CDN'S DEFLUORIDATION EXPERIENCES ON A HOUSEHOLD SCALE

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The following summary is based on the defluoridation experiences of the Catholic Diocese of Nakuru, Water Quality (CDN WQ).
This document has been prepared jointly by CDN WQ and the Swiss Federal Institute of Aquatic Science (Eawag) and aims at giving a summary of the current development stage. Further research and development of the described techniques and processes are still ongoing.

1 Introduction

The household filters are designed to supply a household (5-12 persons) with water containing low fluoride concentrations for drinking and cooking purposes. A recently developed filter design removes not only fluoride but also bacteria.
Since the beginning of the defluoridation project at CDN WQ in 1998, almost 900 household units have been sold (see Figure 1-1).

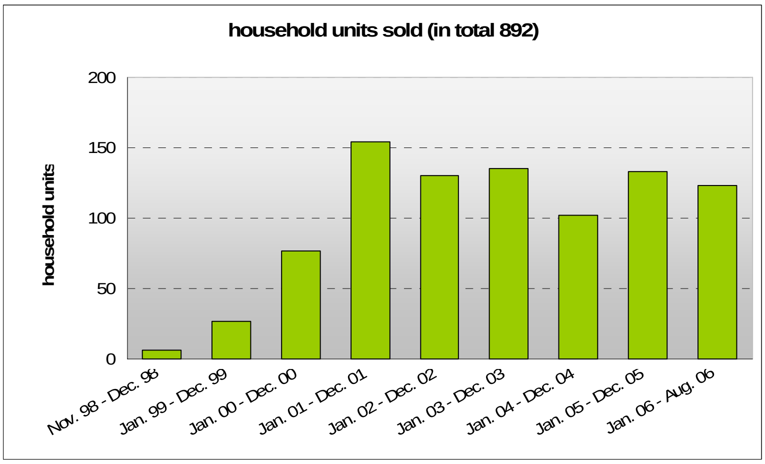


Figure 1-1: Number of household units sold during the last 8 years.

Selling of these household units has been carried out through different channels, grouped according to the type of customer:

- Private customers buy the units directly at CDN WQ. Information on the operation and maintenance of the filter is passed on by CDN WQ’s staff.
- Agents buy the filter units from CDN WQ and resell them to other customers.
- Institutions buy the units from CDN WQ and distribute/sell them to their staff.

Figure 1-2 shows the number of household units sold by CDN WQ to these different types of customers. Most of the household units were sold to institutions, followed by private customers and agents.

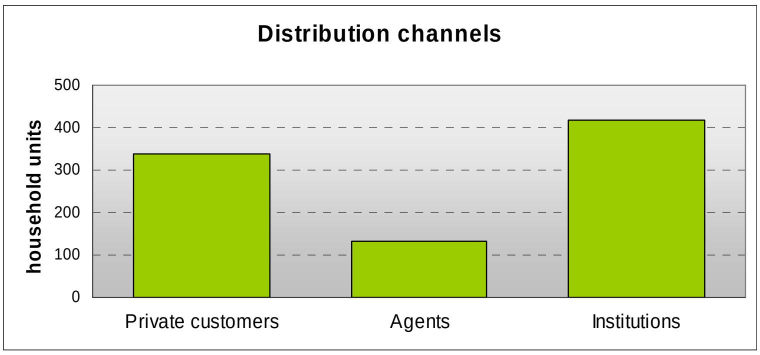


Figure 1-2: Number of household filters sold to the different customers.

2 Different household filter designs and their operation

CDN WQ has developed and sold different types of household units in the past. Currently two different household filter designs are availabe: A simple defluoridation bucket filled with bone char and a combined filter system that removes microbiological contamination, heavy metals and fluoride.

2.1 Defluoridation bucket

A 20 L bucket is filled with 12 L of bone char (~ 8.4 kg). Previously a bigger household unit containing 24 L of bone char was available, but due to supply problems of these buckets they are no longer sold.
A tap is fixed at the bottom of the bucket after adding a drainage pipe, wrapped with a nylon cloth to avoid leakage of the filter material. Then bone char is filled in. A perforated concrete plate is placed on the surface of the bone char to prevent disturbance of the filter medium during addition of raw water (see Figure 2-1).
The customer can choose between two different taps: The peglar tap is more robust but more expensive (KES 650; 9.1 USD) comparing to the China tap (150 KES, 2.1 USD).
The whole defluoridation unit costs either 1200 (17 USD) or 1650 KES (23 USD), depending on the tap. Running costs for replacement of the filter medium and fluoride analysis amount to approximately 130 KES (1.8 USD) per 1000 L of treated water.
In total, around 10 L of raw water can be placed in the bucket. The lower part of the bucket containing bone char takes up ~3 L, the part above the filter medium another 7 L of water.

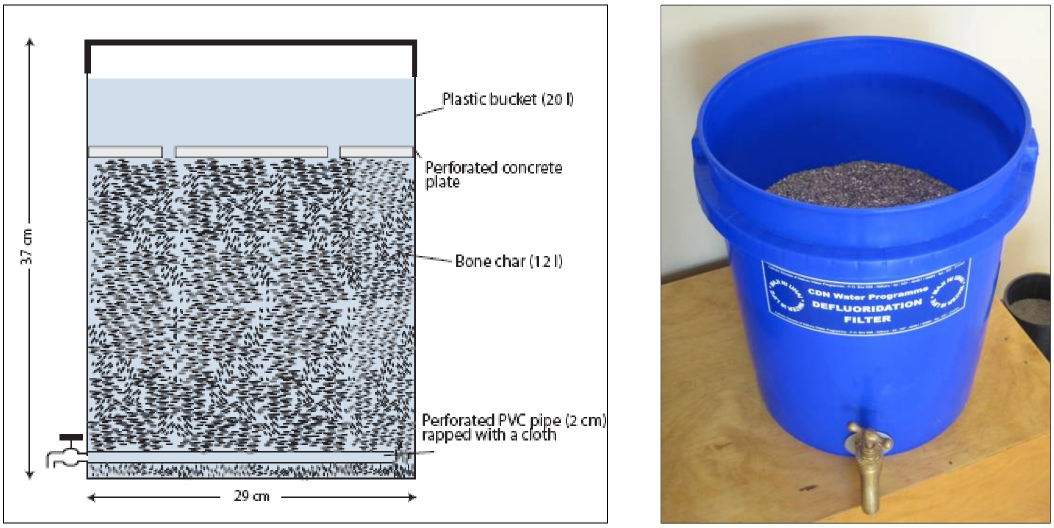


Figure 2-1: Sketch and picture of a 20 L defluoridation bucket.

Operation and maintenance

The customers are instructed to use the defluoridation unit as follows:

- Before the purchase of a filter, the fluoride concentration of the raw water is measured to check the necessity of treatment. Fluoride testing at CDN WQ costs 100 KES (1.4

USD). Estimations of the lifespan of the filter can be made based on the fluoride concentration of the raw water, the water consumption and the adsorption capacity of the bone char (~ 2 mg F/g bone char according to Albertus et al (2000)).
- The first few batches of treated water need to be discarded due to elevated turbidity and color in the treated water, deriving from the bone char.
- The water level in the bucket should never drop below the level of the bone char to avoid the filter medium from drying up. If the bone char is left dry, the adsorption capacity of the medium will decrease due to inhomogeneous loading of the filter.
- 20 min of contact time is necessary to guarantee efficient fluoride removal.
- The water is drained through a perforated PVC tap at the bottom of the bucket.
- After ~ 6 months (depending on the above mentioned estimation) a water sample needs to be sent/brought to CDN WQ for fluoride analysis. If the fluoride concentration exceeds 1.5 mg/L the saturated filter medium has to be replaced at CDN WQ. The saturated bone char is regenerated at the working site of CDN WQ (see “Draft of CDN’s experiences in producing bone char”).

Studies on the fluoride-removal efficiency of defluoridation buckets of CDN WQ, carried out by Egerton University, Kenya and published by Mavura and Bailey (2002) proved very high removal efficiency ranging between 97.4% and 99.8% (in general >99%).
According to CDN WQ’s laboratory research, ~ 200 bedvolumes of water containing 6 mg F/l can be treated before the national Kenyan standard of 1.5 mg F/L is exceeded.

Table 2-1: Main advantages/disadvantages of defluoridation buckets

Advantages	Disadvantages/Constraints
• Low-cost design • Simple design, hence little problems with maintenance	• If not used adequately, the filter medium may dry up and hence shorten the lifetime of the filter • Only limited amount of treated water can be released at once • Adsorption capacity of the bone char is not fully utilized

2.2 Combined filter

At the beginning of 2005, the first combined filters were field tested. The combined filter is a recent development, arising from the need to remove fluoride and microbiological contaminants from the water. The combined filter consists of 2 filter processes within the same system. The upper bucket for raw water storage is transparent hence the water level is visible without opening the lid. The raw water passes through a ceramic candle filter containing silver nitrate and activated carbon. Two different processes lead to a removal of microorganisms: Filtration through the ceramic candle and toxic silver nitrate that kills microorganisms that passed through the filter. Additionally activated carbon adsorbs chemical impurities, such as dissolved organic material or/and heavy metals. The ceramic filter is imported from Brazil as this filter candle is more effective than locally manufactured ones. Then the water first flows top-down through a PVC pipe filled with bone char then bottom-up through an inner bucket also containing bone char (6 L). The treated water spills over to the 20 L water bucket where it is stored and ready for withdrawal.

Apart from removing bacteria, organic impurities and heavy metals from the water, the first filtration step with the candle filter also controls the flow rate to the defluoridation part of the system. Studies showed that the flow rate strongly depends on the turbidity of the raw water (the higher the turbidity, the stronger the clogging) and the raw water level (decreasing flow rate with decreasing amount of water). Tests with 10 L of raw water filled to the bucket containing the candle filter showed that the flow rate is constant for the first few liters of water passed through the ceramic filter. At the beginning the flow rates of raw water with 1 NTU were more than twice as big as for raw water with 5 NTU (25 mL/min and 10 mL/min, respectively). After 4 hours, 5.5 L and 2.4 L of treated water can be withdrawn for raw water with 1 NTU and 5 NTU, respectively (see Appendix). The contact time in the defluoridation filter at the beginning of the filtration process amounts to ~30 min for the raw water with 1 NTU and increases with time and turbidity of the raw water. Further experiments are ongoing to determine the maximum turbidity that still allows the use of the combined filter system.

The special design of the defluoridation part of the unit leads to an increased filter distance and therefore optimizes the removal ability of bone char.

The combined filter costs 3200 KES (45 USD).

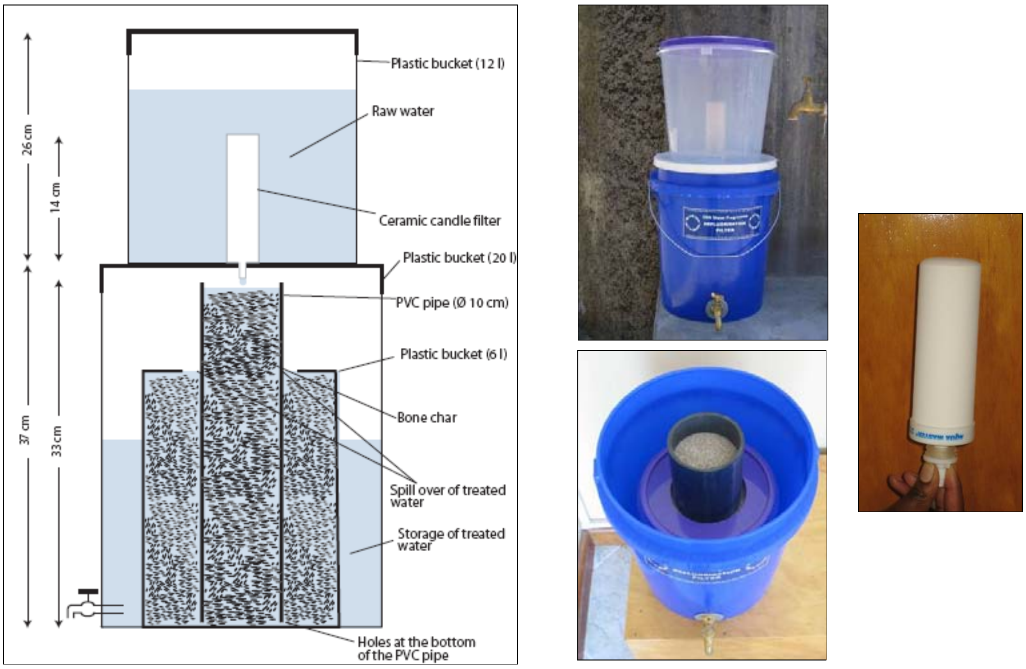


Figure 2-2: Sketch and picture of a combined filter and the ceramic candle.

Operation and maintenance

- Before the purchase of the combined filter, the fluoride concentration of the raw water is measured to check the necessity of treatment. Estimations of the lifespan of the filter are made based on the fluoride concentration of the raw water, the water consumption and the adsorption capacity of the bone char. The users are advised to bring a sample for fluoride and bacteriological analysis after 6 to 12 months, depending on the above mentioned estimate. This combined testing costs 500 KES (7 USD) for treated water and between 400 KES (5.6 USD) and 1000 KES (14 USD) for raw water, depending on its contamination. In general, analyzing surface water is more expensive than groundwater since 3 bacteriological tests with different dilutions have to be run in parallel.

- After the purchase of the filter, the first few batches of treated water have to be discarded, due to elevated turbidity and color in the treated water. The treated water should then be clear and without any taste.
- The upper bucket is filled with raw water. The users can withdraw treated water anytime as the contact time in the bone char filter is regulated by the flow deriving from the candle filter.
- The surface of the ceramic candle filter needs to be washed regularly, whenever the flow rate decreases. Washing should be carried out with clean water and a soft cloth.
- If the fluoride concentration exceeds 1.5 mg/L the saturated filter medium has to be brought to CDN WQ for replacement. The saturated bone char is regenerated at the working site of CDN WQ (see "Draft of CDN's experiences in producing bone char"). New candle filters can also be bought at CDN WQ.

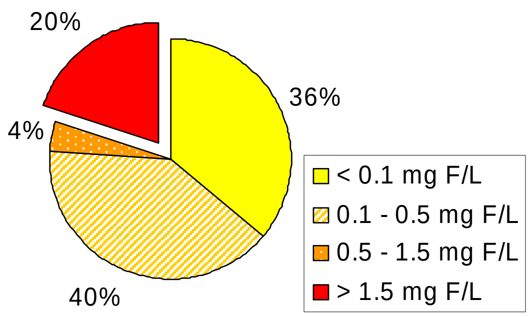
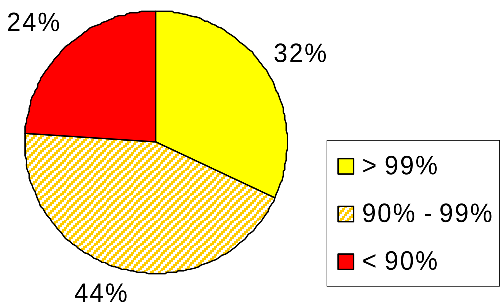
Table 2-2: Main advantages/disadvantages of combined filters

Advantages	Disadvantages/Constraints
• The user does not have to be concerned about the required contact time as the candle filter regulates the flow through the bone char filter • Apart from removing fluoride, microorganisms and heavy metals are also removed in this filter system. Hence the treated water is ready for human consumption (no additional treatment is required) • Optimal utilization of the adsorption capacity of the bone char due to the column design • Filter medium never dries up due to the bottom-up flow in the inner bucket containing bone char • Replacement of the bone char is facilitated. Transport is easier because only the inner bucket with the PVC column has to be carried to CDN WQ. Replacement at CDN WQ is faster as bucket and PVC column can be exchanged for new one containing fresh bone char	• More expensive than a simple defluoridation bucket • Maintenance of the candle filter requires regular washing • Ceramic candles may brake if not handled carefully • Testing of the water quality has to be carried out for both, bacteriological and fluoride contamination • Raw water with elevated turbidity can not be treated with this filter design due to clogging of the candle filter. • If no treated water is withdrawn, but raw water is added, the water may overflow from the defluoridation bucket.

3 Monitoring of household units

In October 2006, 34 household filters of CDN WQ were monitored to obtain an impression of their use and problems related to their operation, lifespan, efficiency and to receive a general feedback on the practicability of defluoridation treatment on a household scale. The desired information was gathered by questioning the users on the one hand, and by analyzing the fluoride content of the raw and treated water on the other. The interviewed users were located in and around Nakuru and Naivasha. Table 3-1 gives a summary of the fluoride analysis and the related removal efficiency of the defluoridation units (related figure see Appendix).

Table 3-1: Summary of fluoride analysis and calculated efficiency of household units.

F in raw water	• Total monitoring (39 samples) - Average: 5.9 mg F/L, ranging from 0.5 to 11.3 mg F/L • Monitoring in Naivasha (19 samples) - Average: 8.1 mg F/L, ranging from 4.7 to 11.3 mg F/L • Monitoring in Nakuru (11 samples) - Average: 2.5 mg F/L, ranging from 0.5 to 4.7 mg F/L
F in treated water	• Average: 0.7 mg F/L, ranging from 0.06 to 6 mg F/L • In 36 % (9) of the household units the fluoride concentrations in the treated water was < 0.1 mg/L. • In 80% (20) of the household units the fluoride concentrations in the treated water was <1.5 mg/L. 
Removal efficiency	• Average: 90%, ranging from 32% to 99% • 76% (19) of the household units had a removal efficiency >90% • 32% (8) of the household units had a removal efficiency >99% 

Main findings based on the outcome of the monitoring

- The removal efficiency of 75% of the defluoridation units is higher than 90%, hence bone char is an efficient filter medium to remove fluoride.
- The filter medium becomes saturated and has to be replaced after a certain time of use. As fluoride is invisible, tasteless and odorless, regular sampling and analyzing either in a lab or on-site is necessary to ensure desired fluoride removal.
- Regular monitoring of the defluoridation units, carried out by the organisation that sells the household units is desired. Such monitoring helps in:
  - supporting the customers in defluoridating their water (answering questions, measuring the fluoride concentration, replacing the bone char if necessary, informing on new developments etc.)
  - creating awareness (on-site fluoride analysis involves the users, allows to discuss the results with them and shows them the importance of defluoridating the water)
  - providing valuable information for the manufacturers concerning application and success of their household units and defluoridation activities in general.
- The main two reasons why 26 % of the household units were not used at the time of the monitoring are:
  - leackage or blockage of the tap (reason for 55% of the filters that were not in use). All the filters that faced problems with the tap had china taps. Hence the type of tap is one of the important elements that influence the sustainability of the treatment. Shortly after developing defluoridation buckets with china taps, CDN WQ also introduced filters with high quality taps (peglar taps) and hence reduced the above mentioned problems.
  - problems related to the taste of water (22%). Especially the first few batches of treated water often have elevated turbidity, color and odor. It's important that best water quality can be ensured from the very beginning of the treatment. Although the filters are washed at CDN WQ, the first few liters of treated water still are turbid due to the transportation. CDN WQ therefore advises to flush the filter at least for 3 times before consuming the treated water.
- A short description on how to use the defluoridation unit (manual attached to the defluoridation unit or a simple sticker) could solve the problems related to:
  - the contact time (20 min): Almost half the users didn't keep the required contact time to ensure fluoride adsorption. They filled the bucket and withdrew the water instantaneously.
  - drying up of the filter bed: In 32% of the household units, the total amount of water stored in the bucket was withdrawn. To ensure adequate fluoride removal and to enhance the lifespan of the filter, its filter medium should never dry up.
- Most of the users requested enhanced awareness creation and promotion. Awareness creation on fluoride health effects and promotion of defluoridation treatment are very important activities in combating fluorosis that have to go hand in hand with technical development. CDN WQ currently employes 3 people working on such activities (related report "CDN's activities on awareness creation, promotion and training" is in progress).
- 77% of the users had additional water treatment besides defluoridation (most of the users boiled their water before drinking). Most of the users were therefore interested in replacing the simple defluoridation bucket with the combined filter.

4 References

Albertus J., Bregnhøj H. and Kongpun M. (2000) Bone char quality and defluoridation capacity in contact precipitation. *3rd International workshop on fluorosis prevention and defluoridation of water*. Chiang Mai, Thailand, 57-68.

Mavura, W.J. and Bailey T. (2002) Fluoride contamination in drinking water in the Rift Valley, Kenya and evaluation of a locally manufactured defluoridation filter. *Journal of Civil Engineering*, JKUAT 8, 79-88.

5 Appendix

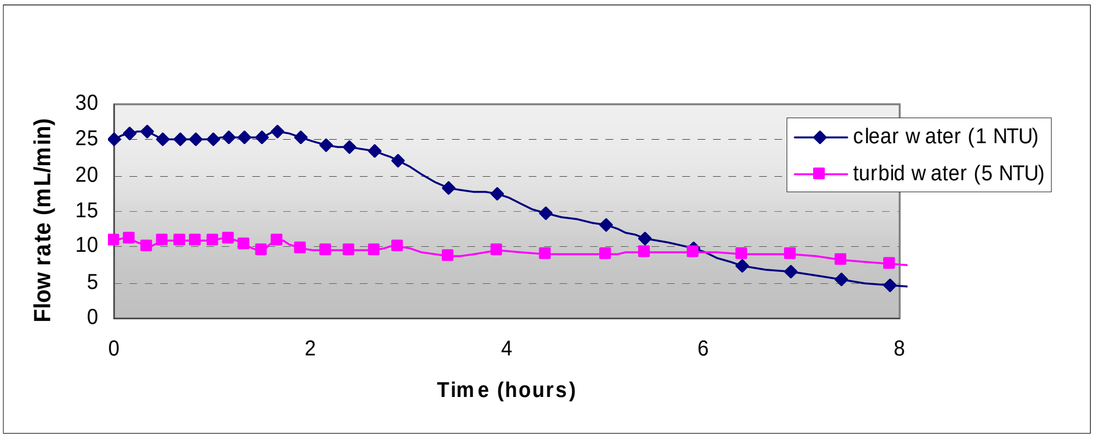


Figure 5-1: Experiment on the flow rate of the ceramic filter for water with 2 different turbidities (1 and 5 NTU). The bucket is filled with 10 L of raw water and the flow rate is measured regularly. Due to the decreasing water pressure the flow rate through the ceramic candle filter decreases. As illustrated by the two graphs, the flow rate also depends on the turbidity of the raw water.

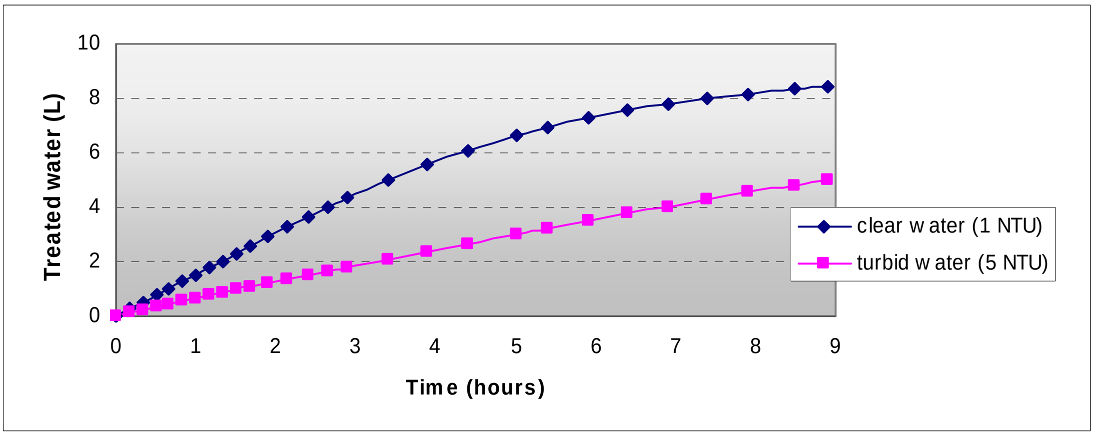


Figure 5-2: Experiment on the flow rate of the ceramic filter for water with 2 different turbidities (1 and 5 NTU). The bucket is filled with 10 L of raw water and the amount of treated water measured regularly. After 4 hours 5.6 L of water is filtered for raw water with 1 NTU and 2.4 L of water for raw water with 5 NTU.

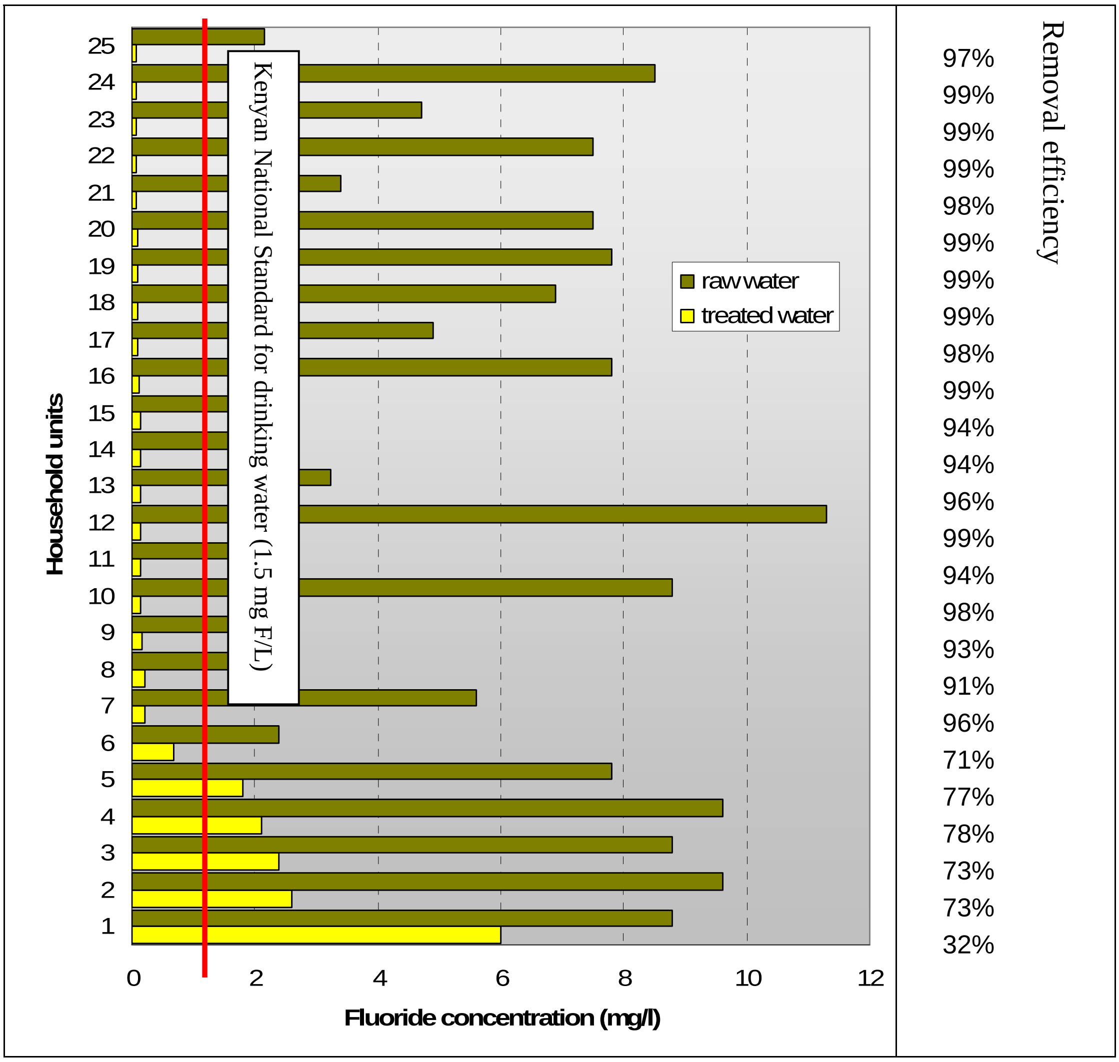


Figure 5-3: Fluoride concentration in the raw and treated water and calculated efficiency of the household units.