ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

DETERMINATION OF THE EXTENT TO WHICH THE BUCKET FLOURIDE FILTERS SUPPLIED BY THE CATHOLIC DIOCESE OF NAKURU ARE ABLE TO REMOVE EXCESSIVE FLOURIDE FROM DRINKING WATER IN NAKURU TOWN, KENYA

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Manuscript Info

Manuscript History:

Received: 10 November 2013
Final Accepted: 28 November 2013
Published Online: December 2013

Key words:
Determination, Extent, Method, Defluoridation Influences, Use, Defluoridated Water, Residents, Nakuru Town, Kenya.

Abstract

The purpose of the study was to assess the contribution of the CDN water quality program in providing safe fluoride free drinking water to the residents of Nakuru municipality. Based on the study, this paper examines the extent to which the method of defluoridation used by the CDN is able to reduce the levels of fluoride in drinking water to an acceptable level. The research was conducted in Nakuru Town. In order to evaluate the effectiveness of the defluoridation program the study employed an experimental design. The CDN provided a list and contacts of the people who they supplied with the buckets. Thirty among them were randomly selected to participate in the survey. The study sought to establish current levels of fluoride in the waters of Nakuru town, the study shows that the current levels of fluoride in unfiltered water is high at 4.744mg/L. This finding also reflects the current levels of fluoride in drinking water before defluoridation. This is way higher than the maximum level recommended by WHO of 1.5mg/L. This means that the residents who use this water without first filtering it are at a high risk of developing dental and skeletal fluorosis. The findings also show that the levels of fluoride in the same waters reduce dramatically to 0.483mg/L after defluoridation using the CDN filters. This is within acceptable levels and therefore safe for drinking. It is recommended that the program should extend its area of operation to include other areas that are fluoride endemic in Kenya.

Introduction

The problem of fluorosis may be as old as human kind itself as evidenced by ancient skeletal remains that exhibit signs of fluorosis found in fluoride endemic areas. This is because the fluoride ion occurs naturally in groundwater and is associated with naturally occurring geological phenomena. Fluorosis is one of the most widespread endemic health problems. Although fluorosis existed long ago, there was little effort made to defluoridate water before the 20^{th} century. This could be due to the fact that people did not really understand its pathogenesis. It is only in recent history that the disease was understood. The earliest diagnoses were made in 1888 in Mexico and 1891 in Italy (Fawell *et al*., 2006). However, it was not until 1920 that the link was established between drinking water and fluorosis. This was done by Dr. Fedrick S. McKay, a dentist in Colorado. People also did not think of fluorosis to be abnormal then. This is because these people affected were in isolated areas and thought it was normal until they got to travel to other parts of the world that weren't affected and realized it was abnormal.

Furthermore, some forms of fluorosis like skeletal fluorosis take long to exhibit visible symptoms so it was difficult for people to see the link between water quality and fluorosis. The first serious attempts to investigate the effects of fluoride and to remove excess fluoride happened the 1930s (Meklau & Shifera, 1997).

Methods of Defluoridation

There exist several methods of defluoridation. The ones most commonly used in developing countries at the moment include; adsorption by activated alumina, contact precipitation with aluminium hydroxide (Nalgonda technique) and sorption on activated bone charcoal (Muller *et al*., 2006). Heat treated aluminium hydroxide, Al (OH)3 at 300 ^{0}C known as aluminium oxide hydroxide (AlOOH) shows a higher adsorption capacity compared to activated alumina (Beneberu *et al.*, 2006; Feleke *et al.*, 2008). It can be locally produced from hydrated aluminium sulfate for use in household treatment units.

It's not possible to remove fluoride using typical water treatment methods like boiling, ultraviolet treatment, filtration and chemical treatment. For ions such as fluoride and arsenic, other methods have to be employed. They include; synthetic ion exchange and precipitation processes, activated alumina filters, and reverse osmosis (Shaw, 1954). No one method is the gold standard and any may be employed by the user depending on availability. The method chosen by a community is mainly dependent on social, financial, cultural, and environmental factors. Most of the defluoridation methods mentioned here are point of use (POU) treatment options and are the preferred methods in the developing countries. They are often cheaper, have reduced risk of recontaminating water. They are mainly used to treat drinking and cooking water and municipal use is rare. However, in some situations, it may be more appropriate to have community defluoridation. In that case, a cost benefit analysis must be carried out first.

Nalgonda Technique

It was developed in the 1960s in Nagpur India by the National Environment Engineering Research Institute (NEERI) and is mainly used there. It involves addition of aluminium sulphate and lime to raw water. This results in the formation of insoluble aluminium hydroxide flocs (Müller *et al.*, 2006). The flocs then remove fluoride from the water as a solid by coagulation and sedimentation. The purpose of the lime is to provide an optimum pH of 6-7 to the complete precipitation of aluminium (WHO, 2006). The lime is also important to help in rapid settling of the aluminium flocs (Gupta & Deshpande, 1998).

The reactions involved in this process are (WHO, 2006):

Aluminium dissolution	$Al_2(SO_4)318H_20 \leftrightarrow 2Al_3{++}\ 3SO_42{-+}\ 18H_20$
Aluminium precipitation	$2Al_3{++}\ 6H_20 \leftrightarrow 2Al(OH_3) + 6H+$
Co-precipitation	$F{-+}\ Al(OH)_3 \leftrightarrow$ Al-F complex + undefined product
pH adjustment	$6Ca(OH)_2{+}\ 12H{+} \leftrightarrow 6Ca_2{+} + 12H_2O$

The amount of each reagent needed is determined by jar testing or by using tables developed by the NEERI (Nawalkhe *et al.*, 1975; Gupta & Deshpande, 1998). The amount of aluminium sulphate needed depends on the fluoride content and the alkalinity of the water. The amount of lime used is one twentieth of the aluminium sulphate concentration. It is not clear in the literature how much fluoride can be removed with this method and if it can reduce levels to those stipulated by the WHO guidelines (Banuchandra & Selvapathy, 2005). The Nalgonda technique can be implemented at a household level with the use of a bucket or at community level with a tank. In the Nalgonda technique at household level, the treatment steps followed are; addition of the chemicals to the raw water, fast mixing, slow mixing and lastly settling. Generally, the fast mixing is a period around one minute (Bjarne, 1996; Dahi *et al.*, 1996), the slow mixing varies from five (Dahi *et al.*, 1996) to twenty minutes (Gupta & Deshpande, 1998) and settling lasts about an hour (Nawlakhe *et al.*, 1975).

This technique, however, carries with it a risk of contaminating treated water with aluminium sulphate. The levels may exceed 0.2 mg/l recommended by WHO. This method is also known to produce toxic sludge which brings a whole new problem of how to dispose of it safely (WHO, 2006)

Activated Alumina

When alumina (Al_2O_3) is activated to become adsorptive, it becomes known as activated alumina. This is achieved by dehydrating aluminium hydroxide at temperatures of between 300-600^{o}C (Fawell *et al.*, 2006). It is a very effective method that has been uses in South Africa since the 1980s. This method has mainly been used in the developed world but has not been used in the developed countries due to its high cost and unavailability. Countries like China, India, and Thailand are now beginning to use it as they now have increased capacity to bear the cost. There are countries like Vietnam which are currently exploring cheaper ways of producing activated alumina.

Activated alumina has the ability to defluoridate water with very high fluoride contents (upto20mg/L). Besides fluoride, it can also rid the water of other contaminants but has an especially high affinity for fluoride (Fawell *et al.*, 2006).

Bone Char

Bone char has been successfully used for defluoridation since the 1940s. It was used extensively in the United States for water defluoridation and sugar refining. Bone char also has the ability to remove arsenic from the water, which is an added advantage. It is produced by calcination and pyrolysis of animal bones. Raw bones may have some defluoridation value but it's limited due to the organic content (Fawell *et al.*, 2006). Bones are collected from various sources like restaurants, butchers, and ranches. This makes use of material that would otherwise be considered waste.

Bone Collection

After collection, the bones are washed, rinsed and dried in the sun. This removes much of the organic content. Virtually all animal bones can be used as fluoride uptake occurs on a reaction with hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$), which is found in all bones. Cows and pigs bones are generally more adsorptive than chicken and fish but not by much. Some cultures may also prohibit the use of bones of some animals like cows for Hindus, pigs for Muslims and hyenas for Africans. Calcination is the process of subjecting the bones to high temperatures (300-700^oC) in the presence of atmospheric oxygen (Gupta & Deshpande, 1998). It results in a bone char product that is mainly hydroxyapatite. The organic portion is burnt off. Ion exchange during fluoride removal takes place on the hydroxyapatite.

Pyrolytic bone char, on the other hand, is charred in the absence of oxygen. It is more difficult to produce but more effective than calcined bone char. This is because it converts the organic content into a usable activated carbon, which can treat the water beyond fluoride (Fawell *et al.*, 2006). Ideally, pyrolytic bone char should contain about 90% hydroxyapatite and 10% activated carbon. Pyrolysis results in black bone char due to increased amount of carbon while calcined cone char may range in colour from white to dark grey (Karthikeyan, 1997).

Physical Properties of Bones Calcined at Different Temperatures

The time it takes for charring to complete depends on the amount of bones being charred. It is a process that takes several days. Once completed, the bones are then crushed to obtain various sizes. The optimal grain size for defluoridation is 0.5-4 mm diameter grains. The grain size doesn't affect the adsorptive capacity but rather the reaction rate. Smaller grain sizes usually mean quicker reactions. Grain sizes that are too small are also undesirable as they clog the filter.

Once produced, the crushed bone char is then used as a filter media. Most bone char filters are made in the form of gravity fed column filters. Configurations include: Bucket Filter, Drum Filter and Column Filter. The column filters more closely resembles a plug flow reactor, while the bucket and drum have a mixed flow (Chikte, 1997). Column filters are generally more efficient. The life of the filter can be estimated from its theoretical defluoridation capacity. This is calculated based on the amount of fluoride that each grain of bone char can hold. Column filters generally operate at 2/3 the theoretical defluoridation capacity, while the bucket and drum filters have a capacity of about 1/3. The main advantage of using a bucket and drum filter is that it is cheap to manufacture as you use locally available materials as opposed to a column filter which has to be custom made (Karthikeyan, 1997). Before they are used, the filters must be rinsed thoroughly to remove residual organic material which affects the taste of the water (Fawell *et al.*, 2006). Pyrolytic bone char yields no odors or unpleasant taste. The chemical composition of bone char may vary slightly due to variations in the charring process. Other methods of defluoridation are also available. These are; reverse osmosis, synthetic materials, solar distillation, and biological methods (Mariappan, & Vasudevan, 2002; Karthikeyan & Shunmuga, 2002).

Alternatives to Defluoridation

Other methods may be used to prevent fluorosis other than defluoridation. Sometimes it's better to abandon a water source completely if defluoridating it is too costly. Rainwater is one such source (Fawell *et al.*, 2006). Diet can also be used to curtail fluorosis. A high protein, calcium and vitamin C diet can help reduce the effects of fluorosis (Jerry *et al.*, 2006). Malnourishment generally worsens the effects of fluoride and a high silicon diet, a mineral critical in bone mineralization, also worsens the effects of fluorosis.

Health Impacts of Fluoride

Fluoride in mild forms is actually very useful. It is antibacterial in the mouth thus inhibiting caries producing bacteria and making the tooth more acid resistant. Fluoride ions also bind with calcium ions, strengthening tooth enamel as it forms (Gupta, 1993). However, in excessive forms, it leads to loss of calcium from the tooth leading to increased tooth breakdown and caries (Gupta *et al.*, 1993). Extremely high exposure leads to more serious and crippling effects associated with skeletal fluorosis. Fluoride being an electronegative element is highly attracted to electropositive elements like calcium. That's why it easily accumulates in bones and teeth which have a high amount of calcium.

Statement of the Problem

Fluorosis is a major problem affecting Kenyans today. Several governmental and nongovernmental organizations have undertaken measures to try and curb the problem. One organization based in Nakuru known as the Catholic Diocese of Nakuru (CDN) has a water quality program that seeks to provide safe defluoridated water to residents of Nakuru and its environs. This study evaluated whether the organization has been able to achieve its objectives. The prevalence of fluorosis is not well documented but it is thought to affect millions of people worldwide. Mild to moderate forms are more common than severe forms (Bregnhoj, 1997).

It is difficult and expensive to remove fluoride from water therefore it's easier to find alternative water sources. However, in the absence of alternatives, defluoridation may be the only option. Methods of defluoridation include; contact precipitation, activated bone char and use of activated alumina (Nalgonda technique). Since they are expensive and produce sludge, not all water can be treated and only water for cooking and drinking is treated (Bregnhoj, 1997).

The Catholic Diocese of Nakuru (CDN) water quality program in Nakuru Municipality uses the activated bone char for defluoridation. This method makes use of locally available raw materials. They burn and crush animal bones in a high temperature furnace (500^0C). This removes all the organic matter leaving an inorganic content of calcium and phosphate which has the ability to adsorb fluoride from water. These are then supplied with filters to the residents.

The Water Quality Program has 3 types of filters suitable for different localities and users (household filters, community filters and institutional filters).They are currently working on a new "self-regenerating" filter which can increase the effectiveness of the bone char. This has been achieved by the development of calcium phosphate pellets which increase the lifespan of the filters when combined with bone char (CDN, 2009).

The study evaluated the effectiveness of water defluoridation process using bone char in Nakuru Municipality.

Limitations of the Study

The research only investigated the research problem based on one district in the Rift valley Province yet the CDN is operational in other districts including Baringo, Koibatek and Naivasha. The study focused on assessing the contribution of the CDN water quality program in providing safe fluoride free drinking water to the residents of Nakuru Town by determining the extent to which the bucket filters removed excess fluoride from water. The study population was limited to Nakuru Town. The findings therefore did not reflect the effectiveness of the program in the other areas of operation.

Materials and Methods

The study was conducted in Nakuru town for the following reasons: the CDN water project is based in Nakuru; there are known incidences of fluorosis due its location in the Rift Valley which is a fluoride belt, and high concentration of fluoride in both surface and underground water in Nakuru. Nakuru is located in the Great Rift Valley. The geology of Nakuru area comprises mainly volcanic soils and rocks and this volcanic activity give rise to the high concentration of fluorides and other inorganic salts in water and soil. There is a major salt water lake, the Lake Nakuru, which is situated within the National park. Another major volcanic feature is the Menengai crater which is also as a result of volcanic activity. Nakuru experiences a hot and dry climate most times of the year (Muller, 2007).

The research was exploratory. The variables to be measured in experiment included: Current levels of fluoride in untreated water and levels of fluoride after treatment using bone char filters. The acceptable levels of fluoride in drinking water should not exceed 1.5mg/L (WHO, 2010).

The study employed the use of an experiment using the AAS to measure actual levels of fluoride in water before and after use of the buckets. The two levels were then compared to determine the extent of fluoride removal in the water. Data collected were checked and edited for correctness. Each objective was then analyzed using appropriate statistical tests. Data was analyzed using; percentages, means and mean difference. The data was then presented in the form of tables and figures.

Experimental Layout

The experimental layout was complete randomized design (CRD). For each of the respondents, water samples were taken from their water sources before and after the defluoridation process.

In order to evaluate the effectiveness of the fluoride filters, 30 users of the fluoride removal buckets were randomly chosen. Their water was obtained and tested for levels of fluoride before defluoridation, and then the levels were again tested after defluoridation. Each respondent provided ten water samples (five before defluoridation and five after defluoridation). Each sample was 300ml. These were mixed to make a composite sample.

A final sample was obtained from the composite for each household for before defluoridation and after defluoridation for laboratory analysis. Five 300ml samples of sterile water were used as a control for the experiment. Five subsamples from the composite sample were analyzed per household and averaged to provide the fluoride levels in the drinking water before and after the defluoridation process. The levels of fluoride in the treated water were compared to WHO and Kenya Bureau of Standards recommended levels of 1.5mg/L.

Measurement of Fluoride Levels in Water Samples

The removal of fluoride from water solutions using a ferric poly-mineral from Nakuru was studied using batch adsorption experiments. After obtaining the water samples as described above, the experiment to determine their fluoride levels was conducted as follows. A water sample was obtained and distilled in an electrical furnace. The furnace was an Atomic Absorption Spectrophotometer (AAS210VGP) at a constant temperature (600^0C) for 15 minutes followed by cooling for 45 minutes. It was then stirred with a magnetic stirrer and tetraflouroethylene coated stirring bars. A calcium oxide reagent and phenolphthalein indicator was then added to the sample. Fluoride reference electrodes were inserted into the solution for 5 minutes and then the reading obtained in parts per million. The reading recorded indicated the level of fluoride in that water sample. If the reading was more than 1.5 parts per million (ppm), it was considered to be too high (www.merckmillipore.com/fluoride-test).

The WHO standard for acceptable levels of fluoride in drinking water is 1.5mg/L. The National standard for fluoride levels in water that is considered safe is the same as the WHO standard (1.5mg/L) (www.naturalpedia.com/flourosis.html).

Results

An experiment was conducted to determine the current levels of fluoride in untreated water and levels of fluoride in the same water after defluoridation with the filter buckets. Those findings are presented below.

Extent of Fluoride Removal from Drinking Water

The fluoride filters were found to reduce fluoride in drinking water as follows:

Total mean average before defluoridation

$$= \frac{\text{Total fluoride level in samples before defluoridation}}{\text{Total number of houses}}$$

$$= \frac{142.33}{30}$$

$$= 4.744 \text{mg/L}$$

This value also reflects the average levels of fluoride in drinking water before defluoridation within Nakuru town. This shows that the fluoride levels are high as compared to the recommended WHO standard of 1.5mg/L.

Total Mean Average after defluoridation using the filters

$$= \frac{\text{Total fluoride levels in samples after defluoridation}}{\text{Total number of houses}}$$

= <u>1.449</u>

30
=0.483mg/L
This value reflects the level of fluoride in drinking water after using the bone char fluoride filters for defluoridation.

Extent of fluoride removal
Therefore the mean difference is
4.744-0.483
= 4.261mg/L
This value also reflects the extent of removal of fluoride from drinking water using the bone char fluoride filters. These findings prove that the fluoride bucket filters are effective defluoridators as they were able to remove an average of 4.261mg/L of fluoride from the water.

Comparison of Fluoride Levels after Filtration to WHO and National Standards
The levels of fluoride in the filtered water as compared to acceptable WHO standards was
1.5-0.483
= - 1.107mg/L

These findings show that the levels of fluoride after defluoridation fall within the recommended WHO standard of not more than 1.5mg/L. This proves that the fluoride filters provided by CDN are an effective way of defluoridation.

These findings are further summarized in the table below.

Table 1: The Extent of Fluoride Removal from Drinking Water

Test	**Levels of fluoride in water in mg/L**	**WHO standard on fluoride levels. (1.5mg/L)**	**National standard (1.5mg/L)**
Mean of samples for 30 houses before defluoridation	**4.744**		
Using filter from CDN(x)			
Mean of samples for 30 houses after defluoridation	**0.483**		
Using filter from CDN(x^1)			
Mean difference (x- x^1)	**4.261**		
Comparison of average levels of defluoridated water in	**-1.107**		
Relation to who standard			
(x^1- 1.5mg/L)			

From the above table, we can see that the average levels of fluoride in water per household are very high when compared to the national and WHO standard of 1.5mg/L. Then after defluoridation, the levels dropped dramatically in all the households and were mostly below 1.5mg/L. It can therefore be concluded that the buckets actually reduced fluoride in drinking water to a safe and acceptable level.

Discussion
The study also sought to establish current levels of fluoride in the waters of Nakuru town, the study shows that the current levels of fluoride in unfiltered water is high at 4.744mg/L. This finding also reflects the current levels of fluoride in drinking water before defluoridation. This is way higher than the maximum level recommended by WHO of 1.5mg/L. This means that the residents who use this water without first filtering it are at a high risk of developing dental and skeletal fluorosis.

The high level of fluoride in the waters of Nakuru means that the residents are at risk of developing fluorosis if nothing is done. Low concentrations would have been beneficial to them as it would lead to stronger bones and teeth that are caries resistant especially in growing children (Dean 1942). The high concentration in the water that is available to them means that they are at risk of developing mild to moderate forms of the disease. They are however cushioned from the severe forms of the disease which can result in skeletal crippling. This normally occurs at fluoride levels of more than 10mg/L (Cao *et al*., 1992)

In this study, it was shown that after filtration, the average fluoride levels in drinking water was 0.483mg/L. This is within the WHO recommended range of not more than 1.5mg/L. This effectively proves that the CDN filters actually carry out their intended purpose of reducing fluoride to acceptable levels thus the residents face a decreased risk of developing dental and skeletal fluorosis as a result.

Conclusion and Recommendations

From the study findings, it is clear that the CDN program has been able to supply an affordable fluoride filtration technology that provides residents with clean and safe drinking water. It can therefore be concluded that the CDN water quality program has been able to achieve that objective.

It is recommended that the program can extend its area of operation to include other areas that are fluoride endemic in Kenya. In addition, subject to the findings of the research, further studies can be carried out on the same subject. The research could also be expanded to include other regions in Kenya that also lie within the fluoride belt for example Baringo and Koibatek where CDN also operates. Additional focus should also be placed on incorporating a wide range of variables to produce a more significant study which could be generalized to a larger population.

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