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PEOPLE-CENTRED APPROACHES TO WATER AND ENVIRONMENTAL SANITATION

The long-term sustainability of household bio-sand filtration

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The introduction of intermittently operated slow sand filters, suitable for use at household level, is gaining momentum in the developing world. An estimated 100,000 bio-sand filters are already in use, providing improved drinking water to more than half a million people. Laboratory and field research has shown that bio-sand filters are capable of impressive reductions of turbidity and pathogen levels. However, long-term sustainability, social acceptance and appropriateness have not been well documented. An evaluation was therefore conducted in rural Kenya to measure the performance of filters introduced 4 years previously. Measuring turbidity and E.coli removal rates, maintenance practices and user perceptions, the study found all but one filter were still in use with over 70% producing water of good quality. Underperformance of some filters pointed at poor maintenance habits. As a 'point-of-use' water treatment solution, bio-sand filtration seems to be very appropriate, effective and cheap. Strategies to introduce this promising technology at a large scale need to be seriously investigated.

The story of bio-sand filtration

The effectiveness of slow sand filtration for water treatment is remarkable: "No other single process can effect such an improvement in the physical, chemical and bacteriological quality of surface waters…" (Huisman and Wood, 1974).

However, in order to be effective, most literature insists that a constant flow of water passing through the filter is essential. This flow provides oxygen (and nutrients) to the organisms that make up the biological layer which occupies the top layer of sand. It is this layer that is responsible for much of the removal of disease-causing organisms. Under stagnant conditions, this bio-film can start to die – sometimes within several hours. Dr. David Manz from the University of Calgary re-designed the traditional sand filter, making it suitable for intermittent use at a household level. This adaptation consists of raising the underdrain pipe back up to 5 cm above the sand – a fool-proof method for maintaining the water level just above the sand. Even when water is not continually added to the filter, oxygen can still permeate into the water to reach the organisms living in the sand through diffusion at the air-water interface. The effectiveness of these intermittently operated slow sand filters has been well demonstrated, for instance by Buzunis (1995), the Massachusetts Institute of Technology[1] and by Medair during the field testing of filters sold to households in Kenya in 2000 (Mol, 2001).

The big question however is: how do these filters perform under real life conditions; out in the bush, in the huts and houses of rural people, years after the experts have left? Performance measured under controlled circumstances in a laboratory, or in the field relatively soon after a filter has been commissioned will only prove the potential of the technology. How the filters continue to function when used and maintained (perhaps incorrectly) under uncontrolled conditions is what determines long-term sustainability and appropriateness. The issue was well phrased in the Final Report of the 2002 Household Water Security E-conference[2]: "New technologies need to be proven in the lab first, but then in the field, in terms of sustained performance; acceptability to the target populations; ease of use; compatibility with local values and beliefs; and compatibility with local needs". The evaluation Medair undertook was designed to measure precisely that.

Project history

In 1999, Medair introduced concrete bio-sand filters to a rural community in Machakos District, Kenya. During one year 362 filters were constructed by local technicians, who sold them to individual households. Each customer received a brief training in maintenance of the filter while it was filled with gravel, sand and water in the home. After one year Medair withdrew, but 2 technicians established a small commercial business, which successfully operates even today. As demand for the filters spread from village to village, they transported the metal filter mould by bicycle: after 4 years, over 2,000 filters had been sold. At an estimated 5 people per family, this represents clean water for ten thousand people. Currently, the filters sell for 1,000 KSh (approximately 12 Euros). Using an improved round mould[3], four to five filters can be made from one bag of cement and some PVC pipe. The cost of material is about 450 KShs; the rest is profit for the technicians.

During the project, both raw and filtered water was tested, usually between 3-4 weeks after a filter had been put into operation. The results[4] showed that 80.7% of the filters produced water with faecal coliform levels below 10 CFU/100ml[5]. Four years later, 51 filters bought in 1999 or 2000 were tested, 70.6% of which were producing water below 10 CFU/100ml. While a slight reduction was anticipated after so many years in use, note that the difference is not large and statistically not significant[6]. It is therefore accurate to conclude that the filters perform as good now as 4 years ago.

Evaluation results

The study measured turbidity and bacteriological removal rates of 51 filters. The table below lists turbidity removal.

Regarding bacteria removal, the evaluation recorded an average CFU of 462 in raw water for all filters, while 66 CFU was recorded as the average for filtered water. Regarding filtered water, out of 51 households:

- 36 showed acceptable coliform levels (0-10 CFU/100 ml) regardless of an overall decrease, increase or no change in coliform levels from raw water (70.6%);
- 12 showed unacceptable coliform levels despite overall decrease in coliform numbers from raw water (23.5%);
- 3 showed unacceptable coliform levels with no change or an overall increase in coliform numbers from raw water (5.9%).

Table 1. Turbidity removal rates

Turbidity removal	Acceptable (< 10 NTU)	Unacceptable (> 10 NTU)
Percentage filters	82.4%	17.6%

Based on these results it would be interesting to discuss the relation between levels of pathogen reduction and the risk of catching water-borne disease. Developing an illness depends on many factors, such as the general health of a person and his level of immunity. In addition, exposure to a significant 'infective dose' is often needed. Therefore, if a poorly functioning filter removes a significant proportion of the pathogens present in raw water, but not all, the owner nevertheless would need to drink more water than before in order to ingest an infective dose. If this increased quantity of water is more than his normal consumption, then it is unlikely that this person will fall ill.

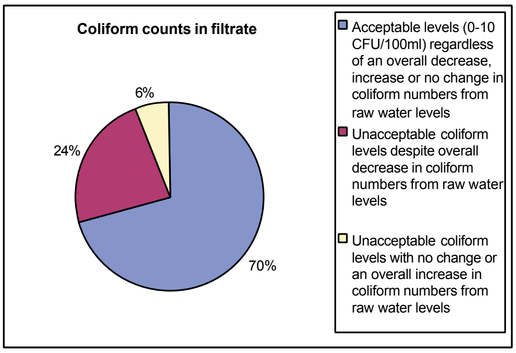

Figure 1. Coliform counts in filtrate

Risks affecting filter performance

Laboratory studies show that the intermittent bio-sand filter can easily be expected to remove in excess of 96% of faecal coliforms (Buzunis, 1995). Further investigation was therefore required to determine the possible cause of poor filter performance in certain households, since all filters were still structurally sound. Prior to the evaluation, the team assumed that environmental factors, poor operation of the filter and faulty maintenance practices were likely contributors. These possible risk factors were as follows:

- Whether the filter had been cleaned or moved within 1 month of the test, or had been brought out of hibernation[7] without having been drained during its inactive period;
- Whether children or animals had access to the filter;
- Whether heavily contaminated raw water was used (from dams/wells/spring, rather than rain water), in combination with a depth of fine sand in the filter of less than 46 cm;
- Other reasons, such as cleaning of the spout with a toothbrush, or a generally bad state of hygiene in the house.

Remembering that 70.6% of the examined filters produced water with acceptable coliform levels, the evaluation team observed that only 19% of these had been cleaned in the previous month, compared to 40% of filters showing unacceptable levels. The use of heavily contaminated water in combination with low sand levels also produced remarkable differences, with 25% and 60% respectively for filters showing acceptable and unacceptable coliform levels. Access by children to the filters compared 6% to 27% for filters showing acceptable and unacceptable coliform levels. There was not enough data to show the effect on performance of the following factors: moving of the filter, access by animals, and recent hibernation of the filter.

From this analysis then, it appears likely that cleaning of the filters within a month prior to the test, access by children and depths of fine sand that had fallen lower than 46 cm in combination with raw water quality all possibly contribute to filtrate water of unacceptable quality. This idea was based on an increased proportion of filters with unacceptable filtrate given these factors, in comparison to filters with acceptable filtrate. Admittedly other factors could well have played a role, such as sand of a different size having been initially installed.

Since various factors may interact, and filtrate quality may not be the result of only one factor, an attempt was made to analyse this further using a risk scoring system. The percentage of acceptable or unacceptable filtrate results could then be viewed in relation to a sum of risks:

Table 2. Risk scoring system

For the 70.6% that had acceptable coliform levels:	For the 29.4% that had unacceptable coliform levels:
20 households had a risk score of 0 (55.6%)	3 households had a risk score of 0 (20%)
16 households showed one or more risks (44.4%), of which:	12 households showed one or more risks (80%), of which:
• 14 households had a risk score of 1 (38.9%)	• 5 households had a risk score of 1 (33.3%)
• 1 household had a risk score of 2 (2.8%)	• 4 households had a risk score of 2 (26.7 %)
• 1 household had a risk score of 3 (2.8%)	• 3 households had a risk score of 3 (20%)

These figures indicate that the cumulative effect of risks can contribute to filtrate water of unacceptable quality. In fact, there is a 4 times higher risk for water to be contaminated (more than 10 coliforms per 100ml) in filters with 2 or 3 risks, in comparison to the group with 0 and/or 1 risks present. In order to better understand these results, user habits and perceptions were measured.

Cleaning of the filters

When the flow rate becomes unacceptably low, the filter can be cleaned by removing accumulated dirt from the top few centimetres of sand. Various methods are possible, but all disturb the biological layer, which results in less effective filtration for some time afterwards. Some methods however are less disruptive than others, so an analysis of filter cleaning methods and frequency is of interest:

- 24.6% were cleaned irregularly once in the last 3 years;
- 35.1% were cleaned irregularly 2 – 4 times in the last 3 years;
- 7% were cleaned regularly once per 9 – 12 months for the last 3 years;
- 26.3% were cleaned regularly between 2 – 6 months for the last 2 – 3 years;
- 7% were cleaned regularly monthly or bi-monthly.

One third of households cleaned their filters anywhere between twice a month and every 6 months. Most of these households (79%) did so because of flow problems, meaning the rest did it out of routine rather than necessity. Interviews confirmed this. Some filter owners stated they clean their filter out of routine, rather than because of blockage or reduced flow rate. This conclusion is important, because this category of filters unnecessarily produced water of less than perfect quality, since their bio-layer was disturbed more often than necessary. Better teaching of correct maintenance could therefore be an effective and simple method to improve the quality of water produced by a large percentage of filters.

More than half of all households experienced a flow rate that was slower than convenient. However, the evaluation coincided with the rainy season, and consequently the quality of the raw water for many households using dam water was considerably more turbid than normal due to run-off. Some households specifically mentioned that the flow rate problem was seasonal. It seems that during this time, blockages can occur in the filters every few months.

The following cleaning procedures were used:

Box 1. Using ‘convenience’ to measure filter maintenance interval

It is important to remember that a ‘dirty’ filter actually can produce water of better quality. Due to a reduced flow rate better filtration takes place, while there is an increased contact time with a mature biological layer. Cleaning should therefore only take place when the outflow of water has become inconveniently slow.

While a bio-sand filter can produce 1 litre per minute, filling a 20-litre jerry can in 2 hours can still be very convenient to an African family, even though this equals a flow rate of only 0.16 litres per minute.

- Stirring the water on top of the sand with hands and removing the dirty water (no sand removed): (12.3%);
- Stirring with hands and collecting dirty water, with a scraping of sand removed and washed: (3.5%);
- Up to 5cm sand removed and washed: (7%);
- Between 5 - 30cm sand removed and washed: (42.1%);
- All fine sand (average 46cm) removed and washed: (28.1%);
- All fine sand and some/all of coarse sand/gravel removed and washed: (4%).

Interestingly, 12.3% had figured out that wet harrowing worked very well. This technique is effective, needs less work and disturbs the biological layer less (Lukacs, 2002), allowing water to be drunk after a shorter time than where other techniques are used. It should therefore be promoted by future projects.

About 74% of households washed large amounts of sand per cleaning. Usually this is unnecessary, as most particles get trapped in the top few centimetres only. Furthermore, excessive cleaning can lead to sand loss. The evaluation found that 47.4% of filters contained a sand column of less than the recommended 46cm, which might negatively affect filtration.

After cleaning:

- 39.3% of filter owners immediately drank water with no run-to-waste time;
- 34% let water run to waste from 1-13 days before drinking;
- 26.7% let water run to waste for 14-21 days before drinking.

Those who waited between 2 and 3 weeks before drinking did so almost entirely because of what they were initially taught by project staff 3 years previously, rather than based on improving clarity of the water, taste or other factors. For the three-quarters of households that did not wait more than 13 days before drinking, 84.2% of them did not base their decision on what they had been taught by technicians, and over half of them based this decision on sight / taste alone. The evaluation did not find out what alternative sources of water were used during the waiting period.

These findings have implications for the implementation of slow sand filter projects. If the majority of households will either forget or ignore cleaning advice, bio-sand filters cannot be considered a 100% failsafe method of water purification despite their potential, but rather as a 'better-than-nothing' interim method of water treatment. However, the original project did not use intensive teaching methods and it is likely that better information, teaching of cleaning methods, or improved or more frequent follow-up will lead to much better results.

Procurement and marketing

97% of all households were generally satisfied with the filter, while 100% thought the filter had been a worthwhile purchase. In fact, only one family had permanently stopped using the filter for a reason unrelated to filter performance, which proves an amazing level of social sustainability.

Generally, the filtered water was much appreciated. 6% of the owners considered the taste of raw water to be good, compared to 51% for filtered water. There were no bad perceptions of filtered water but only one case of rainwater becoming tasteless where it had been sweet before. Perceptions of colour also changed dramatically: 35% of raw water was considered clear, compared to 92% of filtered water.

In Machakos, it seems that there is a high level of awareness of health benefits associated with the filter. Out of all households, 67% cited health reasons and awareness as their main reason for purchasing a filter. The other major argument cited by 40% of users was that the use of the filters saves firewood that would otherwise be needed to boil the water. If the filters were to be introduced in areas where people are generally less aware of the links between clean water and good health, other convincing reasons should be found to market the technology. For instance, where bacteriological improvement of the water is not understood or accepted as a reason to purchase a filter, colour improvement can be used as a marketing message. The same applies to temperature. Since these filters are made from concrete, some 'sweating' through the walls occurs. Evaporation then cools the filter and the water inside. 94% of households perceived a decrease in temperature from raw to filtered water, which was generally considered an advantage.

References

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Huisman, L.; Wood, W.E., (1974), Slow Sand Filtration, World Health Organisation, Geneva.

Lukacs, H. (2002). Appropriate Drinking Water Treatment: A Framework for Point-of-Use Technology Evaluation. Available at: http://web.mit.edu/11.479/www/Lukacs.doc

Mol, A. (2001). The success of household sand filtration, Waterlines, Vol.20, No.1.

Note/s

1. Find several studies, evaluations and project reports on household water treatment, including bio-sand filtration at: http://ceemeng.mit.edu/~water/.
2. UNICEF, WHO and HTN, Final Report on Household Water Security E-Conference, Oct. 14 to Nov. 1, 2002. See: www.unicef.org/wes/files/HHrep.pdf
3. Blueprints, construction guidelines and photo guide for this improved sand filter mould are available free of charge at: www.biosandfilter.org.
4. Data taken from: Medair (2000). Evaluation/Final Report. Family Bio-Sand Filtration Project in Machakos District June 1999 – September 2000. Project report, Medair East Africa, Nairobi, Kenya.
5. CFU = Colony Forming Units of faecal coliforms. Data was analysed against Sphere Standards that stipulate acceptable levels of 0-10 for un-disinfected supplies.
6. Calculated using a Chi Square test, with a result of 2 and a P value of 0.15. Statistics by Dr. David Sauter of Medair.
7. In this case, hibernation describes the time when a filter remains unused for periods over 1 week.

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