8	4.5	13.5	75.0
2880	6.9	4.3	13.7	76.1

The filtration process was repeated by draining the container completely first, and washing and cleaning the clay pot chips using tap water. The chips were then put back into the container and rinsed using tap water. After the rinsing process was over, fresh water of about 15 litres from the sources under experiment was put into the container and left for half an hour thus allowing the contact and reaction to take place. After half an hour two litres were drawn from the container and analysis for fluoride and pH performed. This procedure was continued at different time intervals. The results obtained during the experiment are summarized in Table 30.

Table 30. Results obtained by re-using the clay pot chips.

Time intervals minutes	pH value	Water collected litres	Fluoride content mg/l Residual	Removed	% - age Removed
30	8.0	2.0	15.0	3.0	16.7
60	8.0	2.5	15.0	3.0	16.7
90	8.0	1.5	15.0	3.0	16.7
240	7.8	1.0	13.5	4.5	25.0
1440	7.3	1.0	8.8	9.2	51.1
2880	7.2	2.0	9.2	8.8	48.9

The same clay pot chips were re-used in the experiments. But this time they were further broken down. A total of 3.5 kg of the material was filled into the unit and into it 3 litres of raw water with a fluoride concentration of 21.0 mg/l and a pH value of 8.7 was added.

A contact time of 30 minutes was allowed, then a litre was drawn through a bib cork and a litre was passed into the model. The volume drawn was analysed for fluoride and pH. This procedure was repeated at 30 minutes interval. The results obtained are summarized in Table 31 and represented in Figure 22 while Figure 23 shows the pH trend.

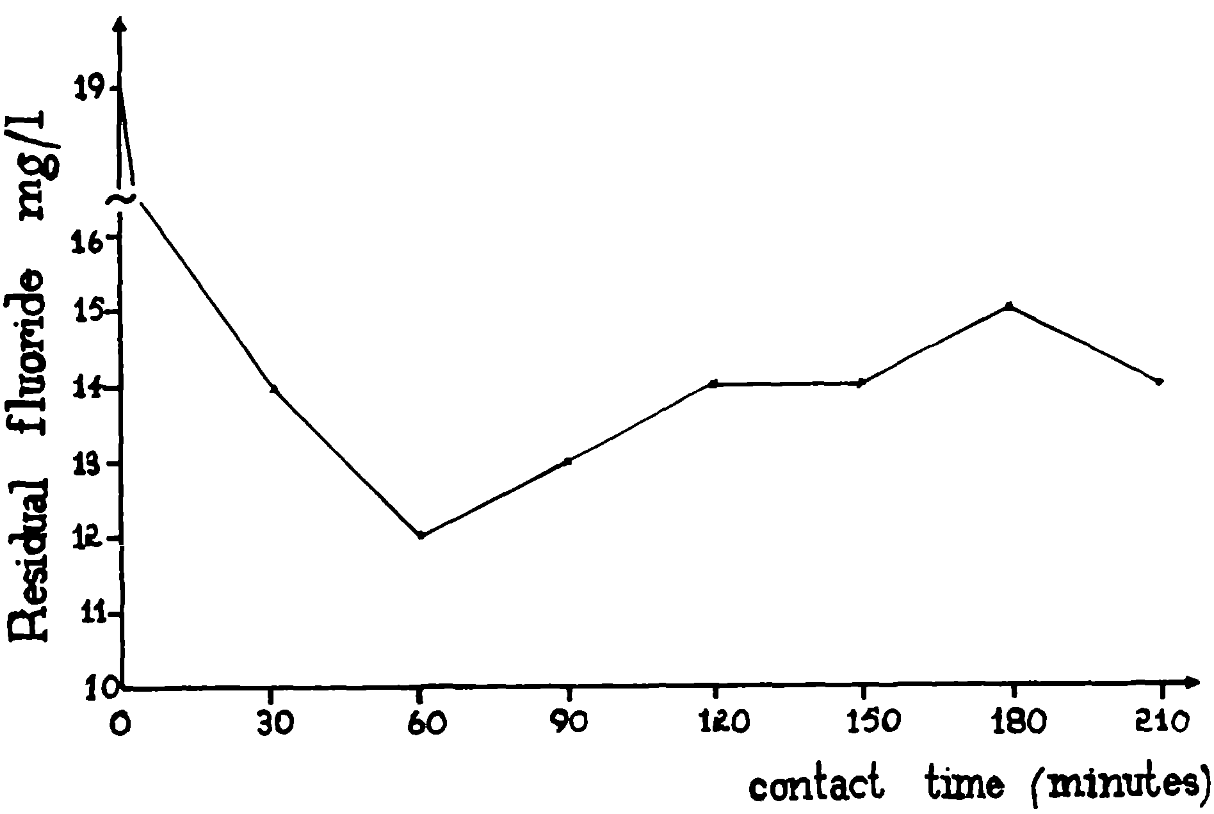


Figure 22. Performance results of fluoride reduction using clay pot chips.

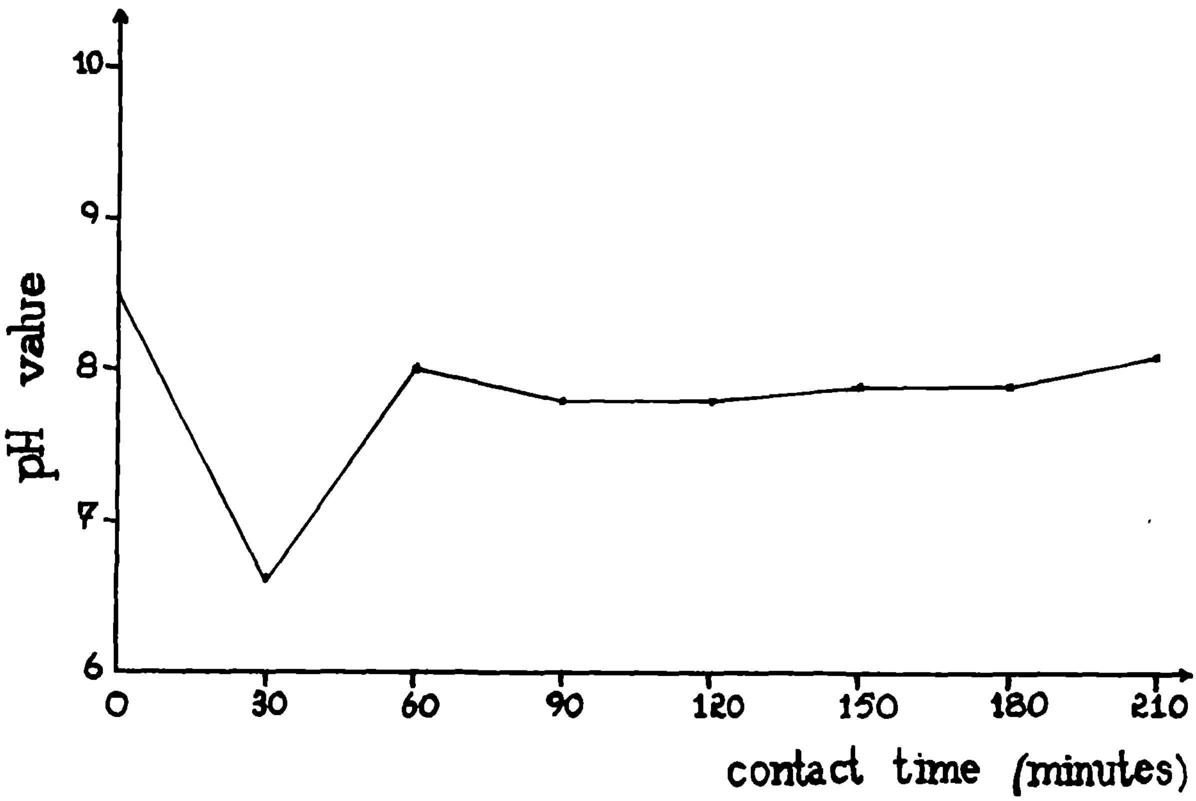


Figure 23. pH values obtained during fluoride reduction using clay pot chips.

Table 31. Results obtained by re-using clay pot chips in fluoride reduction.
Raw water: initial fluoride concentration 21.0 mg/l
pH value 8.7
Clay pot chips: diameter approximately 6.0 mm

Contact Time minutes	pH value	Volume collected litres	Fluoride content mg/l		% - age
			Residual	Removed	Removed
30	6.6	1.0	14.0	7.0	33.3
60	8.0	1.0	12.0	9.0	42.9
90	7.8	1.0	13.0	8.0	38.1
120	7.8	1.0	14.0	7.0	33.3
150	7.9	1.0	14.0	7.0	33.3
180	7.9	1.0	15.0	6.0	28.6
210	8.1	1.0	14.0	7.0	33.3
240	8.0	1.0	15.5	5.5	26.2
270	7.9	1.0	16.0	5.0	23.8

Then the experiment was left over night thus allowing enough contact time between clay pot chips and the water under treatment. On the following day, the treated water was drawn through a bib cork and analysed for fluoride and pH.

The results obtained showed a residual fluoride concentration of 10.0 mg/l and pH value of 7.8. This meant 54.5 % removal efficiency.

7.3.3 Use of Bone Media in Fluoride Reduction

In most countries where high fluoride concentration in water sources is a problem, bones are also available at a very low cost from slaughterhouses. In some countries these can be available free of charge. The bones to be used can be of any type of animal. In the experiments conducted in Arusha bones were collected from Tanganyika Packers Ltd which is a meat processing factory in Dar es Salaam.

Besides the bones collected from Dar es Salaam, bone charred secured by the Central Dental Unit, Ministry of Health was also used in the experiments. In both cases the experiments were performed using the Thailand developed device shown in Figure 24.

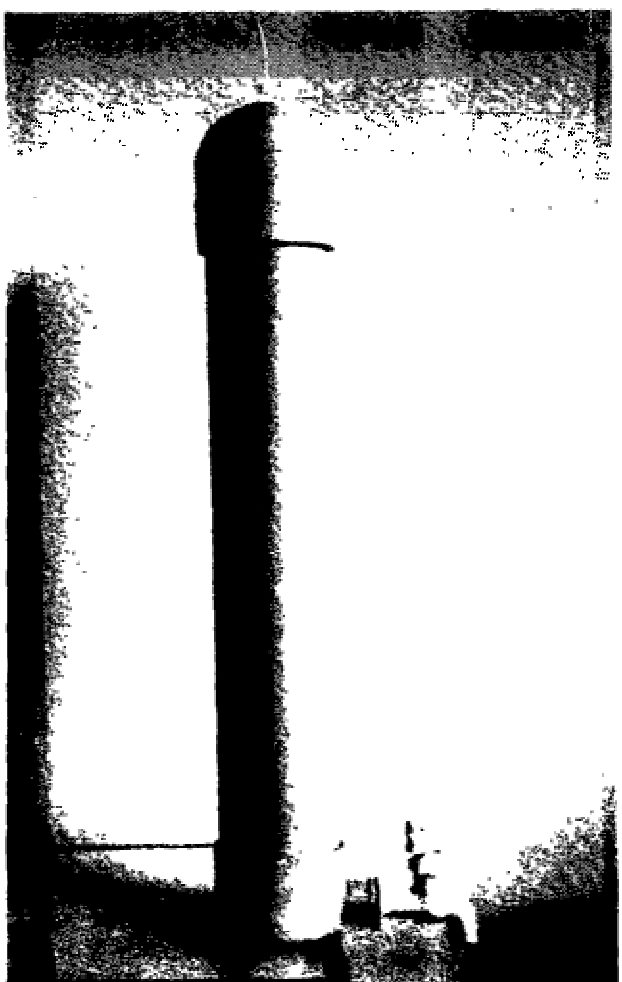


Figure 24. a) A picture of the plastic device from Thailand.

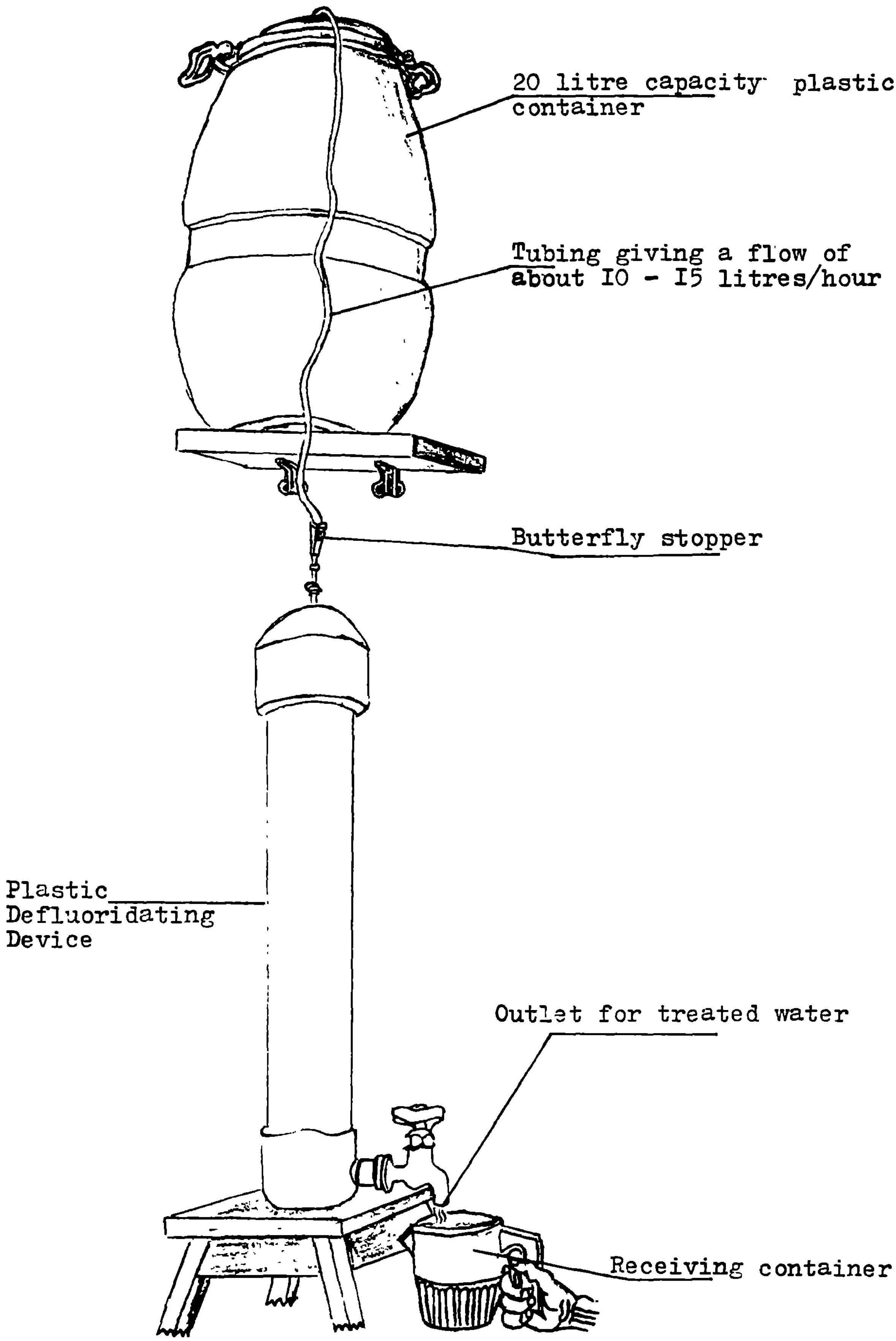


Figure 24. b) Arrangement of a household defluoridating unit.

The experiment procedure was as follows:

1) Granulated Bone Media

The preparation of the bones consisted of cleaning of all flesh and blood, followed by degreasing. This was achieved by soaking the bones in sodium hydroxide solution. When the bones were clean and free from flesh and blood, they were washed and sundried. When dry the bones were crushed and granulated. This was accomplished by a crusher after failing to crush them manually. The job was done so carefully making sure that the material is free of contamination.

The material was sieved, thus getting three types of filtering media of particle size: 1.0 mm, 2.0 mm and 3.0 to 6.0 mm as particle diameter. In the experiments 1.0 mm and 2.0 mm particle sizes were used.

The bone media was filled into the Thailand defluoridation device. To start with about 300 grams of charcoal was placed at the bottom followed by 500 grams 2.0 mm diameter bone media and then 500 grams 1.0 mm diameter bone media. The material was thoroughly washed with tap water. After the washing was over the device was well fixed thus ready for the experiment.

A bucket containing 10 litres of raw water with a fluoride concentration of 19 mg/l and a pH of 8.5 was placed at the top. Using a small tube the water was allowed to flow into the defluoridator. When the defluoridator was full, 15 minutes of contact time was allowed. After this period the water was collected and analysed for fluoride and pH.

Another quantity of water from the bucket was allowed into the defluoridator which was left for 30 minutes before it was collected and analysed for fluoride and pH. This was followed by other collections at different periods which were also analysed for the same parameters. The results are summarized on Table 32.

Furthermore, 4 litres were filtered through the device without allowing any contact period to elapse. Out of this a sample was collected and analysed. The water gave a fluoride concentration of 0.22 mg/l and a pH value of 9.6. This means 98,8 % removal efficiency. In spite the good results obtained, the pH value was slightly not within the acceptable limits. As the media was used further the pH showed a trend of being lower as indicated on Table 32, thus being within the acceptable range. The flow rate through the device ranged between 10 - 15 litres per hour. This depended on the arrangement of the device.

Table 32. Performance of granulated bones in fluoride reduction.
Raw water: fluoride concentration 19.0 mg/l
pH 8.5
Filter media: 500 grams diameter 1.0 mm, on the surface
500 grams diameter 2.0 mm, in the middle
300 grams charcoal, at the bottom

Contact time minutes	pH value	Volume collected ml	Fluoride content mg/l Residual	Removed	% - age Removed
15	9.7	750	0.5	18.5	97.4
30	9.8	750	0.3	18.7	98.4
60	9.4	1100	0.2	18.8	98.9
90	9.2	1100	0.1	18.9	99.5
120	8.3	1100	< 0.1	18.9	99.5
150	8.0	1145	<< 0.1	18.9	99.5

2) Bone Char Media

The device was ready packed in Thailand but had to be repacked in order to have the ingredients properly placed. The order was charcoal first, followed by bone char and then pebbles at the top. The arrangement is as seen on Figure 14 on page 36.

The material in the unit was completely washed with tap water. After washing, the device was fixed ready for the experiment to start, see arrangement of the device on Figure 24.

The experiment was performed in the same manner as in the case of granulated bones. The results obtained are as illustrated on Table 33. Then 5 litres were filtered through the device without allowing any contact period to pass. A sample was collected from the amount treated and analysed for fluoride and pH. The water gave a fluoride content of 0.96 mg/l and a pH value of 8.6.

The flow rate through the media ranged between 10 to 11 litres per hour. But the observation made was that the flow rate depended on the arrangement of the device and the volume of water to be treated.

Table 33. Performance results of bone charred in fluoride reduction.
Raw water: fluoride concentration 19.0 mg/l
pH value 8.5
Filter media: 200 grams pebbles, on the surface
1000 grams bone charred diameter 3.0 mm, in the middle
300 grams charcoal, at the bottom

Contact time minutes	pH value	Volume collected ml	Fluoride content mg/l Residual	Removed	% - age Removed
15	8.6	1260	1.0	18.0	94.7
30	8.8	1260	0.8	18.2	95.8
60	8.8	1260	0.5	18.5	97.4
90	8.7	1260	0.3	18.7	98.4

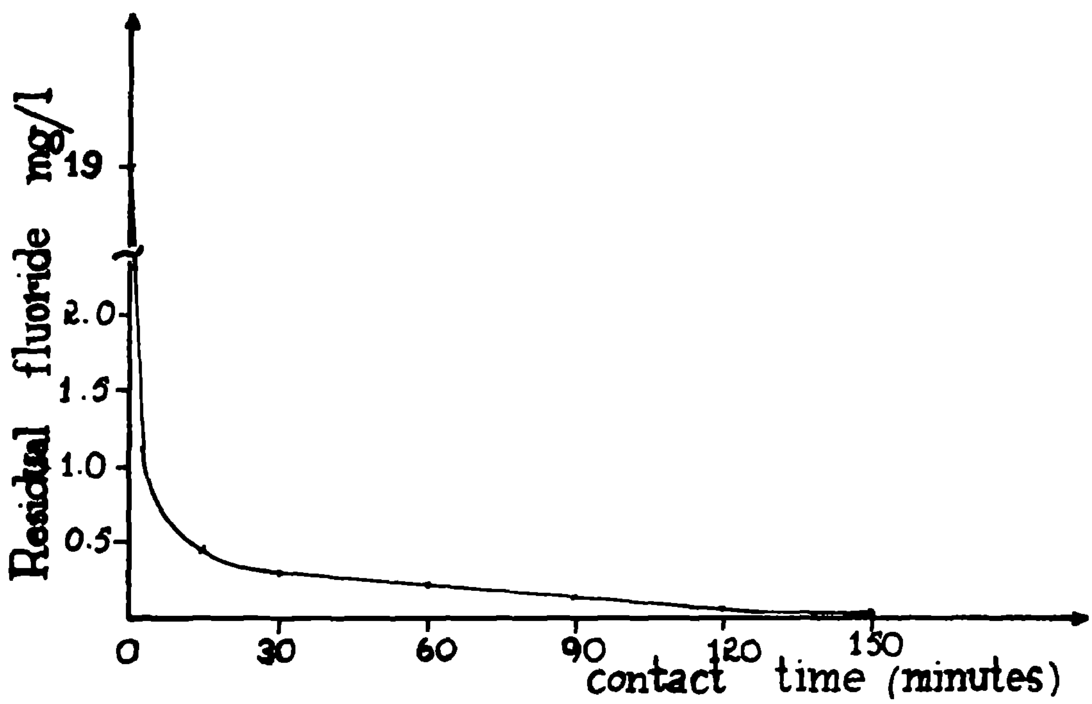


Figure 25. Performance results of fluoride reduction using granulated bone media.

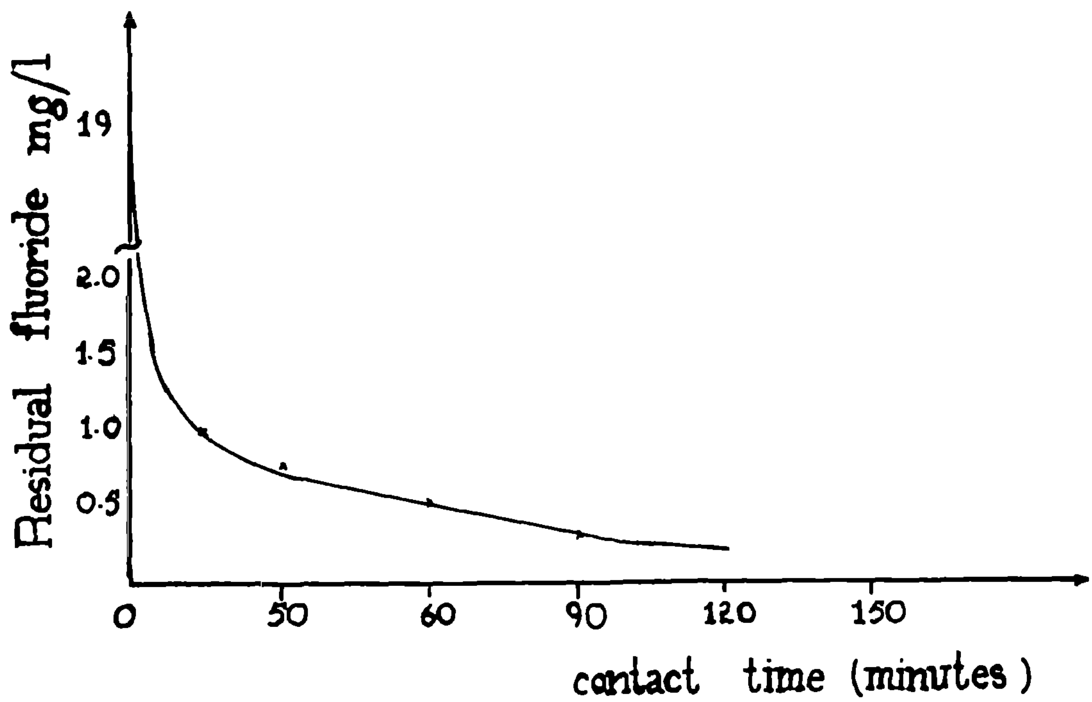


Figure 26. Performance results of fluoride reduction using bone charred media.

After the experiments, testing of the material with different waters followed. Raw water was collected from 3 water sources whose fluoride concentration was well above the WHO guideline. The waters from the 3 sources were treated using granulated bone and bone charred one at a time. The treatment consisted of filtering water through the media that was packed into the device from Thailand. Minimum contact time was allowed, that is the time water reached the outlet.

The treated water was collected into a container and later on a sample was collected and analysed for fluoride and pH. The results obtained are summarized in Table 34.

Table 34. Results when treating water from the 3 water sources using granulated bone and bone charred.

a) Granulated bone: filtration rate through the media was at an average of 10.0 litres/hour.

Name of water source	pH	Fluoride before treatment mg/l	Volume treated litres	pH	Fluoride mg/l Residual	Fluoride mg/l Removed	%
Maji Yard B/H 246/78	7.7	4.0	10.0	7.9	< 0.1	3.9	97.5
Sakina B/H 92/78	8.1	6.2	8.3	7.3	< 0.1	6.1	98.4
Maji ya Chai (Inatake)	8.5	19.0	12.6	8.3	< 0.1	18.9	99.5

b) Bone charred: filtration rate through the media was at an average of 10.5 litres /hour.

Name of water source	pH	Fluoride before treatment mg/l	Volume treated litres	pH	Fluoride mg/l Residual	Fluoride mg/l Removed	%
Maji Yard B/H 246/75	7.7	4.0	8.2	8.4	0.4	3.6	90.0
Sakina B/H 92/78	8.1	6.2	9.4	8.7	0.5	5.7	91.9
Maji ya Chai (Inatake)	8.5	19.0	8.5	8.8	0.3	18.7	98.4

7.4 Use of Polyaluminium Chloride and Magnesite in Fluoride Removal

The experiments were conducted based on the result obtained on the previous experiments on polyaluminium chloride and magnesite on fluoride reduction. An attempt has been made to reduce fluoride by combining the use of the two materials.

The predetermined dosage of polyaluminium chloride (PAC) used in the treatment was 3.0 millilitres per 500 millilitres of raw water, which is 6.0 millilitres per litre of raw water.

The ability of magnesite to remove fluoride was noted by using bigger particle sizes of more than 3.0 mm diameter. Efforts were made to use smaller particle size in experiment. Five kilograms of magnesite was further crushed and sieved. Four types of material were obtained based on the diameter, these were powder form, 0.5 mm, 1.0 mm and 2.0 mm. Out of these 0.5 mm particle size was tried in the experiment. The rest will be tried during the Ministry's research programme on fluoride currently in progress.

The filtering device was filled with 1.5 kilograms of 0.5 mm particle size magnesite. Raw water with an initial fluoride concentration of 19.0 mg/l was filtered through after cleaning the filtering media. Several contact periods were allowed and the water was collected. The filtrate was analysed for fluoride and pH. The results obtained are summarized on Table 35.

The device being discussed here is a plastic pipe with a diameter of about 9 cm and a height of 75 cm. It was fitted with an outlet from which the treated water could easily be collected.

Table 35. Results obtained for testing the efficiency of smaller particle size of magnesite in fluoride removal.
Raw water quality: fluoride content 19.0 mg/l
pH value 8.6
Filtering media: diameter 0.5 mm
quantity 1.5 kg

Contact time minutes	pH value	Volume treated (ml)	Fluoride concentration mg/l		% Removed
			Residual	Removed	
15	10.2	1300	6.7	12.3	64.7
30	10.2	1443	4.9	14.1	74.2
60	10.3	1397	5.1	13.9	73.2
90	10.4	1427	7.4	11.6	61.1
120	10.2	1445	8.4	10.6	55.8

From these results it can be seen that smaller particle sizes have greater removal efficiency. Even the contact time allowed is reasonable compared to that of bigger particles. Despite the fluoride reduction, there is an increase of pH which was raised from 8.6 to 10.4 as clearly illustrated in Figure 28.

The fluoride results are also presented graphically in Figure 27. From the graph it can be observed that the maximum removal is achieved after 30 to 60 minutes.

Inorder to combine the application of the two processes in fluoride reduction, 10 litres of raw water was collected and into it 60 millilitres of polyaluminium chloride was added. The mixture was manually and slowly stirred for 15 minutes. The content was left to settle for half an hour before being filtered through the filtering column containing magnesite of 0.5 mm diameter particle size. A sample was collected before and after filtration and analysed for fluoride content and pH. The results obtained are illustrated on Table 36.

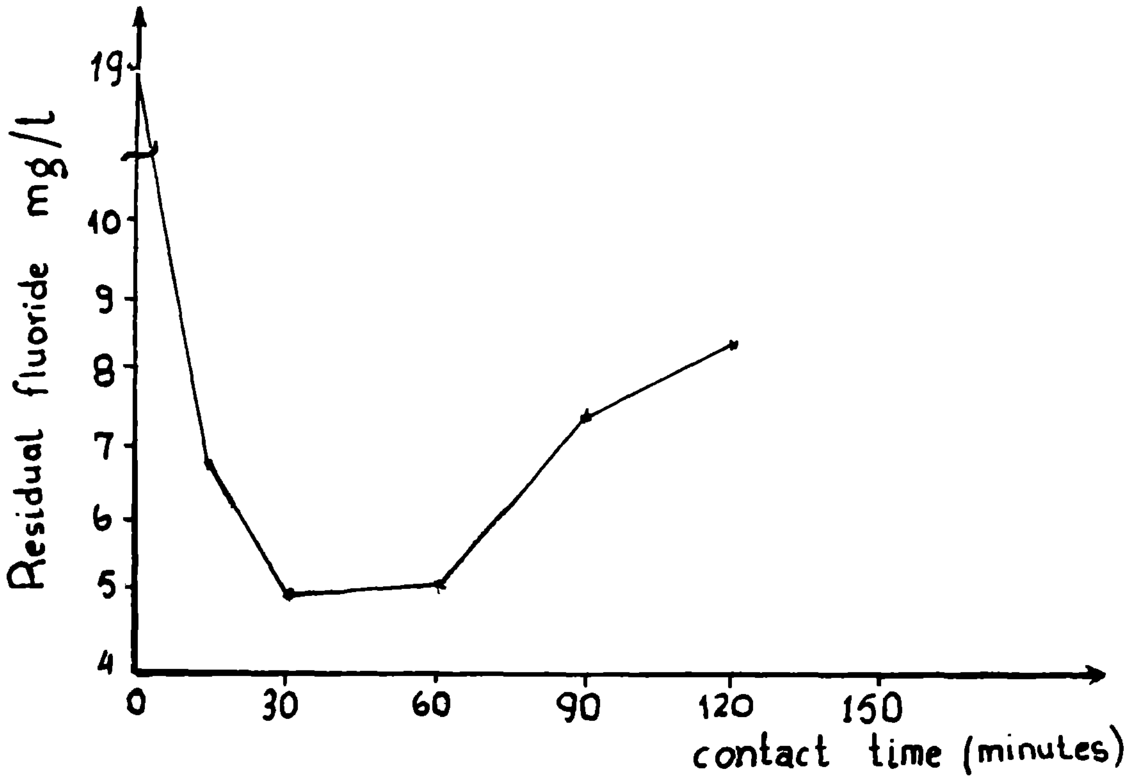


Figure 27. Fluoride reduction using smaller particle sizes of magnesite.

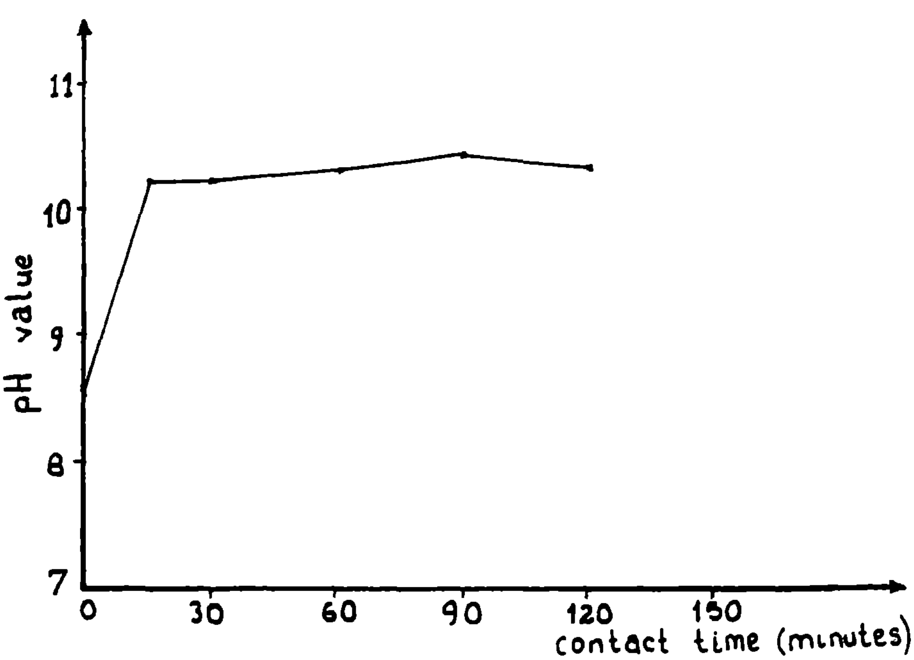


Figure 28. pH values obtained when using smaller particle sizes of magnesite.

Table 36. Results of fluoride removal using PAC and magnesite.

Type of water collected	pH	Fluoride content mg/l		%
		Residual	Removed	Removed
Raw water	8.6	19.0	-	-
Before filtration	4.4	2.2	16.8	88.4
After filtration	9.9	1.8	17.2	90.1

From the results obtained it has been noted that despite the good fluoride reduction, there was a raise in the pH value.

The experiment was repeated by reversing the trend in the application of the two materials. The raw water was first filtered through magnesite in the filtering device without allowing the contact period to pass. The time which was considered here, is the time the water takes to reach the outlet. Total of 4.5 litres were filtered through the media and collected into a container. Out of it a sample was collected and analysed for fluoride and pH. The filtered water gave a fluoride content of 6.4 mg/l and a pH value of 10.0. Into the filtrate 24 millilitres of PAC was added and slowly stirred and left to settle. After settling a sample was collected from the clear water and analysed for fluoride and pH. The treated water gave 0.5 mg/l fluoride and a pH of 5.9. Despite the good results of fluoride reduction, the pH is too low to make the water acceptable for domestic use.

In noting these results, the experiment was repeated in the same way as previously done. More than 4 litres of raw water was filtered through the same device and collected into a container. Out of it a sample was later on collected and analysed for fluoride and pH. The sample gave 8.1 mg/l fluoride and a pH of 9.9.

From the filtrate 4 litres were collected and into it 16 millilitres of PAC was added. The same treatment process was applied to the mixture as in the last experiments.

The analysis of the treated water gave 0.4 mg/l fluoride and a pH of 7.2.

The filtration rate through the device was about 10 litres per hour.

A summary of the results obtained is well illustrated in Table 37.

Table 37. Results of fluoride reduction using magnesite and PAC.

Type of water collected	pH	Fluoride content mg/l Residual	Fluoride content mg/l Removed	% Removed
Raw water	8.6	19.0	-	-
After filtration	10.0	6.4	12.6	66.3
Filtrate plus 24 ml PAC	5.9	0.5	18.5	97.4
After filtration	9.9	8.1	10.9	57.4
Filtrate plus 16 ml PAC	7.2	0.4	18.6	97.9

From the experiment and the results obtained, it is economical to filter the water through magnesite first followed by the application of polyaluminium chloride.

Advantages obtained include the reduction in the volume of polyaluminium chloride required in fluoride removal. pH adjustment can be accomplished by proper application of the two material.

From the previous experiments the dosage was determined to be about 6 - 7 ml of PAC per 1 litre of raw water. The use of magnesite has brought this figure to less than 4 millilitres of PAC per litre of raw water.

Based on the results obtained the following fluoride reduction process is proposed. This can be achieved by pretreatment using smaller particle sizes of magnesite (diameter 0.5 mm - 1.0 mm) followed by the addition of PAC. The PAC added would reduce the remaining fluoride and at the same time adjust the pH to acceptable levels. The process is clearly indicated in Figure 29.

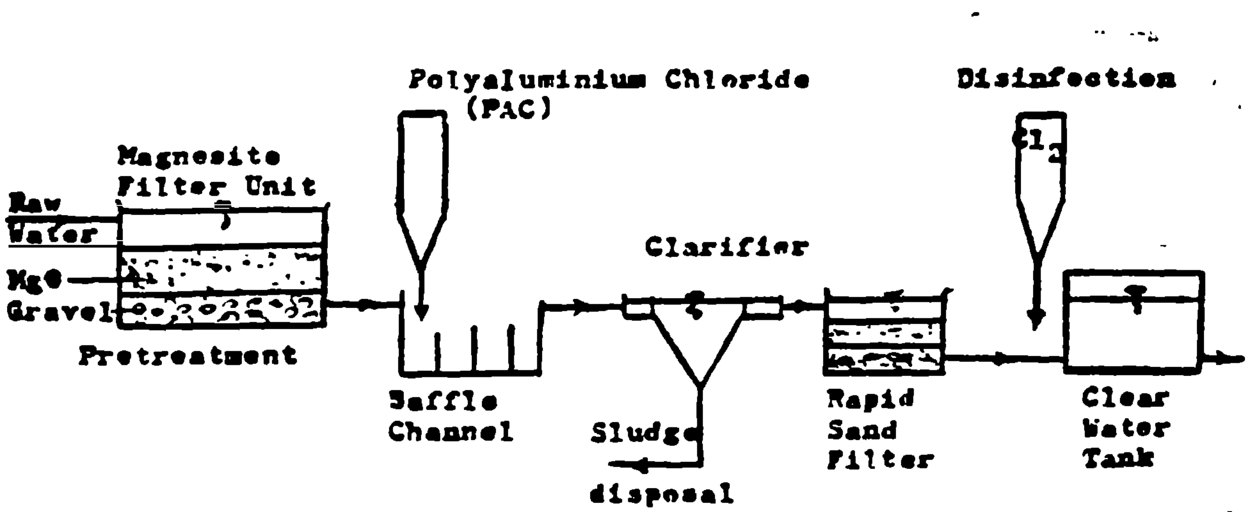


Figure 29. Technological flow diagram for fluoride reduction.

8 DISCUSSION OF FINDINGS

This chapter discusses the results obtained on each of the techniques experimented. Apart from highlighting the main features of the chemicals and the different contact beds used, cost estimates for each method are given in general terms only. The prices are based on March, 1988 figures.

8.1 Evaluation of Findings

8.1.1 Coagulation and Flocculation

a) Lime and Alum

From the jar test experiments performed using lime and alum, it was found out that removal efficiency of 77 % was achieved. The quantity of alum was found to be 104 mg/l. This quantity was within the limits of alum needed for a normal treatment plant. The amount added was able to remove 14.0 mg/l of fluoride ion. Besides alum, lime was added. The quantity added was higher than the one used by the Indian researchers. When doing the jar test experiments on lime and alum efforts were made to work with slightly high pH values in order to prevent the aluminium ion in treated water. According to the experiments it is very difficult to achieve high fluoride removal by using lime and alum.

Alum has to be imported from abroad while lime is locally available. Besides the cost of importation, there is also transportation cost from the harbour to the site in question.

Advantages: it is little bit easy to handle and furthermore it is a common chemical used in water treatment.

Disadvantages: it cannot be used in household units because the chemical needs trained staff to handle it. When used at large treatment plants, then personnel has to be trained to take care of the operation and maintenance. The removal efficiency is not very effective. To attain good removal efficiency large quantities of alum have to be used.

The cost of alum is about 25 000 TAS per ton CIF Dar es Salaam if bought from Finland. The Maji Central Stores sells alum at 50 TAS per kilogram. Taking this price into consideration and the 74 % removal efficiency it costs about 0.04 TCents to remove 1 mg fluoride 1 mg alum costs 5 x 10^{-3} Tcents, 104 mg alum removes 14.0 mg fluoride (see Table 18) and it costs 0.52 Tcents, thus 1 mg fluoride can be removed with 0.04 Tcents . This does not include the price of lime and other components.

b) Polyaluminium Chloride (PAC)

This chemical is a new product to be used in water treatment plants. According to the experiments carried out, the chemical is able to remove fluoride to the lowest possible levels. The problem noted during the experiments was the low pH value which makes the water unfit for domestic use. This made pH adjustment a must.

The pH adjustment was accomplished using sodium carbonate which is commonly used in water treatment plants.

The cost of PAC is about 71 000 TAS per ton CIF Dar es Salaam. The chemical is expensive, but with proper use running costs could be cut down. When PAC alone is used in fluoride reduction process, it costs 3.3 Tcents to remove 1 mg fluoride, other components exclusive 8 ml PAC removes 17.4 mg fluoride (see Table 22), and 8 ml PAC costs 56.8 Tcents, thus 1 mg fluoride can be removed with 3.3 Tcents .

The main advantage of this chemical is its high fluoride removal capacity. PAC is in a liquid form thus difficult to transport, but easy to dose. It is acidic, hence it needs to be handled with care. Being a new chemical the people who are to handle it need to be oriented on the use of the commodity. Polyaluminium chloride could be used in large scale water treatment plants.

8.1.2 Filtration and Adsorption Processes

a) Magnesite

The material is capable to reduce fluoride down to 3.4 mg/l from 19.0 mg/l if left over night using particle sizes, 3 - 6 mm diameter. This means 81 % removal efficiency. Smaller sizes, 0.5 mm diameter gave 74 % removal efficiency after 30 minutes of contact period. From the experiments it was observed that the most important factor with magnesite in fluoride reduction is the contact time allowed for fluoride to react with magnesium hydroxide. During this period two processes take place, these being adsorption and ion exchange as illustrated by the following formula:

$$MgO + H_2O = Mg(OH)_2 \qquad (5)$$

$$Mg(OH)_2 + 2F^- = MgF_2 + 2OH^- \qquad (6)$$

Adsorption produces fluoro magnesite complexes ($Mg(OH_2F)$).

From the equations it can be seen that there is a formation of hydroxide which explains the raise in pH during the treatment process. In spite of achieving some fluoride reduction there is an increase in pH of the treated water thus making it unfit for domestic use.

Magnesite is locally available which means there is an indirect foreign exchange component. The treatment process of the material was achieved by heating using firewood. To get one ton of treated magnesite one needs a ton of firewood. The cost of treated magnesite is 10 000 TAS per ton.

b) Clay Pot Chips

Clay pot chips are able to reduce fluoride with about 75 % removal efficiency. This is achieved after 24 hours contact time. Half an hour contact time gave a fluoride reduction of 66 %. Another feature noted during the experiments was that of the water became a little bit turbid and acquired the smell of the chips used. These features have not been reported by any of the researchers who have used clay pot chips in fluoride removal.

When the chips were closely investigated it was observed that some of them were not properly burned or treated.

Not much has been reported in the literature on the use of clay pot chips in fluoride reduction. Thus it is difficult to make any comparison with previous work.

On preparing clay pot chips, firewood would be required to burn or treat the pots before chips can be made out of them. A pot in Arusha costs about 150 TAS. This figure is not enough to give a hint on cost involved in preparing the chips required in defluoridation, at least the cost of firewood and labour should be taken into account.

Advantages of clay pot chips are: they are easily and locally available, and they are easy to handle and use in household defluoridation devices.

c) Use of Bone Media

1) Granulated Bone Media

According to the experiments performed granulated bones have removal capability of up to 99 % by using smaller particle sizes 1 and 2 mm. This efficiency has not been reported in any of the literature the author came across. A kilogram was used in the experiments. Unfortunately the material was not used up to the period when it showed loss of fluoride reduction. Thus it was difficult to calculate the amount of water a kilogram is able to treat.

Reaction taking place
Granulated bones react with fluoride as bones and teeth of the human body. The removal of fluoride is achieved by ion exchange process. This reaction is presented by the following equation:

$$Ca_5(PO_4)_3OH + F^- + H_2O = Ca_5(PO_4)_3F + OH^- + H_2O \qquad (7)$$

From the experiments it was observed that proper bone selection has to be made. The bones have to be chalky white, should exclude joints and any other parts that are porous in nature.

Advantages of granulated bone media are: The material has a very high fluoride removal capacity. It is possible to use the material in a household defluoridation device, because there is no need of training the user when handling the material. The material is locally and easily available and in some cases free of charge.

Generally speaking it is cheaper to use granulated bone than charred bone.

2) Bone Charred Media

The material is able to remove fluoride to the lowest possible level. Its removal efficiency goes up to 97 %.

The problem associated with bone charred preparation is the strong disagreeable smell which is caused by burning the bones. The bone preparation needs special skill, an oven and a good site thus not causing inconvenience to the nearby dwellers.

The two types of media used were able to produce good quality water.

The device in which the two media were tried was cheap in capital investment and simple in design.

8.1.3 Combination of Polyaluminium Chloride and Magnesite

The experiments conducted on the two materials on fluoride reduction led to the use of the combined form of polyaluminium chloride and magnesite. The reason behind this application was the low pH value caused by polyaluminium chloride which need to be adjusted.

From the experiments carried out, it was found out that is is better and economical to filter the water to be treated through magnesite of smaller particle size (0.5 mm) followed by the dosing of polyaluminium chloride. This application reduced the volume of PAC required from 6 - 7 millilitres to less than 4 millilitres per litre of raw water.

The use of magnesite has solved the problem of pH adjustment. Its application is very simple and it is easy to handle compared to other pH adjusting materials.

The efficiency of magnesite in fluoride reduction is high when using smaller particle sizes. With minimum contact period the material is capable to remove about 66 % of fluoride. This means fluoride was reduced from 19.0 mg/l to 6.4 mg/l. Hence when applying the method this has to be taken into consideration.

The problem associated with this technology is the rate of flocs formed. The flocs seem to be light which makes complete settling difficult.

From the preliminary investigations the method seems to be cost effective because only polyaluminium chloride will have to be imported while magnesite is locally available. The cost of removing 1 mg fluoride using polyaluminium chloride only was found to be 3.3 Tcents other components exclusive. When combining the use of magnesite and polyaluminium chloride the cost was found to be 1.65 Tcents. Thus the combination has cut down the volume of polyaluminium chloride required per 1 litre of raw water by 50 %. The actual figure was found to be 4 ml PAC/1 litre of raw water.

The combination has cut down the volume of polyaluminium chloride required per 1 litre of raw water by almost 50 %.

When applying magnesite, then smaller particle sizes are to be used. The cost involved in preparing the material will have to include the crushing of the magnesite into smaller particle sizes.

8.2 Choice of Technology

In areas with high fluoride, the water authority is faced with a situation whereby the possible water source earmarked for community water supply has fluoride concentration well above the acceptable limits. In such a case several options will have to be lookéd into, amongst them there is also defluoridation. In case the defluoridation becomes the only alternative, then a proper choice on technique should be considered. Based on the experiments conducted on the use of magnesite, granulated bone, bone charred and clay pot chips, they should be considered first for the development of a household unit. The materials in question are locally and easily available in the country. Treatment at the source could be considered later depending on the need.

8.2.1 Treatment at Water Source

No concrete guidelines have been put forward on the design criteria of a treatment plant for fluoride reduction using polyaluminium chloride. The experiments conducted dealt mainly on the initial dosage of polyaluminium chloride required in removing fluoride. Predetermined also during the experiments was the dosage of sodium carbonate required for pH adjustment.

The amounts of polyaluminium chloride and sodium carbonate determined during the experiments are subjected to change by taking into account the prevailing conditions and the quality of the raw water and the initial fluoride concentration. The adjustment of the amount of chemicals to be used could be obtained by carrying out jar test experiment.

Magnesite can be used in pH adjustment, but this needs further studies before guidelines could be given on its use as pH adjusting material.

8.2.2 Treatment Using Household Units

Possibilities of using media like magnesite, granulated bone, bone charred and clay pot chips under a household unit have been explored. The device used in the experiments conducted in Arusha has been developed in such a way that its operation is simple and within the capability of any family. The family concerned needs only to add water to be treated in the container and leave for some time before water can be drawn for domestic use. In case of bone media minimum contact time can be allowed, though some researchers suggest half an hour.

The time for media change was not determined during the experiments. Some researchers have confirmed 1 to 3 months as being the period required for replacing the media if 20 litres per day are treated. It is the author's feeling that the media could be used even for more than 3 months. This feeling is based on the results obtained where a residual fluoride of less than 0.1 mg/l was noted, from the initial concentration of 19.0 mg/l. But generally speaking the period between media changes will vary inversely proportional to the concentration of the fluoride to be reduced.

9 CONCLUSIONS AND RECOMMENDATIONS

a) Conclusions

Excess fluoride concentration is a problem in ground and surface water sources in Tanzania. The occurrence of contaminant levels of fluoride are widespread in Arusha, Kilimanjaro, Singida, Shinyanga, Mara and Mwanza Regions. In addition to these areas, other small areas with high fluoride concentration are also found in several other parts of the country.

Health problems associated with prolonged high fluoride ingestion have been noted in some parts of Arusha Region and other parts which are severely hit by high fluoride concentration in their water sources. These health problems are in the form of dental, skeletal and crippling fluorosis.

Use of water for domestic purposes with excess fluoride concentration can cause adverse health effects. An obvious and economical solution to the problem of high fluoride concentration in a water source meant for domestic use is to replace it with another source having optimum levels of fluoride content, thus every attempt and effort should be made to locate such a source. If this proves unsuccessful, then a programme to reduce fluoride from the community water supplies should be initiated in order to prevent dental, and even skeletal or crippling fluorosis.

Defluoridation of water can be done in two ways:
- treatment of the water at the source
- use of household devices for fluoride reduction.

With regards to treatment of water at the source, polyaluminium chloride has proved to be very successful in fluoride reduction. Preliminary results have shown that the chemical has a very high ability of removing fluoride to the lowest possible level. Granulated bone and bone charred have shown very good fluoride removal capacity followed by magnesite and clay pot chips. These materials could be used in household devices meant for fluoride reduction. The materials considered as suitable defluoridation media are locally available in the country. Furthermore their use in treating water at the source seem to be feasible, especially this is true with magnesite because it is found in the country in large quantities. The technology of combining magnesite and polyaluminium chloride for large scale water treatment could be considered.

b) Recommendations

Based on the findings from the research project the following recommendations are made:

1. A lot of work has already been done on the fluoride problem in Tanzania. Thus efforts should be made to compile the information available on the fluoride situation in the country, in order to have a well

documented report. This would help in the evaluation of the work so far done, evaluating the magnitude of the problem and in implementing some of the resolutions passed in 1982 and 1987 during the National Fluoride Workshops.

2. Preliminary findings have shown positive results on fluoride reduction by using polyaluminium chloride. Hence more research should be done on the use of this chemical and the cost effectiveness of the method in order to come up with proper guidelines on the design of such a treatment plant including ways of operation and maintenance. Emphasis should be put on the use of Magnesite - PAC process.

3. Magnesite, clay pot chips and bones have given very encouraging results in fluoride removal. More research could be done on the use of these materials in household devices meant for defluoridating water for family use for cooking and drinking only. Their use could also be considered on treating water at the source or point of use.

Aspects to be investigated when doing the research are:

Magnesite:
- the quantity of magnesite needed
- the percentage of magnesium oxide used in the experiments
- temperature of calcination
- particle size
- contact time
- when does it get exhausted thus needing replacement or regeneration
- checking the behaviour of the pH.

Clay pot chips:
- type and quality of clay used in making the pots including the chemical composition
- temperature at which the pots are heated
- particle size of the chips
- contact time
- when does it get exhausted thus needing replacement or regeneration
- possible modes of regeneration

Granulated bone and charred bone:
- mode of preparing the bones
- more studies on the behaviour of the material in fluoride removal
- period of replacement
- checking the bacteriological quality.

In all the three cases possibilities should be explored on the use of the materials at large scale.

Generally it is recommended to continue the research on defluoridation technology based on the findings obtained so far in order to avoid duplication work.

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was 18.0 mg/l and the pH was 8.5. The quantity of water treated was 5 litres. This quantity was put into a 20 litre capacity container fitted with a bib cork, as seen on Figure 19.