Low-Cost Water Treatment Technologies for the Rural Sector

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ABSTRACT

With the advent of the water decade in 1981–1990 several water projects funded by agencies such as FINNIDA,[2] DANIDA,[3] and GTZ[4] were involved in improving water supply in the Central, North Central, Northwestern provinces in Sri Lanka. The majority of the population (nearly 90%) in all these provinces lives in rural areas. Some of the hand pump wells (nearly 10% installed) had an iron content of more than 1.0 mg/l, which made the consumer reluctant to utilize these for drinking purposes. This content has been reduced to the required level of 0.3 mg/l of iron using granite and sieved sand as filter media in low-cost iron-removal plants. This is an appropriate and affordable technology for the rural sector.

Nearly 50 percent of the wells including traditional wells in dry zone areas have fluoride-rich water in excess of 1.0 mg/l. The low cost, domestic fluoride removal filter has been developed to reduce the fluoride content to the required levels. The main features of this defluoridator are simplicity of design, easy operation, maintenance-free operation, and the availability of the filter medium in the locality. Presently, 1,200 such defluoridators are in operation in 60 villages in the North Central Province. The beneficiaries have already used the first batch of 400 defluoridators for 3 years and are continuing to use them.

INTRODUCTION

Nearly 80 percent of the population in Sri Lanka belongs to the rural sector. In most instances, groundwater is utilized as the drinking water source in the form of ordinary shallow wells, deep wells, and tube wells. Most of the groundwater sources have high mineral contents such as iron and fluoride due to the hydrogeological features and these need rectification. A considerable number of consumers belong to the low-income or less-privileged groups, with a poor educational background. Because of these social factors, an appropriate village-level treatment mechanism is necessary.

IRON AND MANGANESE REMOVAL

The prime objective of the National Water Supply & Drainage Board is to supply safe drinking water to all the people in Sri Lanka. This task is more difficult, especially when considering the rural community, which is scattered in a large area. It is also necessary to introduce

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[1] National Water Supply and Drainage Board, Sri Lanka.
[2] Finnish International Development Agency.
[3] Danish International Development Agency.
[4] Deutsche Gesellschaft für Technische Zusammenarbeit.

low-cost technologies as most of the beneficiaries belong to the low-income groups. However, it is important to adhere to the standards of quality of the drinking water. An important strategy followed in the rural water sector was the involvement of beneficiaries in the construction, operation, and maintenance of water supply activities. In this paper, it is proposed to discuss a few parameters that caused quality problems, such as color, turbidity, and the contents of iron, manganese, and fluoride and the results achieved by using low-cost technologies.

In the rural areas of the Kandy District about 2,500 hand-pump wells were installed to provide safe drinking water. Of these wells 10 percent (250) had iron-rich water and 1 percent (25) had a high manganese content, which made the consumers reluctant to utilize them for drinking purpose and led them back to using their traditional, polluted, but low-iron content water sources. The technology of the existing iron-removal plant was improved to facilitate easy maintenance and operation, thus achieving sustainability. In the beginning, there were two types of filter units in operation, namely UNICEF fiberglass and FINNIDA prefabricated circular types. Although both these types were used for the removal of iron and manganese and were found to be comparatively effective, certain limitations were observed in these types of filters. In the UNICEF rectangular fiberglass unit, the main limitations were the cost of the unit, about US$125 (Rs 5,000)[5] and its maintenance. Since there are four chambers to clean, it has become a cumbersome job at the village level. The limitations encountered in the FINNIDA circular type were the difficulty of manual transportation of the precast filter unit to remote locations and the handling of the cover slab during maintenance. Other disadvantages were the high costs of production (US$60), and the necessity for having a precasting yard for production.

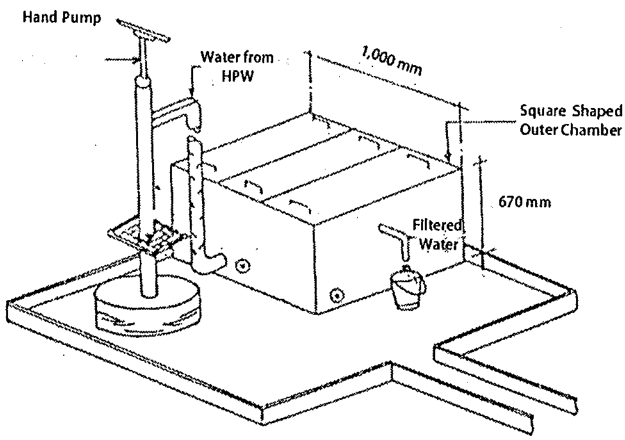
The main design consideration in this development had been community adaptability in the cleaning process with special features such as simplicity in construction in-situ, easy operation, and maintenance. The utilization of local raw materials and skills at village level was also optimized. The filter media used for these FINNIDA square type filter units (figure 1) were granite (0–30 mm) and sieved sand (0.5–0.8). The iron compounds usually found dissolved in the groundwater area in the form of ferrous bicarbonate are stable only in the absence of oxygen. The iron gets oxidized to higher states due to the aeration taking place in the filter systems thus producing insoluble oxyhydroxides. These are easily removed by filtration through sand. Aeration also reduces the dissolved carbon dioxide, thereby increasing the pH value.

The results of iron removal efficiency monitored over the first 5 years show that the efficiency of the unit increases with the increase of the iron content of the inlet loading. The variations of the high iron content in these wells were in the range 1.2–4.5 mg/l of Fe. The efficiency of iron removal in all the wells was above 88 percent as shown in figure 2. Most of these units have been in operation for more than 8 years. In the two filters it was found that the consumers had changed the filter medium from sand to granite chips of the size 2–3 mm, as they were freely available in the vicinity.

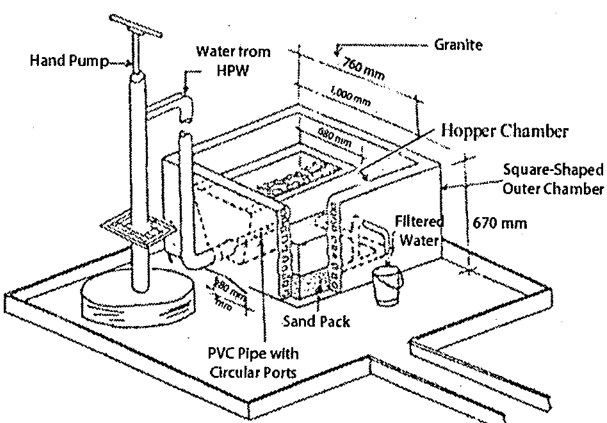
[5] In December 1999, US$1.00=Rs 71.

Excess of manganese was removed by using similar filter units but using laterite as the filter medium in the first chamber instead of granite. The manganese removal was found to be satisfactory but not uniform as in the case of iron removal.

Figure 1. Iron/Manganese reduction plant-FINNIDA square type.

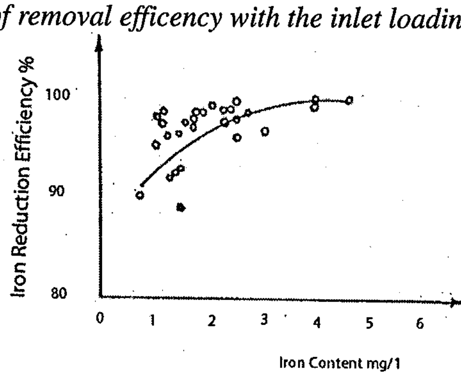


Iron/Manganese Reduction Plant
FINNIDA Square Type



FINNIDA Square-Type Filter
Construction Cost = Rs 1,600 (US$40)

Figure 2. Variation of removal efficency with the inlet loading.



FLUORIDE REMOVAL

Dental and skeletal fluorosis is an endemic problem in certain parts of the world such as China, India, Ethiopia, and Tanzania. Several methods have been practiced to defluoridate water but in developing countries, the application of these techniques has certain drawbacks at the time of implementation. The most common drawback is the difficulty in finding the filter medium. In contrast, the filter medium used in suggested defluoridators is freshly burnt bricks, which are freely available in the affected localities. In addition, the low cost involved in replacing the filter medium, easy operation at domestic level, negligible maintenance cost, and the absence of environmental hazards in releasing the used filter medium are the other important features.

Table 1 shows the villages selected for the survey of fluoride content in wells during 1994–1998. Table 2 shows the fluoride contents of wells in Anuradhapura, Polonnaruwa, and Monaragala districts. The data show that in these areas more than 67 percent of the wells have fluoride-rich water. The limit of the fluoride content of water considered as safe for Sri Lanka is 1.0 mg/l. In the Thambuttegama area of the Anuradhapura district, out of 424 wells tested 17 wells had a fluoride content of more than 4.0 mg/l.

Table 1. Villages surveyed.

District	Villages
Anuradhapura	Olukarada, Negampaha, Thalkolawela, Karawilagala, and Thambuttegama
Polonnaruwa	Lankapura, Patunagama, Hingurakdhamana, Chandranapokuna, and Kaudulla
Monaragala	Hambogamuwa, Athiliwewa, Hadapanagala, Kahakurullan pelessa, Bodagama, and Nikawewa

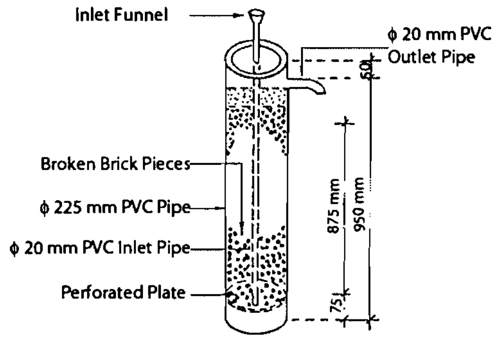
Table 2. Fluoride content of wells in mg/l.

District	Fluorides content in mg/l				Number of wells
	10-4	4-2	2-1	<1	
Anuradhapura	17	111	172	124	424
Polonnaruwa	-	128	121	145	394
Monaragala	-	48	44	44	136
Total	17	287	337	313	954
Percentages	1.8	30.0	35.3	32.9	-

The newly designed household defluoridator is 100 cm in height, 20 cm in diameter, and is fabricated using PVC pipes. The diameter of the inner pipe is 2 cm with a circular perforated plate fixed at 5 cm from the base of the filter. The outlet is fixed 5 cm below the top of the filter (figure 3). The filter unit is packed with broken pieces of freshly burnt bricks of sizes

8–16 mm up to a height of 75 cm. The fluoride-rich water is fed through the inlet pipe. At the beginning, the filter is filled with fluoride-rich water and kept for at least 12 hours to obtain an equilibrium.

Figure 3. Low-cost defluoridator.



Thereafter, when fresh fluoride-rich water is fed through the inlet an equal volume of defluoridated water pours out automatically through the outlet pipe. The efficiency of the said defluoridator was further tested by analyzing the fluoride-rich water that was fed and the defluoridated water that was collected from the outlet pipe at various time intervals.

The filter medium used for the removal of fluoride constituted brick clay pieces burnt at low temperatures. The burnt brick (clay) has silicates, aluminates, and hematite. When this is soaked in water for several hours, these oxides get converted to oxyhydroxides of iron, aluminium, and silica. The Si–O and Al–O bonds are much stronger than the Fe–O bonds (Cotton and Wilkinson 1998). The geochemistry of the fluoride ion (ionic radius 1.36 A) is similar to that of the hydroxyl ion (ionic radius 1.40 A) and these can be easily exchanged between them (figure 4). The other possible formation is

$$Al^{3+} + 6F\ Alf^{3-}_{6}$$

The bricks were analyzed in Finland using the particle-induced X-ray emission (PIXE) method. The composition of the bricks plays an important role in this ion exchange reaction (table 3). It has to be iron-rich bricks in order to facilitate the ion exchange reaction. The Sri Lankan bricks are richer in iron content than the Finnish bricks. Similar trials carried out in Finland did not show the removal of fluoride in water; instead they showed that addition has taken place. The beneficiaries were advised to use reddish colored bricks, which have a high-iron content, to get a better fluoride removal. In addition, the aluminum content of Sri Lankan bricks is more than that in Finnish bricks. The silicon content of bricks in Polonnaruwa is much higher than that of bricks in Anuradhapura.

Figure 4. Mechanism of exchange of fluoride ions.

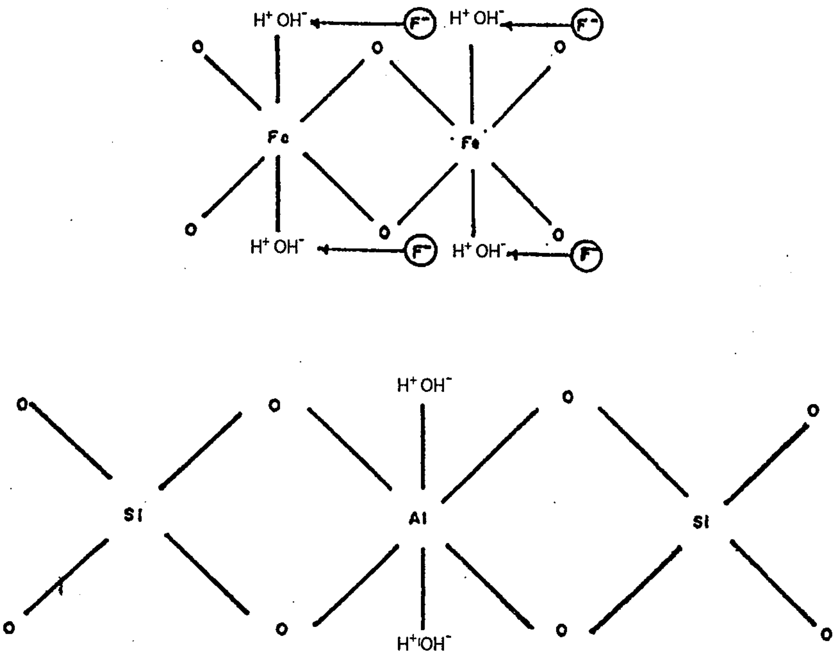


Table 3. Composition of bricks (in %).

Locations	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Others
Finland	58.10	15.60	6.75	0.85	1.80	3.40	13.5
A/Ketakale	49.88	26.44	10.00	0.62	1.37	4.77	6.95
A/Galnewa	59.38	26.08	7.90	0.51	1.58	4.55	-
A/Kithulhitiyawa	47.27	36.64	9.33	0.84	1.81	4.06	0.05
P/Medirigiriya	65.97	15.10	8.29	0.92	1.39	4.15	4.18
P/Minneriya 1	60.20	23.95	9.19	1.02	1.13	4.50	0.01
P/Minneriya 2	64.48	20.59	9.83	0.88	1.15	3.84	-

PERFORMANCE OF THE DEFLUORIDATORS AT VILLAGE LEVEL

These defluoridators were distributed among the beneficiaries in stages to ascertain both the acceptability at village level and the capability or otherwise of maintaining the filter. The following criteria were adopted in selecting the suitable beneficiaries for the defluoridation program.

- The age of the first child is more than 8 years (flurorosis visible)
- The age of the second child is 2 to 5 years
- The age of the third child is less than 2 years (or expecting mother)
- Content of well water 1–5mg/l of fluoride

Since April 1994, 1,200 such defluoridators have been in operation in 50 villages in the North Central Provinces. Once the villages were selected the defuoridators were distributed irrespective of their family income and level of education. The assistance of the field health officer of the village concerned was sought in this regard. Presently, community-based organizations and nongovernment organizations are involved in the selection criteria. This was helpful because of the long duration of the monitoring required, nearly 5 years to see the results of this program. Several case studies are discussed below to show the acceptability and the operation and maintenance capabilities of these units by the community.

Table 4 shows several defluoridators run by beneficiaries at Olukaranda. All the units except nos. 14 and 41 had changed their filter medium on time showing that villagers could manage these units on their own. Column 4 of this table gives the fluoride content of the defluoridated water at the time of changing the filter medium. In units nos. 14 and 41 it was observed that the fluoride contents at the time of changing were high. The well water used in unit no. 41 had a minimum fluoride content of 3.02 mg/l during this study period. Similarly, defluoridator no. 14 had a minimum defluoride content 0.76 mg/l and a maximum of 2.46 mg/l. It shows that the filter medium has to be changed at the appropriate time depending on both the fluoride content and the consumption. Column 5 gives the fluoride removal efficiency of these units. The advantage of these units is that fluoride removal varies from 80 to 30 percent. In other words, it does not completely remove fluoride from the fluoride-rich water. It is a known fact that a certain amount fluoride, about 0.5–to 0.8 mg/l, is required for the human body. Defluoridator no. 9 had run for 326 days, because this particular well had a minimum fluoride content of 0.2 mg/l and a maximum of 1.42 mg/l during the study period.

Table 5 shows the details of the defluoridators introduced at different dates in four villages in the Polonnaruwa district. The duration of operation varies from 8 months in the recently introduced ones to 3 years in the initial lot. The villages, which had the longest duration of operation of defluoridators, have been visited at least four times per year showing the need of regular visits in achieving sustainability. In the first village, these units were distributed with the involvement of the chief incumbent of the Buddhist temple while in the other three villages women leadership took an active part. Thereafter, the same leadership continued in guiding the maintenance and operation. The expenditure of maintenance was only for the replacement of bricks every 3 months, which cost less than US$1.00 (Rs 60).

Table 6 shows the current status of the units in the four villages. The outlet pipes in some of these units were broken due to bad handling. This was found to be the only repair in these units. The seventh column shows the number withdrawn after beneficiaries showed a lack of interest within a few months of operation. In some instances, the beneficiaries cleaned the filter to change the bricks but they were not conscious enough to restart immediately due to other involvements. This is mainly due to bad planning, as they do not make the bricks ready prior to cleaning. Column 5 shows the number of such units. The relatively high success rates of villages 2 and 3 are mainly due to the active role played by the women leaders of these villages.

Table 4. Fluoride removal of the defluoridators (in %).

I	II	III	IV	V	VI
06	1.74	94.09.08 to 95.05.15	250	0.83	65.5 – 21.7
09	0.42	94.11.17 to 95.10.05	326	1.26	29.1 – 11.3
11	1.86	95.03.20 to 95.08.30	160	1.23	76.2 – 35.3
12	1.45	94.09.10 to 94.04.15	220	0.87	49.3 – 33.0
13	1.60	94.11.17 to 95.03.20	124	0.77	82.7 – 40.3
26	2.35	95.05.10 to 96.12.30	235	1.43	77.6 – 31.3
41	3.24	95.01.02 to 95.03.28	87	2.30	76.7 – 29.2
10	2.85	94.09.26 to 95.02.20	155	0.65	72.6 – 22.6
14	1.43	95.05.21 to 96.02.07	270	1.47	74.4 – 39.5
29	2.30	95.04.21 to 95.08.25	120	1.40	53.9 – 37.2

Notes: I – Defluoridator number; II – Average fluoride content of the well in mg/l; III – Period of the tested cycle; IV – No. of days to complete the cycle; V – Flruoride content of the outlet at the end of the cycle; VI – Percentage of the fluoride removal.

Table 5. Details of defluoridators.

Villages	Date of Installation	Period of operation in months	Number of units
1. Patunagama	95.02.03	36	57
2. Athumalpitiya – West	96.09.30	17	67
3. Athumalpitiya – East	97.03.08	12	54
4. Sirisangabo Pedesa	97.06.28	08	54

Table 6. Current status of defluoridators.

Villages	Date of last inspection	Number inspected	In use	Temporarily suspended	Outlet pipe broken	Withdrawn
1	98-01-02	35	08	16	10	01
2	98-03-01	44	21	11	04	08
3	98-02-28	19	13	04	-	02
4	98-02-27	19	07	08	01	03
2	98-08-14	41	30	05	01	05
3	98-06-16	10	07	01	01	01
4	98-07-15	16	06	04	01	05

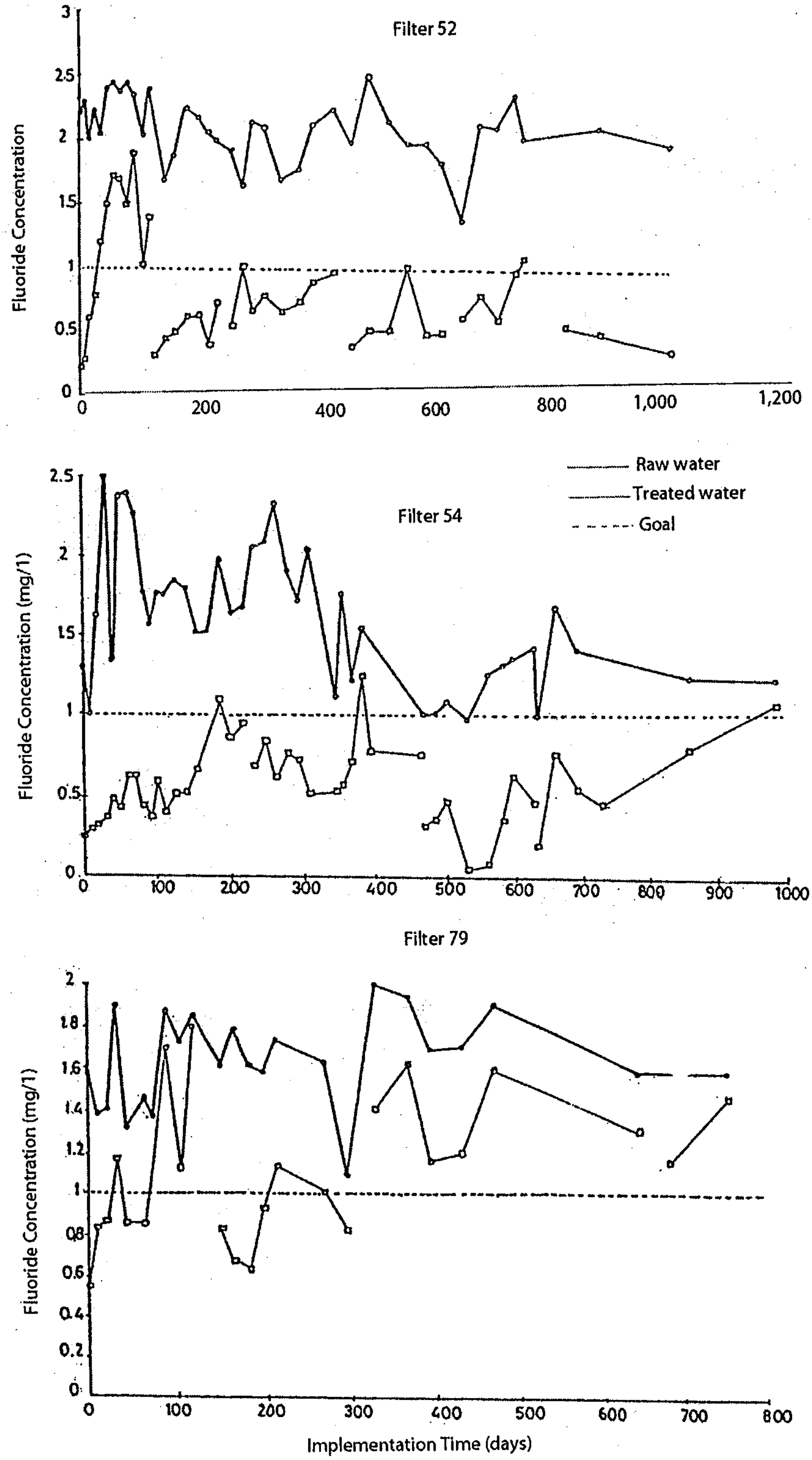
Case studies of three randomly selected filters are discussed below to highlight the sustainability of these units. Figure 5 shows the performance of defluoridator nos. 52, 54, and 79. The thick lines indicate the fluoride contents of well water used in filtration. The thin lines indicate the fluoride contents of defluoridated water. The break points in the thin line denote the replacement of the filter medium. Filter no. 54 performed very successfully in all four cycles. Filter no. 52 had a bad cycle to start with. The fluoride removal was very poor due to the high consumption rate. Since this was a novel item in the household they started drawing out water more frequently without giving much concern for the optimum quantity to be withdrawn. The optimum withdrawal should be about 15 liters per day whereas 20 liters were removed during the first cycle. After further guidance, the filter unit was used correctly resulting in the efficient removal of fluoride. In filter no. 79, the performance was poor during the first cycle due to the use of larger brick pieces, instead of the recommended size of 10–15 mm. This was corrected during the second cycle but was repeated in the third and fourth cycles showing a lack of commitment. In this unit too consumption was above the optimum level.

To ascertain the workability of these defluroidators at field level, first, 250 units were closely monitored and evaluated. The data of every fifth defluoridator performance were evaluated out of this lot. It was found that nearly 80 percent of them are in good working order and that beneficiaries have accepted them as important household work. By considering the cases discussed above the changing of filter medium in these areas can be generalized as shown in table 7.

Table 7. Life span of filter medium in months.

Fluoride content of the well in mg/l	Broken pieces of freshly burnt bricks	Laterite
1–2	3–4	5–6
2–3	3	4
3–4	2.5	3
4–5	1	2

Figure 5. Performance of filters.



CONCLUSIONS

1. The FINNIDA square iron removal plants were found to be highly efficient in iron removal among taste sensitive communities. The technology of these units seems to be more acceptable and adaptable at the village level.
2. For the low-cost defluoridator, the village community is able to prepare and change the filter medium since the bricks are freely available in the villages thus achieving village-level operation and maintenance (VLOM status).
3. This defluoridator has the capacity to reduce the fluoride content from 5 mg/l to less than 1mg/l.
4. Monitoring and evaluation, at least once in three months, will help in the successful usage of the defluoridators.
5. Some level of subsidy is essential for the low-income groups to encourage the usage of defluoridators.
6. With the help of awareness programs and in collaboration with health staff and nongovernmental organizations, fluorosis could be alleviated in Sri Lanka.

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