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Measuring use of household drinking water filters: field experiences from Ethiopia

R.B. Johnston, T. Edosa, & L. Osterwalder, [Switzerland]

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In rural Ethiopia, household defluoridation filters have been distributed in an effort to reduce fluoride exposure through drinking and cooking water. Submersible dataloggers were used to measure stored water levels in household filters, and to calculate the frequency of filter filling, as well as the amount of water added to and withdrawn from filters. These quantitative estimates of filter use are compared against different measures of self-reported filter use. Tally counters were also investigated as an alternative to simple self-reported filter usage. Comparison to datalogger records shows that tally counters underreport the frequency of filter filling, while household reports of filling frequency matched rather closely. However, households report treating much larger volumes of water than were calculated from datalogger records. Datalogger records indicate consumption of approximately 12.5 litres per day per filter, or 2.0 litres per person per day, which is probably adequate for drinking but not for cooking.

Introduction

Groundwater is often a preferred source of drinking water because it is generally of higher microbial quality than surface water. However, because of long contact times with aquifer sediments and minerals, under certain geochemical conditions groundwater contains elevated levels of harmful inorganic compounds. More than one hundred million people worldwide are exposed to high levels of fluoride (Amini et al., 2008a) or arsenic (Amini et al., 2008b) in drinking water. Chemical filters have been proposed as a potential tool for reducing exposure to arsenic and fluoride in drinking water, at least in the short term. Filters can treat water at either a community (Sarkar et al., 2005) or household level (Hussam and Munir, 2007).

The capacity of chemical removal filters depends principally upon the water chemistry: the concentration of the contaminant to be removed is obviously important, but pH and the presence of competing ions can also play important effects (Hug et al., 2008). Filters typically display lower removal capacity under field conditions compared to laboratory settings. Attempts to estimate the expected lifetime of removal filters are complicated by imprecise measurements of water consumption. Community treatment plants may be fitted with meters, but conventional meters cannot be used in household filters which treat small volumes of water, at slow and intermittent flow rates. Researchers investigating usage of household filters tend to rely on self-reported use by household members, but this method may be vulnerable to courtesy bias. Improved measurements of usage of treated water are required, not only to more precisely understand filter capacity, but also for better measurements of reductions in exposure to toxic chemicals through filter use.

Groundwater in the Great Rift Valley of Eastern Africa is extensively contaminated with naturally occurring fluoride. In the Ethiopian Rift Valley, fluoride contamination has led to widespread dental fluorosis and significant levels of skeletal fluorosis (Tekle-Haimanot et al., 2006). Water resources are scarce in the Rift Valley, and defluoridation at community and household levels is promoted especially in rural communities. As part of a multi-disciplinary project, defluoridation technologies are being optimized and tested in Switzerland, Kenya, and Ethiopia (Samuel et al., 2009; Korir et al., 2009). We report on an assessment of several alternative methodologies for measuring use of household defluoridation filters in rural Ethiopia.

Methods

The Oromia Self-Help Organization (OSHO) is an Ethiopian NGO active in fluoride mitigation in the Ethiopian Rift Valley, with financial support from the Swiss NGO HEKS (Swiss Interchurch Aid). As part of a broader collaboration with the University of Addis Ababa, the Swiss Federal Institute of Aquatic Science and Technology (EAWAG), and the Water Quality Section of the Kenyan Catholic Diocese of Nakuru (CDN), innovations in defluoridation are being piloted and optimized in rural Ethiopia.

In April 2010, two hundred household defluoridation filters were distributed by OSHO, with support from HEKS, in several rural communities near to Meki town in the Ethiopian Rift Valley. Household water managers were given basic training in operation and maintenance, and were encouraged to use filtered water for drinking and cooking, but not for non-consumptive uses (e.g. hygiene). The filters consist of two stacked plastic buckets (Figure 1). The upper bucket, approximately 26 cm in diameter, contains coarse sand for turbidity removal. The lower bucket, approximately 31 cm in diameter, contains bone char mixed with calcium phosphate pellets for fluoride removal. The defluoridation media is housed in a smaller internal bucket, leaving a reservoir of approximately 18 litres in the annular space within the lower bucket. Treated water is collected through a tap.

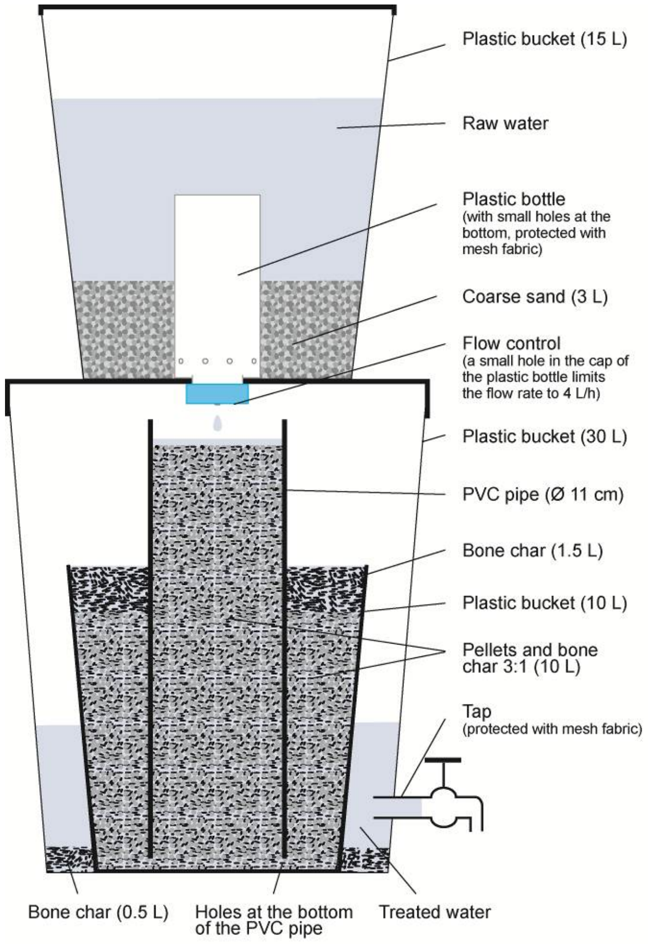

Figure 1. Defluoridation filter design

In eight households submersible dataloggers (Omega, Stamford, CT) were placed in the treated water reservoir. The dataloggers contain a pressure transducer, and were set to record the hydrostatic pressure and temperature every five minutes. A ninth datalogger was kept outside of the filter in one of the households, recording changes in barometric pressure. By adjusting the recorded hydrostatic pressure for changes in barometric pressure, the height of the water column (and thus the volume of stored water) in the reservoir could be calculated for each time step. This time series could then be converted into a dynamic record of the amount of water added to or removed from the reservoir. The sensitivity of the measurement was quantified by measuring the variability in water levels during periods when usage was negligible (e.g at 3:00 am). Data were downloaded from the dataloggers every two weeks. In one household, curious household members removed and inspected the datalogger to see what it was, in the process damaging it. In each of the other households, a nearly continuous record of approximately 50,000 readings was collected over 177 days, from April 20 through October 14.

Datalogger records were processed to identify individual filling and consumption events, independently. Only records which exceeded two times the standard deviation of the recorder readings during dormant periods were considered as authentic filling or consumption events. The sensitivity was calculated separately for each datalogger, and averaged four mm per five minute interval.

All households having dataloggers were visited on a weekly or biweekly basis, from April 20 through September 2, during which counter readings were recorded, and household water managers reported the number of times daily they had filled the filter since the last visit, as well as the size of the jug used to fill the filter. The self-reported number of times the filter was filled was directly comparable to the counter records; the volume of water treated could be calculated from either counter readings or self-reported usage based on the volume of the jug used.

Fifty of the households receiving filters, including three households with dataloggers, were also given a manual tally counter, which advances a counter each time a button is pushed. Water managers were requested to push the counter button each time the filter was refilled, and the counter was stored near the defluoridation filter but out of the reach of small children. A brightly colored sticker was affixed to the filter as a reminder to use the tally counter each time the filter is filled.

Photograph 1. Tally counter and datalogger

Filling events

The frequency of filter filling events was calculated in three ways.

1. **Self-reported**: during household interviews, respondents were asked how many times per day they filled the filter. This question was repeated at each interview.
2. **Tally counters**: readings from the tally counters were also collected at each interview, and converted into a daily frequency.
3. **Dataloggers**: an algorithm was devised to identify filling events based on the time series of water level readings. Filling events were defined as four consecutive records in which water level increased by more than the sensitivity of the datalogger. Filling events were then tabulated for each day and converted into frequencies.

Water treated

The amount of water treated per day was calculated in four ways.

1. **Self-reported**: during household interviews, respondents were asked which container they used to fill the filter, how many containers were used per filling event, and the approximate volume of the filling container. The number and volume of filling containers were then multiplied by the number of filling events to get a daily treatment rate.
2. **Tally counters**: the same data regarding the number and volume and filling containers were multiplied by the number of filling events recorded with tally counters.
3. **Dataloggers (filled)**: the total volume of water treated per filling event was calculated simply as the difference in stored water volume between the start and end of a filling event.
4. **Dataloggers (consumed):** the algorithm which identified filling events also identified consumption events, in which water level decreased between consecutive time steps. Consumption events tend to be shorted in duration than filling events, so the requirement of four consecutive records was not applied. The volume of water consumed was calculated by summing the amount of water removed from storage during each consumption event.

Results

In most households the self-reported frequency of filling matched reasonably well with datalogger records of filling events (Table 1), with an average of approximately two fillings per day. In the three households which also had tally counters, the frequency calculated from counters was much lower (one filling per day), indicating substantial failure to record filling events with this methodology.

Dataloggers were used to independently measure the amount of water filled (from increases in water column depth) and the amount of water consumed (from decreases in water column depth). Obviously, the two figures should be the same, but the calculations consistently show the amount of water consumed was always somewhat larger (on average, 16% more) than the amount water filled for the datalogger calculations. This is an artefact of the digital data collection process: small increases in stored water volume occurring near the end of filtration events could not be distinguished from random fluctuations, and were not counted. In contrast, consumption events were typically short and resulting in easily detectable drops in water level. Thus water consumption is considered a better indicator of filter usage than water treatment, in interpreting the datalogger records.

The calculation of daily water treated from self-reports (19.4 lpd) was substantially higher than the consumption measured with dataloggers (12.5 lpd), while the calculation based on tally counters (10.1 lpd) matched datalogger measurements more closely. This seems to indicate that while households could accurately report the number of times they filled a filter per day, they overestimated the amount of water used in each filling. Thus in the tally counter calculations, errors introduced by underestimating the number of filling events are partially compensated by overestimating the volume of each filling event.

Table 1. Household characteristics and usage of defluoridated water

Filter number	**4**	**7**	**9**	**10**	**18**	**22**	**31**	**Avg.**
Household characteristics								
Total household residents	10	7	6	5	9	4	4	6.4
Children under 5 years	1	2	3	0	2	0	2	1.4
Children between 5 and 13 years	2	2	2	1	2	1	0	1.4
Average number of filling events per day								
Self-reported	1.8	2.2	2.8	2.0	2.7	1.9	1.6	2.1
Tally counters	0.9	1.4	--	--	--	--	0.8	1.0
Dataloggers	1.8	1.8	3.3	1.4	2.3	1.1	1.2	1.8
Litres of water treated per day								
Self-reported	16.4	19.9	25.5	18.9	26.5	13.9	14.6	19.4
Tally counters	8.4	13.5	--	--	--	--	8.3	10.1
Dataloggers – filling	8.5	10.3	15.4	8.7	9.9	13.3	9.7	10.8
Dataloggers – consumption	11.3	13.0	16.7	10.3	12.1	14.1	10.1	12.5
Dataloggers – consumption per capita	1.1	1.9	2.8	2.1	1.3	3.5	2.5	2.0

When datalogger consumption is normalized by the number of household residents, the consumption ranges from 1.1 to 3.5 litres per capita per day, with an average of two litres per capita per day. This amount is probably adequate for meeting drinking water needs, but not for providing cooking water as well (WHO, 2003). Survey respondents also reported that they mainly used the filters for drinking rather than for cooking.

Dataloggers allow calculation not only of total water consumption, but of short- and long-range dynamics of water use. Figure 2 shows how water filling and consumption varies over different time scales in filter number 7 (chosen as it represents fairly average usage). Visual inspection shows that the algorithm used to identify filling events worked well, but in some cases did not recognize the start of the filling event until a few litres had been treated.

Figure 3 shows longer-term trends in filter use in filter number 7. A seven-day moving average was used to smooth weekly variations (filter usage is higher on Fridays and Saturdays). The graph shows that usage steadily increased while the filter was new, peaking in mid-June at approximately 20 litres per day. Usage then declined for several months, reaching a low in late August. Usage then increased and held fairly steady in September and October. Records from the other filters show similar trends. Part of this trend can be explained by heavy rainfall in the summer season – people traditionally collect and drink rainwater when it is available. Another important factor is that during the last week of August the water source used by these households experienced technical problems, and there was a general lack of drinking water availability.

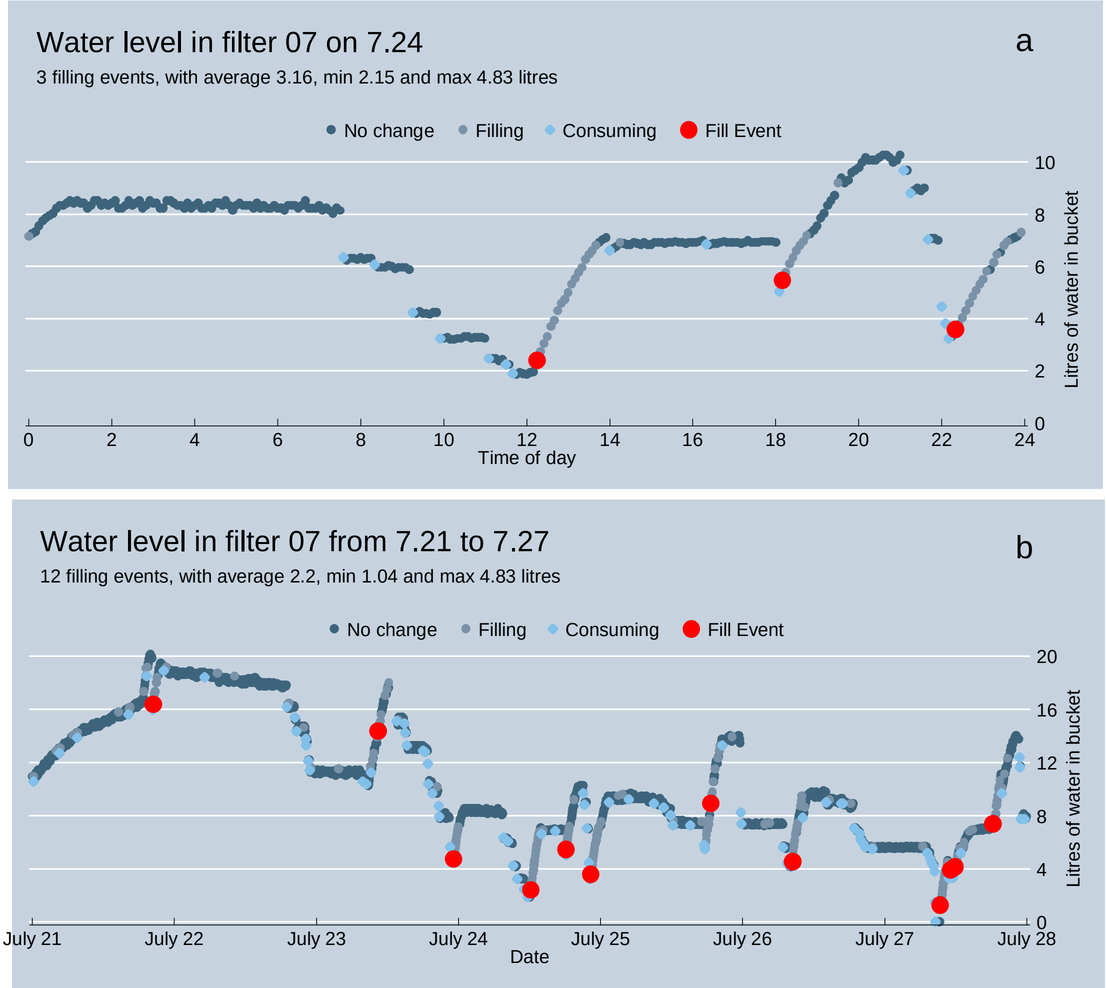

Figure 2. Stored water levels in filter 7 on daily (a) and weekly (b) basis.

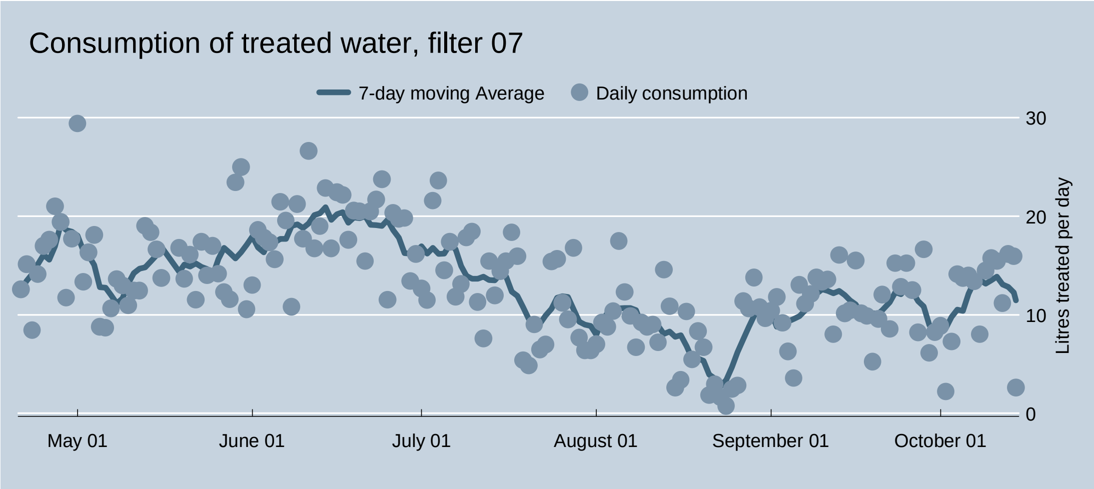

Figure 3. Average daily water consumption throughout study period.

Discussion

Different measures of household filter use were evaluated, and self-reported usage was compared against digital records from dataloggers. Self-reported water treatment was substantially higher than that calculated from dataloggers, though the number of filling events per day matched fairly well. The main source of error in self-reported use seems to be an overestimation of the volume treated per filling event, rather than the frequency of filling events. It might be possible to improve on self-reported water use measures by training enumerators to quantify container volumes, or having respondents demonstrate a typical filling.

There is evidence that households neglected to consistently use tally counters. However, this error seems to cancel out to some degree the overestimation on the part of households of the volume of water treated per filling event, so that the overall calculation of water treated matches datalogger estimations relatively well.

Dataloggers yielded objective measurements of overall water consumption, but more importantly provide insights into the short- and long-term temporal trends in filter usage. While such data collection would be prohibitively expensive for routine use, this method can give valuable data for research studies.

Although the number of households surveyed is small, this research suggests that defluoridation filters are more or less consistently used in the rural communities where they have been distributed, but that households use filters only for some of their consumptive needs. Future promotion efforts could target use of filtered water for cooking as well as for drinking purposes.

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Contact details

Richard Johnston
Überlandstrasse 133
8600 Dübendorf, Switzerland
Tel: +41 044 823 50 11
Email: Richard.johnston@eawag.ch
www: www.eawag.ch

Lars Osterwalder
Überlandstrasse 133
8600 Dübendorf, Switzerland
Tel: +41 044 823 54 61
Email: Lars.Osterwalder@eawag.ch
www: www.eawag.ch