Defluorination Effectiveness of Modified Biosand Filters

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Abstract

The most substantial sources of fluoride exposure are located in the Rift valley. It has been reported that people in the Rift Valley are consuming water with up to 33 mg/L of fluoride. The WHO has set 1.5 mg/L as the maximum permissible limit for fluoride in potable water. The use of water with high fluoride concentration poses a health threat to millions of Kenyan residents. Biosand filter (BSF) is a low-cost technology that has been implemented in Kenya. Several studies have shown that the BSF can reduce the turbidity and microbial contaminants effectively however, limited studies have focused on removal of fluoride. Various low-cost materials like bamboo activated charcoal, bone char, diatomite and steel wool were investigated to assess their capacity to remove fluorides from water by batch adsorption studies. Experiment was also conducted to determine the effect of the modified filter on bacteria reduction using E. coli as an indicator. The measurements of the standard Biosand filter were scaled down and 18 modified filters were designed. The modified and standard Biosand filters were subjected to trials in the laboratory where 1.5, 2.26 and 3.0 mg/L initial fluoride concentration were subjected to 30, 60 and 90 minutes contact time in order to reduce fluoride concentration to the desired level of below1.5 mg/L. E. coli was cultured and serially diluted into sterile saline deionised water and passed through modified biosand filters. Data obtained was subjected to Microsoft Excel t- test and analysis of variance. The modified filters absorbed a significant amount of fluoride ($p>0.05$). It was also observed that there was a significant removal on the contact time ($p>0.05$). Modified filter performed significantly better ($p<0.05$) than the standard filter, removing 97% of fluoride after 24 hours and treating the water to below the WHO fluoride limit of 1.5 m/L. This study also indicated that the standard biosand filter removed the highest amount of E. coli bacteria with removal rate of 96%. bamboo activated charcoal, diatomite, bone char and iron oxide (Fe^0) removed 90, 85, 81 and 70% respectively. This study's findings indicate that the modified filters can be an effective in removing fluoride from water so the study recommends that it be manufactured using locally available materials and implemented for local communities.

Keywords: Defluorination, Bio-sand Filter, activated charcoal, bone char, diatomite and steel wool

INTRODUCTION

Water is crucial component of all forms of life (Westall & Brack, 2018, Chaplin, 2001). As a result, humans have a fundamental/basic right to healthy and dependable (clean and fresh) water (Sallah-Phillips, 2006; Crawford, 2020). However, owing to water contamination, 2.2 billion people worldwide do not have access to clean drinking water (Raimi *et al.*, 2019). Water dissolves a slew of minerals because it is a universal solvent that interacts with environmental materials (Moss, 2009). Mineral elements present in a given area can naturally dissolve in varying amounts in water sources as a result of the geological composition of soils and bedrock (Malago *et al.*, 2017; Binda *et al.*, 2018; Peh *et al.*, 2010). Fluorides are one of these mineral elements in water that is a significant source of concern (Mann & Mandal, 2014).

In humans and animals, fluoride is considered as an essential mineral but its importance depends on the concentration there is in drinking water or the amount that one consumes (Jha *et al.*, 2011). Fluoride is essential for the maintenance of strong and healthy bones (Ringe, 2004). About 260 million citizens that are from six different countries are believed to ingest a daily uptake of water that contains close to 1.0 mg/L of fluoride (Huang *et al.*, 2017). Fluoride levels have been confirmed to be high in Kenyan regions such as the Great Rift Valley and Mount Kenya's slopes (Owen *et al.*, 2008). Dental fluorosis and skeletal fluorosis have been reported in these areas (Olaka *et al.*, 2016; Renaut *et al.*, 2013; Gevera, 2017).

Under the social pillar of Kenya Vision 2030, water and sanitation aim for all to have access to clean water and healthy sanitation by 2030 (Awuonda, 2015). The supply of safe drinking water is regarded as critical and pivotal to overall development (WHO, 2004). The presence of contaminants in water can cause economic burden to the population by treating waterborne-related diseases caused by their toxicity (Naidoo & Olaniran, 2014). The health effects of water contaminants in drinking water are irreversible (Dauphiné *et al.*, 2011). Therefore, it is vital to remove these water contaminants so as to reduce or eliminate economic and health burdens.

Researchers have been working tirelessly to come up with appropriate technologies to alleviate the fluoride pollution during the past 80 years (Naseri *et al.*, (2017; Kamathi, 2017; Collivignarelli *et al.*, 2020). Drinking water defluoridation is normally achieved by precipitation or adsorption processes (Collivignarelli *et al.*, 2020). Electro dialysis, reverse osmosis, ion exchange, chemical precipitation, and adsorption are the most popular methods for defluoridating water (Wang *et al.*, 2019; Waghmare & Arfin, 2015). The method for removing fluoride is calculated by factors such as capital and operating costs, environmental effects, and fluoride removal effectiveness (Alkurdi *et al.*, 2019; Chakrabortty *et al.*, 2013). Only a portion of the materials that have been examined contain activated alumina, activated charcoal, activated clay, bone char, clays, ion exchange membranes, laterite, magnesium compounds, phosphate rock, poly-aluminium salts, serpentine, and zeolite (Craig *et al.*, 2015; Nabbou *et al.*, 2019; Madhukar *et al.*, 2014). Most defluoridation techniques are complicated, require skilled labor, have a high initial and ongoing expense, and are technically unfeasible due to strict pH and other experimental conditions, as well as the use of toxic chemicals, all of which are limiting factors for their use in water defluoridation (Karunanithi *et al.*, 2019; Damtie *et al.*, 2020). Given their high efficacy in eliminating fluoride, this renders them unaffordable to most local communities. As a result, it is beneficial to find locally accessible defluoridation media that are clean, simple to use, and low in cost at both the household and small community levels (Murutu *et al.*, 2012; Marwa *et al.*, 2018).

Because of its high removal performance, superior adsorption rate, ease of operation, and large range of adsorbents, adsorption has been identified as the most promising method for removing fluoride from water (Wang *et al.*, 2009). It also has the benefit of being adaptable to a decentralized water supply scheme. Since different adsorbents are available in large quantities and at low prices, they are possible candidates for defluoridation in remote areas (Anurag & Ashutosh, 2009).

Bone char is an inorganic material that has been recorded as a good material due to its use in the field of electrochemistry and as a catalyst (Iriarte-Velasco *et al.*, 2014). Defluoridation with bone char is easy to do, typically inexpensive, and can be used for decentralized water treatment (Marwa *et al.,* 2018). According to a study by Korir *et al.* (2009) on the use of defluoridation treatment in east Africa, he concluded that bone char filtration is effective for fluoride removal. Diatomite is a mineral found in nature which is believed to be fossilized remains od diatoms (Ikusika *et al.*, 2019). It has not only got used in water purification but its chemical and physical characteristics has made it of use in so many other industrial processes. Bamboo is a member of the Poaceae family and the Bambusoideae subfamily, and is found in Asia, Africa, and South America, with rapid growth, high productivity, and short development cycles (Kumar *et al.*, 2021). Bamboo charcoal (BC) is gaining popularity as an environmentally sustainable and low-cost fiber (Tan *et al.*, 2011). Recently, much emphasis has been placed on the use of BC as an adsorbent in the treatment of water toxins such as fluoride (Wendimu *et al.*, 2017). Steel wool commonly known as an iron wool or a wire wool or wire sponge is defined as a bundle made up of sharp-edged filaments which are very fine which got defined as a novel product by researchers in the year 1896 (Beveridge *et al.,* 2005). The ability of Fe0-based filters to remove/inactivate various biological and chemical contaminants from water has been demonstrated. Results from different researches on the suitability of safe drinking water after the use of FeO filters have shown that it is effective *(*Lata & Samadder, 2016). *Escherichia coli* was first discovered in the year 1885 by Theodor Escherich who described is a Gram-negative, facultative anaerobic bacteria that is rod shaped. As part of the human beings and animals' natural flora, *Escherichia coli (E. coli)* majorly are found in the gastrointestinal tract (Obisesan, 2021). Although a majority of them are non pathogenic, some strains have the ability of causing disease from the intestines and outside the intestines. The EPAs water guidelines states that in the United States to measure the amount of water bacterial contamination by fecal matter is by measuring the amount of *E. coli* in the water (Ishii & Sadowsky, 2008). If the stipulated amount of *E. coli* required for drinking water exceeds what is accepted by EPA, then that water is considered as toxic and poses a risk to the health of consumers (Oloruntoba *et al.*, 2021).

The biosand filter (BSF) is a low-cost, easy-to-use water treatment system that advances conventional slow-sand filters (Shah *et al.*, 2015). It is designed for intermittent use. The biosand Filter is a tried-and-true method of removing bacteria, viruses, protozoa, and turbidity from water (Budeli *et al.,* 2021). In laboratory experiments, bacteria could be reduced by up to 96.5 percent, and by 87.9–98.5% in the field. Based on laboratory tests, virus reduction ranged from 70 to over 99 percent. The turbidity of the influent water could be decreased by 95 percent to less than 1 NTU (Saturday, 2016). The number of protozoa could be decreased by 99.9%. Dissolved chemicals (like organic pesticides or fluoride) are not excluded.

Several researchers have proved bamboo activated Charcoal, Bone Char, steel wool and diatomite to remove fluoride levels in water, therefore in cooperating Biosand Filter with these materials while monitoring the microorganism levels such as *E. coli* could promise a filter which will solve a number of water problems and also making it affordable to most local communities. This formed the basis of this study, which focused on investigating the potential of different bio-sand filters incorporated with bamboo activated charcoal, diatomite, bone char, and steel wool to remove fluoride and *E. coli* from water. Therefore, the main objective of this study was to determine effectiveness of modified Bio-sand filters bamboo activated charcoal, diatomite, bone char, and steel wool in removal of flouride, and *e. coli* in water

METHODOLOGY

Chemicals and reagents

All of the solutions were made with double distilled water and analytical grade reagents from Kobian Kenya Limited, a Sigma Aldrich's outlet in Kenya.

Instrumentation

The fluoride content of the solutions was measured using a potenometric method using a fluoride ion selective electrode (JENWAY 3345 Ion Meter). The test solution combined 25 mL of the overall ionic strength buffer (TISAB) of 25 mL, which remained constant in the ionic strength. Standard solutions with concentrations of 0.1, 1, 3, 5, 7, 10, and 20 mg/L were used to calibrate the ISE.

Adsorbents sourcing and preparation

Activated carbon preparation from Bamboo

Bamboo plant *(Arundinaria alpina)* was obtained from a local resident, the plant was generously donated and the plant was identified using dichotomus key. Bamboo was cut into small pieces 20cm long and 3-5cm wide to allow uniform burning in the furnace, then dried for seven days in the sun. After sun drying the resulting material then gets heated in sealed oiled drums whuich gets lit from the bottom. Combustion type that gets to happen is the anionic one whereby the material gets ignited burns under low oxygen and is heated until all wter is spent out and evaporates. The material was successfully carbonized and charcoal was produced over the next two to three hours (Singh, 2010).

After charcoal was produced as described above, the prepared charcoal was then washed with distilled water to remove remaining organic material content and finally dried in an oven at 110^0C). Without grinding the substance to a fine powder, it was broken into smaller parts. Enabled carbon comes in sizes ranging from 0.5 mm to 1.0 mm. The parts were then soaked in a 25% solution of CaCl2 or NaCl2 for 24 hours after this phase was completed. They were then thoroughly rinsed and dried in the sun or in an oven set to 100°C for about an hour (Baek et al., 2019).

Bone char, Diatomite and Fe^0 sourcing

The Catholic Diocese of Nakuru provided the bonechar. Charring animal bones to carbonize at a temperature of 400 to 500 ^{0}C with a regulated air supply produces the char. Following that, the charred bones are crushed, sieved, cleaned, and dried. The adsorption media were particles with a diameter of 0.5 to 4 mm (Jacobsen and Dahi, 1997). Before using, diatomite was collected from the Kariandusi mining plant, sieved, and washed. Before use, the Steel Wool was bought from a local store, weighed, and washed.

Escherichia coli culture

Initially, the *Escherichia coli* strain was grown on nutrient agar plates and incubated for 24 hours at 36 °C. One loop of this bacterial culture was inoculated into 100 mL sterile nutrient broth and incubated at 37 °C in a shaking incubator for 16 hours before being serially diluted in 9 mL sterile physiological water (0.9 percent w/v NaCl) and spread-plated on MacConkey Broth agar (Merck) plates. The plates were incubated at 37 °C for 24 hours before counting the colonies to assess the initial bacterial concentrations in cfu/mL. *E. coli* culture aliquots were inoculated into 5 L of borehole water (final volume). The spiked water samples were shaken vigorously several times before being passed through the BSF.

A 0.45um filter was used to filter the filtrate water from the regular BSF and adjusted filters. The media was prepared and nutrient agar was used. By sucking bacteria back from the filters, *E. coli* bacteria were collected. The spread plate approach involves suspending the sample in a petri dish with molten agar that has been cooled to about 40-45 degrees Celsius. The plates were incubated at 37 °C for 24 hours after the nutrient agar solidified, and the colonies were counted.

Stock solution preparation

A 2.26 g sodium fluoride was dissolved in 1000 ml water to make a fluoride standard stock solution with a concentration of 1000 mg/L. Following this solution, subsequent working solutions were created. To change the working solutions' pH to the appropriate value, 0.1 mol/L nitric (V) acid and 0.1 mol/L sodium hydroxide solutions were used. Prior to use, the stock solution was also stirred for at least 10 minutes.

Filter construction, design and testing for efficacy

A 10-liter plastic pipe, PVC pipe, and fittings were used to make twenty Biosand filters. This design's bottom bucket has a valve under the outlet to help in the restoration of the adsorptive media. The gravel layers remained constant regardless of whether each bucket contained grit, a biochar/sand mixture, or pumice, and were prepared in accordance with the CAWST Biosand Filter Construction Manual (2012). According to Manz's standard procedures for BSF, the sand was washed several times with tap water before the wash water became clear. The filters were made from a plastic container purchased from a local store. The container was washed with tap water before being filled with 5 cm of deep under drain gravel, 5 cm of coarse sand sheet, and 50 cm of fine sand pipe in order to maintain a water depth of 5 cm over the filter media for the normal BSF. The updated BSF was built with 5 cm of under drain gravel, 5 cm of coarse sand sheet, 25 cm of fine sand, 10 cm of adsorbent media (Activated charcoal from bamboo, Diatomite, Bone char, and Stee wool), and pipe installed to keep a water depth of 5 cm. A plastic diffuser plate was created on the filter's lip to avoid disrupting the top layer of sand during regular charging of the filter with raw water. Before using the filter, it will be fed 40 liters of water per day, 20 liters in the morning and 20 liters at night, for 21 days to allow the filter to mature (formation of biological film). Fluoride concentrations of 1.5, 2.26, and 3 mg/L were passed through 10 filters to assess removal efficacy. The residual fluoride concentration in the filtrates was determined in the laboratory. Individual filters were diluted five times (by halving subsequent dilutions) after being inoculated with cultured *E. coli* bacteria colonies in 2 liters of sterile water. The 5-liter samples were filtered using 0.45um filters after passing through normal Biosand filters and adjusted Biosand filters. They were then taken to the lab for culturing.

Statistical analysis

T-tests with 95 percent confidence values and 0.05, assuming equivalent variance, were used to determine statistical significance between outcomes. To see if there was any correlation between the filtration material and Cfu’s obtained, the Chi-square test of independence was used. Microsoft Excel Data Analysis Tools were used to analyze the data.

RESULTS

Fluoride calibration for the standards using fluoride ion selective electrode

The calibration graphs used in determination of the concentration of the fluoride ion using fluoride ion selective electrode is shown in figure 1.

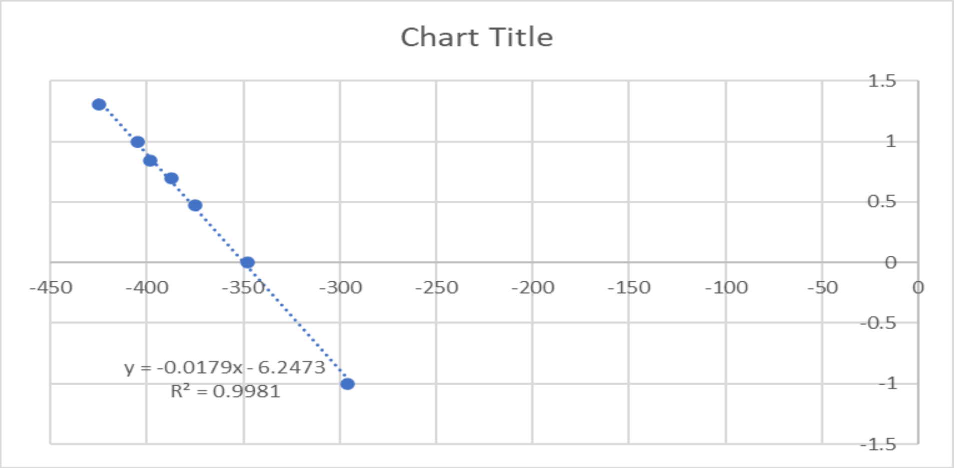

Figure 1: Calibration standards for the flouride

Mean Concentration of adsorbed fluoride in standard biosand filter and four modified filters

Biosand filter, activated charcoal, diatomite Bone char and steel wool (Fe^0) removal of fluoride from water were evaluated for different contact times using batch tests. Variation of fluoride concentrations with contact time is presented in figure 2, 3, 4, 5 and 6.

Standard Biosand filter

Fluoride adsorption batch tests were conducted on the biosand filter as a control to see whether it absorbs fluoride. Initial fluoride concentrations of 1.5, 2.26, and 3.0 mg/L were spiked into the filter. The effects of 30, 60 and 90 minutes of contact time were assessed. The effects of overnight contact time were also investigated, and the findings are shown in Figure 2 below.

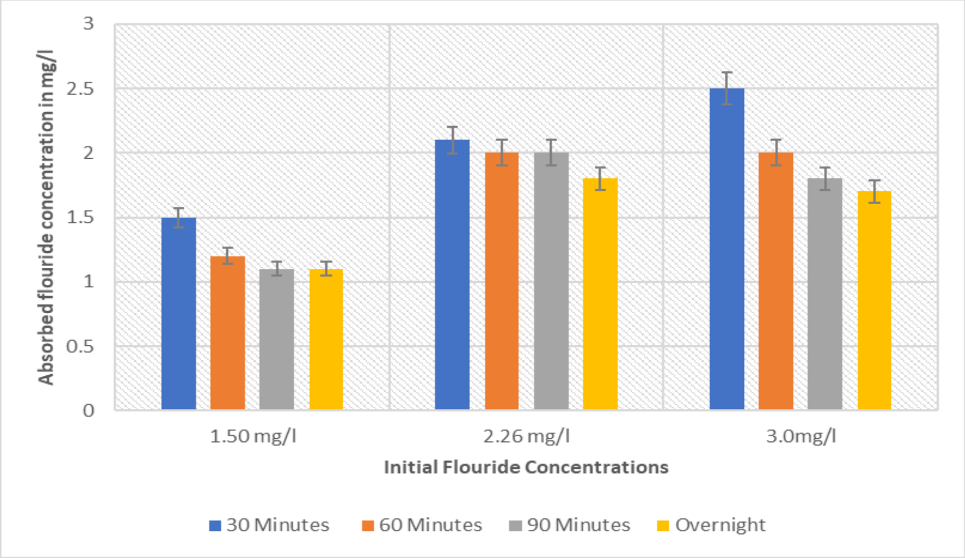

Figure 2: Effects of time on adsorption of fluoride ions in Standard Biosand Filter

According to the findings, normal biosand filters did not adsorb a large amount of fluoride ($p>0.05$). It was discovered that the interaction period had not been substantially reduced.

Bamboo activated charcoal

The biosand filter modified with activated charcoal from bamboo was investigated where fluoride adsorption batch experiments were performed. The filters were spiked with 1.5, 2.26 and 3.0 mg/L initial fluoride concentration. The results of effects of contact time of 30,60 and 90 minutes were evaluated.

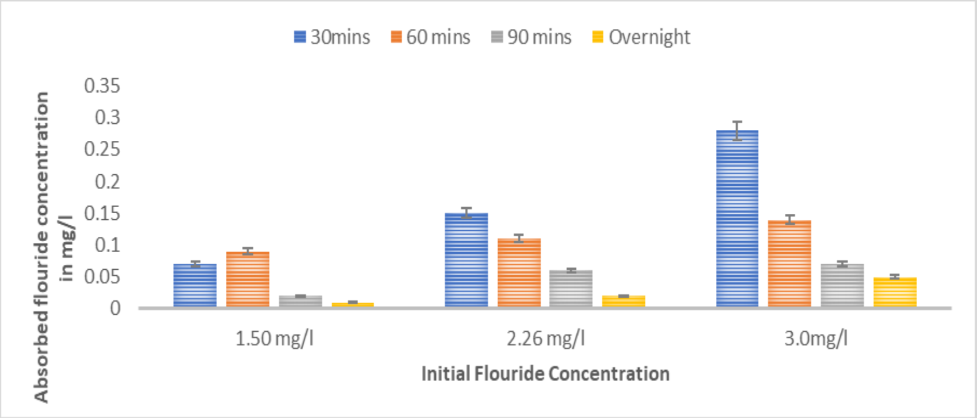

Figure 3: Effects of time on adsorption of fluoride ions in activated charcoal modified Filter

A considerable amount of fluoride was absorbed by the adjusted filters (p>0.05). It was also discovered that the contact time was significantly reduced (p>0.05). The adjusted filter extracted 97 percent of fluoride after 24 hours and filtered the water to below the WHO fluoride limit of 1.5 mg/L, which was slightly better (p >0.05) than the regular filter (WHO 2017).

Diatomite modified filters

The biosand filter modified with diatomite was also investigated where fluoride adsorption batch experiments were performed. The filters were spiked with 1.5, 2.26 and 3.0 mg/L initial fluoride concentration. The results of effects of contact time of 30,60 and 90 minutes were evaluated.

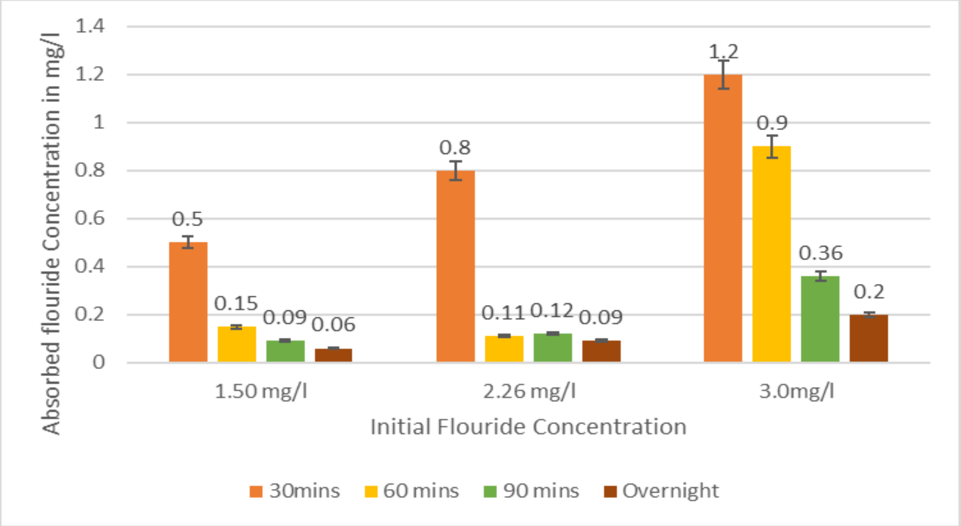

Figure 4: Effects of time on adsorption of fluoride ions in diatomite modified Filter

A large amount of fluoride was also absorbed by the modified diatomite filters ($p>0.05$). It was also discovered that the contact time is drastically shortened ($p>0.05$). The diatomite adjusted filter extracted 93 percent of fluoride after 24 hours and treated the water below the WHO fluoride limit of 1.5 mg/L, which was slightly better ($p>0.05$) than the regular filter (WHO 2017).

Bone char modified filters

The biosand filter modified with bone char was also investigated where fluoride adsorption batch experiments were performed. The filters were spiked with 1.5, 2.26 and 3.0 mg/L initial fluoride concentration. The results of effects of contact time of 30, 60 and 90 minutes were evaluated.

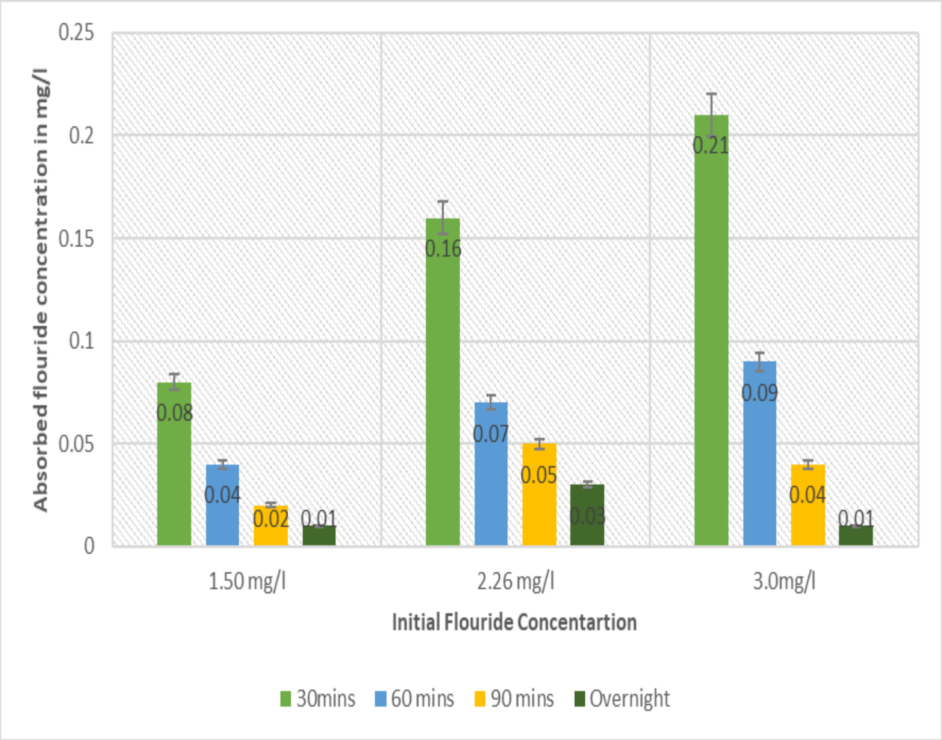

Figure 5: Effects of time on adsorption of fluoride ions in bonechar modified Filter

A large amount of fluoride was also absorbed by the modified bone char filters ($p>0.05$). It was also discovered that the contact time was significantly reduced ($p>0.05$). The diatomite adjusted filter outperformed the regular filter by eliminating 98% of fluoride after 24 hours and bringing the water below the WHO fluoride limit of 1.5 mg/L ($p>0.05$) (WHO 2017).

Steel wool (Fe^0) modified filters

The biosand filter modified with Fe^0 was also investigated where fluoride adsorption batch experiments were performed. The filters were spiked with 1.5, 2.26 and 3.0 mg/L initial fluoride concentration. The results of effects of contact time of 30, 60 and 90 minutes were evaluated.

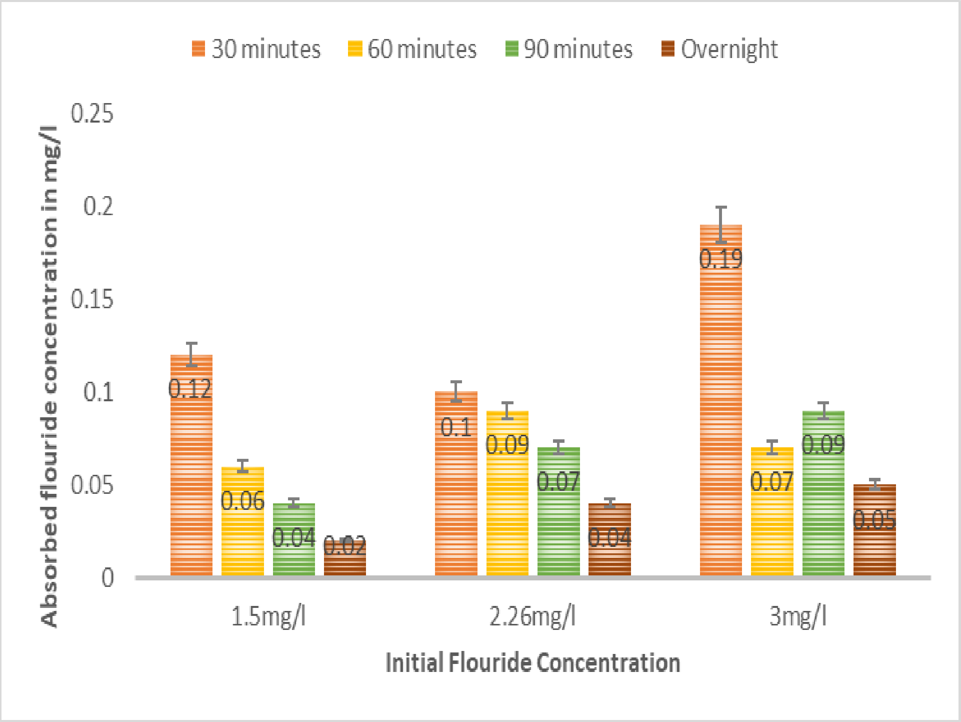

Figure 6: Effects of time on adsorption of fluoride ions in steel wool (Fe0) modified Filter

A large amount of fluoride was also absorbed by the modified Fe0 filters ($p>0.05$). It was also discovered that the contact time was significantly reduced ($p>0.05$). The diatomite adjusted filter outperformed the regular filter by eliminating 98% of fluoride after 24 hours and bringing the water below the WHO fluoride limit of 1.5 mg/L ($p>0.05$) (WHO 2017).

Removal of different initial fluoride concentration in five filters

Comparisons in removal of 1.5 mg/L initial fluoride from 5 filters for different contact time

To determine whether there existed any significant differences in removal of 1.5 mg/L initial fluoride from 5 filters for 30, 60 and 90 mins contact time, one-way analysis of variance was conducted. The results are presented in table 1.

Table 1: ANOVA for 1.5 mg/L initial fluoride concentration for Biosand filter, activated charcoal, diatomite, bone char and steel wool (Fe^0)

		Sum of Squares	df	Mean Square	F	Sig.
30 mins	Between Groups	2.990	4	.748	171.459	.000
	Within Groups	.022	5	.004		
	Total	3.012	9			
60 mins	Between Groups	2.003	4	.501	30.758	.001
	Within Groups	.081	5	.016		
	Total	2.084	9			
90 mins	Between Groups	1.796	4	.449	107.923	.000
	Within Groups	.021	5	.004		
	Total	1.817	9			
Overnight	Between Groups	1.852	4	.463	110.262	.000
	Within Groups	.021	5	.004		
	Total	1.873	9			

The mean of absorbed 1.5 mg/L initial fluoride concentration reported in overnight, 30, 60 and 90 minutes contact time was all ($p > 0.05$) significantly different among the five filters tested Biosand filter, activated charcoal, diatomite bone char, and steel wool (Fe0) (P=0.000, df=4, F=171.459), (P=0.001, df=4, F= 107.923)

Comparisons in removal of 2.26 mg/L initial fluoride from 5 filters for different contact time

One-way analysis of variation was used to see if there were any major variations in the removal of 2.26 mg/L initial fluoride from five filters after 30, 60 and 90 minutes of contact time. Table 2 shows the results.

Table 2: ANOVA for 2.26 mg/L initial fluoride concentration for Biosand filter, activated charcoal, diatomite, bone char and steel wool (Fe^0)

		Sum of Squares	df	Mean Square	F	Sig.
30 mins	Between Groups	5.834	4	1.458	72.200	.000
	Within Groups	.101	5	.020		
	Total	5.935	9			
60 mins	Between Groups	5.809	4	1.452	89.861	.000
	Within Groups	.081	5	.016		
	Total	5.889	9			
90 mins	Between Groups	5.935	4	1.484	90.470	.000
	Within Groups	.082	5	.016		
	Total	6.017	9			
Overnight	Between Groups	4.934	4	1.233	75.211	.000
	Within Groups	.082	5	.016		
	Total	5.016	9			

With the use of one-way analysis of variance of the absorbed 2.26 mg/L initial fluoride concentration recorded in overnight, 30, 60 and 90 minutes contact time were all ($p < 0.05$) significantly different among the five filters tested Biosand filter, activated charcoal, diatomite, bone char and steel wool (Fe^0) (P=0.000, df=4, F=72.200), (P=0.000, df=4, F=89.861), (P=0.000, df=4, F=90.470) and (P=0.000, df=4, F=75.211) for 30 mins, 60 mins, 90 mins and overnight contact time respectively.

Comparisons in removal of 3.0 mg/L initial fluoride from 5 filters for different contact time

One-way analysis of variation was used to see if there were any major variations in the removal of 3.0 mg/L initial fluoride from five filters after 30, 60 and 90 minutes of contact time. Table 3 presents the results.

Table 3: ANOVA for 2.26 mg/L initial fluoride concentration for Biosand filter, activated charcoal, diatomite Bone char and steel wool (Fe^0)

		Sum of Squares	df	Mean Square	F	Sig.
30 mins	Between Groups	8.023	4	2.006	98.520	.000
	Within Groups	.102	5	.020		
	Total	8.125	9			
60 mins	Between Groups	5.589	4	1.397	69.037	.000
	Within Groups	.101	5	.020		
	Total	5.690	9			
90 mins	Between Groups	4.541	4	1.135	69.216	.000
	Within Groups	.082	5	.016		
	Total	4.623	9			
Overnight	Between Groups	4.254	4	1.064	129.700	.000
	Within Groups	.041	5	.008		
	Total	4.295	9			

With the use of one-way analysis of variance of the absorbed 3.0 mg/L initial fluoride concentration recorded in overnight, 30, 60 and 90 minutes contact time were all ($p < 0.05$)

significantly different among the five filters tested Biosand filter, activated charcoal, diatomite, bone char and steel wool (Fe^0) (P=0.000, df=4, F=98.520), (P=0.000, df=4, F=69.037), (P=0.000, df=4, F=69.216) and (P=0.000, df=4, F=129.700) for 30 mins, 60 mins, 90 mins and overnight contact time respectively.

Escherichia coli

Activated charcoal, diatomite Bone char and steel wool (Fe^0) modified biosand filters were tested for the removal of *Escherichia coli* bacteria. The total number of the spiked *E.coli* bacteria was 248, results are presented in figure 7 below.

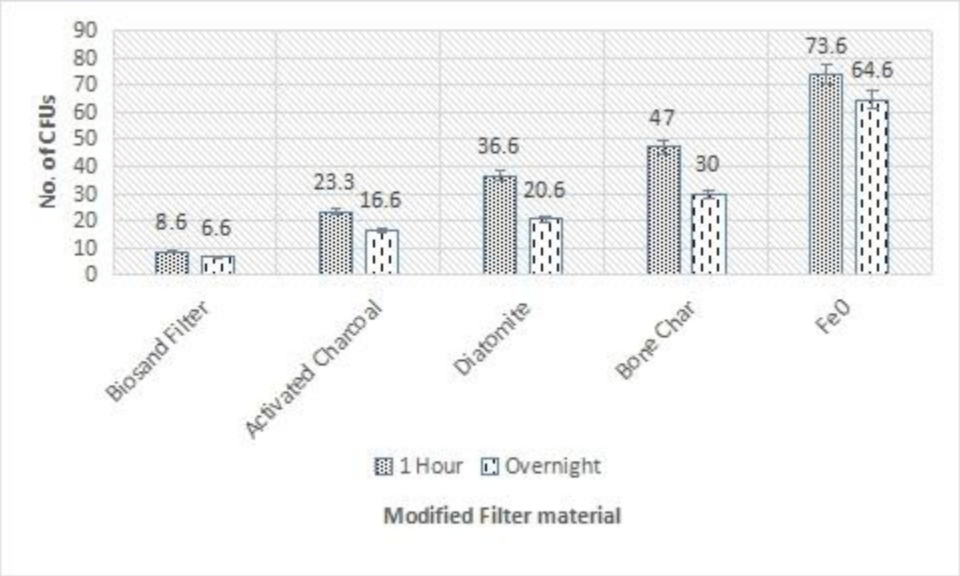

Figure 7: Adsorption of *Escherichia coli* bacteria by the five modified biosand filters

The results of this study indicated that the standard biosand filter removed the highest amount of *E. coli* bacteria with removal rate of 96%. Activated charcoal, diatomite and bone char removed 90,85 and 81% respectively. Steel wool removed the lowest amount of *E. coli* bacteria (70%) in one-hour contact time. It was observed that 24 hours contact time allow more *E. coli* to be removed with bone char removing the highest of 6.8 %.

Comparisons in removal of 248 initial *E. coli* concentration from 5 filters for one hour and 24 hours contact time

Paired t-test was carried out to determine if there was a significant difference in *E. coli* reduction from the five filter for one hour and 24 hours contact time. The results are presented in table 4.

Table 4: Paired Samples Test between one hour and 24 hours *E. coli* contact time

	Paired Differences							
				95% Confidence Interval of the Difference				
Contact time	Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
One hour – 24 hours	1.01333E1	8.78202	2.26751	5.27001	14.99665	4.469	14	.001

Based on the paired t-test results, there was a significant difference in the number of removed *E. coli* in water from Biosand filter, activated charcoal, diatomite, bone char, and steel wool modified filters between one hour and 24 hours contact time (P=0.001, df=14, t=4.469).

Comparisons in removal of 248 initial *E. coli* concentration among the 5 filters for one-hour and 24 hours contact time

One-way analysis of variance was carried out to determine if there was a significant difference in *E. coli* reduction among the five filter for one-hour and 24 hours contact time. The results are presented in table 5.

Table 5: ANOVA among Biosand filter, activated charcoal, diatomite, bone char and steel wool (Fe^0) for one hour and 24 hours *E. coli* contact time

Contact time		Sum of Squares	df	Mean Square	F	Sig.
One Hour	Between Groups	7291.067	4	1822.767	34.349	.000
	Within Groups	530.667	10	53.067		
	Total	7821.733	14			
24 hours	Between Groups	5956.267	4	1489.067	129.860	.000
	Within Groups	114.667	10	11.467		
	Total	6070.933	14			

Based on the one-way analysis of variance results, it was found that there was a significant difference in the number of removed E. *coli* in water among Biosand filter, activated charcoal, diatomite, bone char and steel wool modified filters for one hour and 24 hours contact time (P=0.000, df=4, f=34.349) and (P=0.001, df=4, f=129.860) respectively. Chi-square test of independence was performed to find if there was any relationship between the filtration material and the number of Cfu's obtained. With the calculated chi-square value (137.24) exceeding the tabulated value (5.99), there was a significant relationship between the material used for filtration and cfus obtained.

DISCUSSIONS

According to the results, regular Biosand filters did not adsorb a significant fluoride amount (p>0.05). This may be due to a lack of fluoride ion binding sites in the sand. Raw sand from the Kaliani river in the Kanaighat region of Golaghat district, Assam, India, removed 7% of fluoride from water according to Gogoi *et al.* (2018). Rice (2020) discovered that raw sand did not totally eliminate fluoride using aluminum oxide coated media and a modified filter design.

Poudyal (2015) observed that during the defluoridation studies of the granular activated carbon and experimental data at optimum conditions, the maximum fluoride removal for GAC was 78% for at 5 mg/L fluoride concentration. A considerable amount of fluoride was absorbed by the activated charcoal modified filters (p>0.05). The adjusted filter extracted 97 percent of fluoride after 24 hours and filtered the water to below the WHO fluoride limit of 1.5 ppm, which was slightly better (p0.05) than the regular filter. Fito *et al.* (2019) set out to assess the effectiveness of activated carbon extracted from the *Catha edulis* stem in extracting fluoride from aqueous solutions. The study showed that at the optimum condition of 1.5 g adsorbent in 100 mL contact time of 60 minutes, a cumulative fluoride removal of 73 percent could be achieved. The study also discovered a substantial increase in fluoride removal from 30 minutes to overnight contact time, which could be due to the available active site for during defluorination of groundwater using diatomaceous earth.

Izuagie *et al.* (2016) discovered that the maximum percent fluoride reduction at optimal adsorption conditions (contact time: 30 min, adsorbent dosage: 8 g/L, pH 2, temperature: 298 K, and shaking speed: 200 rpm) for 8 mg/L fluoride spiked water was between 23.4 and 25.6 percent. These findings were lower than those found in this study, which showed that after 24 hours of contact time, up to 93 percent of fluoride was extracted. Yitbarek et al. (2019) used natural and brewery waste diatomite to remove fluoride from drinking water. Using diatomite modified with aluminum hydroxide, Akafu *et al.* (2019) eliminated fluoride from drinking water. From these findings, it is evident that diatomite is able to absorb fluoride in water.

The modified biosand filter's efficiency with bone char was done with 30, 60 and 90-minutes contact time along with overnight. Results showed that the modified bone char filters treated the water to around 1.5 ppm to less than the WHO fluoride limit of 1.5 ppm, 2.26 and 3.0 mg/L of fluoride spiked concentration (WHO, 2017). As fluoride is removed from water using bone char, the fluoride ion is known to exchange with the hydroxyl, carbonate, hydrogen carbonate, and phosphate ions (Kawasaki et al., 2009). Kanyora *et al.* (2015) used regenerated bone char to strip fluoride from drinking water. The highest removal efficiency was found to be 97.63 % in Kanyora's (2014) study, which had an initial fluoride concentration of 100 ppm and a contact time of four hours. Previous research has shown that bone char has a high efficiency of 97.4-99.8%. The highest efficiency of 97.63% had 2.37 ppm fluoride in water. This is an indication that the concentration was above the WHO guideline value of 1.5 mg/L. Therefore, even though bone char has very high efficiency, it cannot be used to remove fluoride from waters with high concentrations up to100 ppm and above for human consumption.

Similar research was conducted on the efficacy of a modified Biosand filter containing steel wool in removing fluoride. The changed steel wool filters reduced the fluoride content in the water to less than the WHO limit of 1.5 mg/L from fluoride spiked concentrations of 1.5, 2.26, and 3.0 mg/L, respectively (WHO, 2017). To exclude fluoride from drinking water, Zhang *et al.* (2017) used a high-capacity iron oxide adsorbent. Since the early 1990s, metallic iron (Fe0) has been commonly used as an adsorbent and reducing agent for the elimination of a wide range of pollutant species from water.

The ability of Fe0-based filters to remove/inactivate various biological and chemical contaminants from water has been demonstrated. Individual filter efficiency was affected by the type of the metallic filters with some having a reactivity that gets considered as intrinsic, another of its characteristic was the size of the materials which will determine the rate of water flow through it, thirdly the design of the filter was an important factor which gets characterized by the dimensions of the filter used in making. Also, the ratio when making the contents for defluoridant, the availability of those chemicals in water which have the ability of countering the work f the metallic filter and finally the flow of water if high or lower. To conclude we can say that metallic based filters have a lot of factors which determines its effectiveness hence it is important to choose those designs that are well built and can operate in any condition optimally.

When using the metallic type filters, it is important to remove all suspended solids failure of which it will affect the normal operationality of the system.an example is coarse and fine sand can get filtered first. On the other hand, for a longer use of metallic filters, corrosive products should get avoided by all means especially in instances where the metallic filters are working in conditions that get considered as anoxic. For a metallic filter to get considered as operable one, it should ensure that all oxygen that it comes across should be gotten rid of failure of which will present good conditions for the formation of biofilms making the filter ineffective.

As shown in the results the process of defluorination in controlled experiments were conducted using four different materials with comparison being done based on each and every materials ability to remove fluoride from drinking water. The mean of absorbed 1.5, 2.26, and 3 mg/L initial fluoride concentrations recorded in overnight, 30, 60, and 90-minute contact times were all (p 0.05) significantly different among the five filters tested Biosand filter, activated charcoal, diatomite, bone char, and steel wool, according to one-way analysis of variance (Fe0).

The activated charcoal and bone char updated BSF designs were found to have a higher capacity to extract fluoride than the other three adsorbents in the sample. The findings are consistent with those of Naliaka (2016), who found that bone char decreased fluoride concentration from 8.1 mg/L to below the WHO limit of 1.5 mg/L in 120 minutes (2 hours). In late 1998, bone char defluorination was first studied in Kenya in a laboratory in batches and columns (Korir *et al.*, 2009). The Catholic Diocese of Nakuru Water Quality established and markets four separate types of defluorination filters, ranging from household filters to institutional, community, and waterworks filters.

E. coli **removal efficacy for the five filter**

The results of this study indicated that the standard biosand filter removed the highest amount of *E. coli* bacteria with removal rate of 96%. activated charcoal, diatomite and bone char removed 90,85 and 81% respectively. Steel wool removed the lowest amount of *E. coli* bacteria (70%) in one-hour contact time. Overflowing septic tanks, storm water runoff, animal carcasses, and runoff from animal manure and manure storage areas are all places where bacteria can be found. Mwabi *et al.* (2012) discovered that the (biosand filter-standard (BSF-S); biosand filter-zeolite (BSF-Z); bucket filter (BF); ceramic candle filter (CCF) were found to eliminate up to 99 percent of *E. coli* bacteria in a sustainable solution for improving water quality. Collin (2009) discovered that the dual sand layer biosand filter reduced *E. coli* by at least 85% and total coliforms by 95% in field tests, which was comparable to unmodified control filters. After filter maturation, laboratory tests revealed minimum average reductions of 93% turbidity, 97% *E. coli*, and 71% total coliform, which were equivalent to the results of unmodified control filters.

CONCLUSION

For this study, modified biosand filters were designed using charcoal, bone char, diatomite, and Fe0 different filters and testing for ability to remove fluoride in drinking water which poses as a threat to human life. According to the findings, the normal Biosand filter was not an effective choice because of its failure to adsorb amounts of fluoride by a significant amount of ($p>0.05$). It was discovered that the interaction period had not been significantly reduced. Fluoride was absorbed significantly by the activated charcoal, bone char, diatomite, and Fe0 Biosand modified filters ($p>0.05$). It was also discovered that the contact time was substantially reduced ($p>0.05$). The modified filter removed 97 % of fluoride after 24 hours and treated the water to below the WHO fluoride limit of 1.5 mg/L, which was slightly better ($p<0.05$) than the regular filter.

RECOMMENDATIONS

Over the past years there has been sufficient evidence that shows that a large Kenya population is suffering from fluorosis which is posing as a threat to human population. Something needs s to get done because it will set a precedence for disaster in the future. Hence in order to arrest and mitigate more effects of contaminated water, there should be an introduction, of BSF techniques that are of an affordable amount to people especially in the rural areas where the problem is rampant. The Government of Kenya in collaboration with the ministry of water should take an initiative of educating the masses on the importance of cleansing water for drinking and cooking by educating them on homemade alternatives.

There is the need of doing further extensive research which would help the government understand why with all the effort there was no improvement. Firsts they need to look into the acceptability of the cleansing techniques and how the community especially those in rural areas viewed it. In addition, the government should ensure that the methods used for water purification should be affordable because most people in the rural areas had no source of funds hence providing them with solutions that require high monetary investment would not be sufficient.

Also, research should be done to determine the life span of different BSF designs so that it they could get evaluated for beingconducive or non-conducive for the country at large. In addition, there should be a continuous evaluation of modified designs so that the country could keep up with an up-to-date design that were efficient to its users.

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