

## A critical evaluation of two point-of-use water treatment technologies: can they provide water that meets WHO drinking water guidelines?

Heather M. Murphy, Edward A. McBean and Khosrow Farahbakhsh

### ABSTRACT

Point-of-use (POU) technologies have been proposed as solutions for meeting the Millennium Development Goal (MDG) for safe water. They reduce the risk of contamination between the water source and the home, by providing treatment at the household level. This study examined two POU technologies commonly used around the world: BioSand and ceramic filters. While the health benefits in terms of diarrhoeal disease reduction have been fairly well documented for both technologies, little research has focused on the ability of these technologies to treat other contaminants that pose health concerns, including the potential for formation of contaminants as a result of POU treatment. These technologies have not been rigorously tested to see if they meet World Health Organization (WHO) drinking water guidelines. A study was developed to evaluate POU BioSand and ceramic filters in terms of microbiological and chemical quality of the treated water. The following parameters were monitored on filters in rural Cambodia over a six-month period: iron, manganese, fluoride, nitrate, nitrite and *Escherichia coli*. The results revealed that these technologies are not capable of consistently meeting all of the WHO drinking water guidelines for these parameters.

**Key words** | BioSand filters, Cambodia, ceramic water filters, household water treatment, point-of-use water treatment, WHO guidelines

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### INTRODUCTION

In an effort to combat diarrhoeal diseases worldwide, the World Health Organization (WHO) has identified point-of-use (POU) water treatment technologies as an option for providing safe water to households in developing countries (Sobsey *et al.* 2008). The United Nations Millennium Development Goal (MDG) target #7 aims to 'halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation' (UN 2006). Many countries around the world are not expected to meet this goal at current rates. POU technologies have been proposed as solutions for meeting the MDG target, as opposed to centralized systems, as they reduce the risk of contamination between the water source and the home.

doi: 10.2166/wh.2010.156

Two commonly used POU technologies found in over 20 countries worldwide are the BioSand filter (BSF) and the ceramic water filter (Clasen *et al.* 2004, 2006; Duke *et al.* 2006). The largest implementation of both of these systems in the world is in Cambodia (Sampson, personal communication 2008; Samaritan's Purse Canada, personal communication 2009). In two epidemiological studies conducted in Cambodia, Liang *et al.* (in press) and Brown *et al.* (2007) found up to 44 and 46% reduction of diarrhoeal disease in households that used BioSand and ceramic filters, respectively, compared with households that did not. In a similar study conducted in the Dominican Republic, Stauber *et al.* (2009) documented a diarrhoeal disease reduction of between 14 and 60%,

depending on the season. While the health benefits in terms of diarrhoeal disease reduction have been fairly well documented for both technologies, little research has focused on the ability of these technologies to treat other contaminants that pose health concerns, including the potential for formation of contaminants as a result of POU treatment (Duke *et al.* 2006; Stauber *et al.* 2006; Oyanedel-Craver & Smith 2008). In addition, these technologies have not been rigorously tested to see if they meet WHO drinking water guidelines.

Consequently, a study was developed to evaluate POU BioSand and ceramic filters in terms of microbiological and chemical quality of the treated water. The research was conducted in rural Cambodia on various Cambodian source waters. The following parameters were monitored as they were identified by a local non-governmental organization (NGO) as well as by a group of authors as being prevalent in Cambodia source waters and posing aesthetic or health concerns in water supplies: iron, manganese, fluoride, nitrate, nitrite and *Escherichia coli* (Feldman *et al.* 2007; RDIC 2007). This paper will examine:

- the ability of both POU technologies to produce treated water that meets WHO guidelines for iron, manganese, fluoride, nitrate, nitrite and *E. coli* on various Cambodia source waters;
- the ability of both POU technologies to treat for chemical contaminants;
- the increase or formation of potential contaminants as a result of using these POU devices; and
- the probability of exceeding WHO guidelines.

## MATERIALS AND METHODS

### BioSand filter design

In the early 1990s, Dr Manz at the University of Calgary adapted the design of a traditional slow sand filter so that it could be operated intermittently and called it the BSF (Buzunis 1995; Palmateer *et al.* 1999). The BSF is a household-operated slow sand filter (Figure 1). The Cambodian design of the BSF consists of a concrete frame and locally available crushed rock as the filter media.

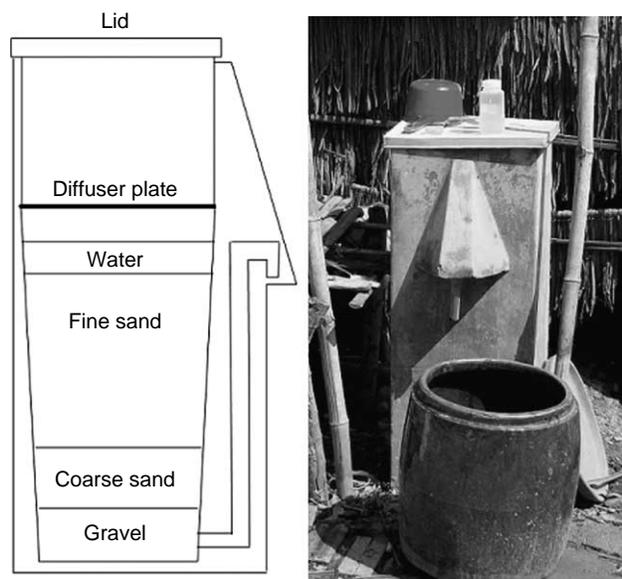


Figure 1 | BioSand filter.

The rock is crushed to two different sizes: a coarse layer and then a fine layer. The fine layer of crushed rock (sand) makes up the majority of the filter bed, approximately 46 cm, and has an effective size of between 0.15 and 0.35 mm and a uniformity coefficient of  $<3$  (Samaritan's Purse Canada 2008). The design filtration rate for the BSF is between 600 and 800 ml min<sup>-1</sup> when the diffuser is full of water. In addition to the filter itself, the household must utilize a storage container to capture the treated water; the storage containers vary from household to household. The typical storage container included with the filter upon installation is an opaque plastic container with a medium-sized opening at the top, coupled with a lid.

Bacterial removals have been reported to vary from no apparent *E. coli* removal to 99% in the lab and field depending on operating conditions and filter ripening (Duke *et al.* 2006; Earwaker 2006; Stauber *et al.* 2006; Baumgartner *et al.* 2007). Very little research has examined the effectiveness of BSFs on virus removal. Elliot *et al.* (2008) observed an average 66.6% reduction of bacteriophage. To date, approximately 25,000 have been installed throughout Cambodia by two local organizations: Hagar and Cambodia Global Action (CGA) (Samaritan's Purse Canada, personal communication 2009). The current study examined filters implemented by CGA in rural Cambodian households.

## Ceramic filter design

The design of the ceramic filter used in Cambodia originated from an organization called Potters for Peace (PFP) who developed ceramic filters in Nicaragua (Lantagne 2001a,b). The PFP design is a ceramic pot filter which resembles a flower pot (Figure 2). It consists of local clay, sand, sawdust and colloidal silver. The sawdust is used to increase the flow rate of the filter as it burns out in the firing process and allows for increased porosity. The colloidal silver is applied on the inner and outer surfaces of the clay filter after firing to act as a biocide. The pore size of the PFP filter ranges from 0.3 to 6  $\mu\text{m}$ . A wide variety of research in a laboratory setting has shown between 97.8 and 99.99% *E. coli* removal and between 63.4 and 99.9% virus removal by ceramic filters (Lantagne 2001a,b; Brown 2007; Johnson 2007; Oyanedel-Craver & Smith 2008). In the field, Brown *et al.* (2007) observed on average 98% reduction of *E. coli*. This lower reduction was attributed to post-treatment contamination in the treated water storage containers (Brown *et al.* 2007; Murphy *et al.* 2009). Three epidemiology studies conducted in Bolivia and Cambodia found that a 40–70% reduction in diarrhoeal disease can be achieved through ceramic filter interventions (Clasen *et al.* 2004, 2006; Brown *et al.* 2007). Three NGOs implement ceramic filters across Cambodia: Resource Development International Cambodia (RDIC), International Development Enterprises and the Cambodian Red Cross. The current study examined filters implemented by RDIC in the field. To date, RDIC has produced approximately 90,000 ceramic filters which have been sold across Cambodia (Sampson, personal communication 2008).

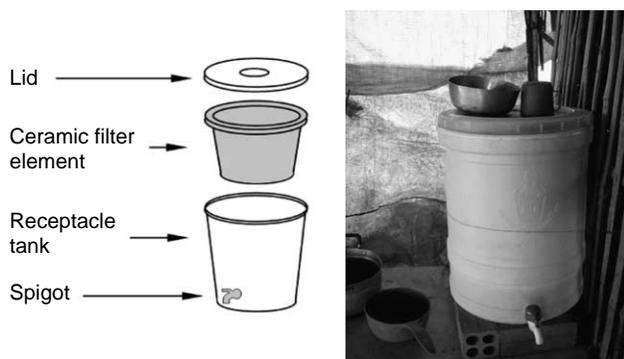


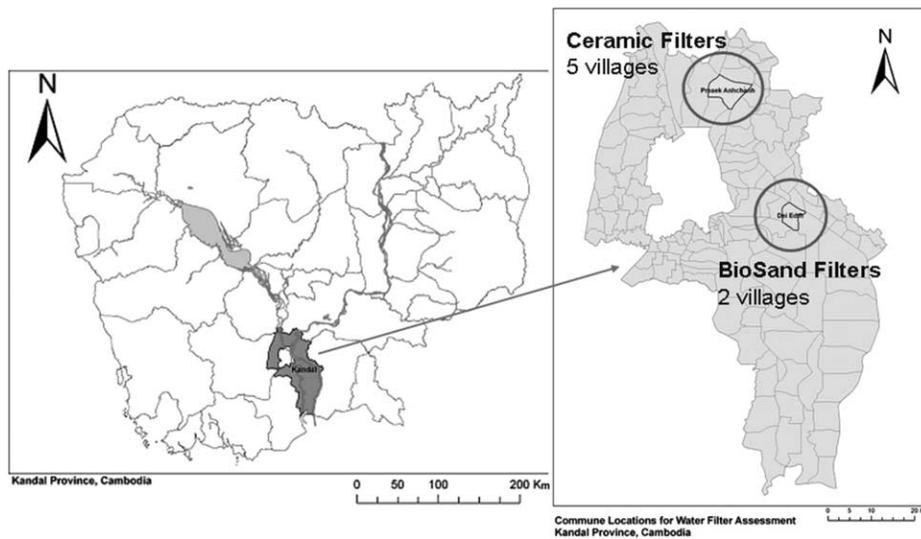
Figure 2 | Ceramic filter.

## Household filter selection

A case study approach was used to assess the performance of BSFs and ceramic filters in rural Cambodia. The project began in September 2008 and took place in two communes in Kandal Province, Cambodia: Prek Anchang and Dei Edith. In Prek Anchang commune, five villages were selected to examine ceramic filters (Figure 3). These villages were: Cheu Teal, Kandal, Prek Taben, Prek Themei and Leu. The ceramic filters implemented in this commune were sold door-to-door six months prior to the beginning of this research for a World Bank project. An area of recent implementation was chosen for study to ensure that as many filters as possible could be located since breakage rates were reported as high by Brown *et al.* (2009). Seventy-four filters were sold in the region during this period. Instead of generating a random sample, attempts were made to locate the entire population. Of the 74 filters, eleven were not found, five were broken, two did not want to participate, and two belonged to households who were not at home at the time of visit. However, three additional filters were found in the same geographic region but they were in a village not specified by the manifest provided by RDIC. In total, 56 filters were found and were still being used at the time of visit. In the current study, usage rates were considerably higher than those found by Brown *et al.* (2009), who found that ceramic filter usage dropped by approximately 2% per month.

For the BioSand filters, Kesom and Popeal Kaye villages were chosen in Dei Edith Commune in Kandal Province, Cambodia. The project was conducted in collaboration with CGA. The senior author was advised by CGA that a total of 81 filters were installed in both villages. Similarly to the ceramic filters, an attempt was made to locate all the filters in the communities. The filters ranged in age from 1 to 7 years old. Although 81 filters were located, only 59 were still being used by households at the time of site visit.

The study design consisted of two parts: (1) initial filter survey and (2) water quality survey of 40 households over time. The initial study consisted of locating all BioSand and ceramic filters currently implemented in the communities identified above. Once a filter was located, a survey was conducted with the household and water samples were



**Figure 3** | Study sites in Kandal Province, Cambodia.

collected from the untreated source water used for the filter and from the treated water leaving the filter spout (Figures 1 and 2). The questionnaire used in the study inquired about filter use, hygiene practices, household demographics and filter maintenance.

From the initial 56 and 59 filters, 40 were chosen (20 BioSand and 20 ceramic) for part 2 of the study and were examined in more detail over a six-month period. The 40 filters were chosen using a series of criteria. For a household to be included in the study, they needed to be using one of the source waters of interest: surface water or well water. The following criteria were used for excluding households from the study: unwillingness to participate in the study, blending of water sources, using rainwater all year round, having a large number of water jars and therefore able to store rainwater for a long period of time, using piped water or bottled water or using their filter infrequently. Once the 40 households were selected, they were visited once every two weeks to collect water samples and complete a short questionnaire regarding filter operation and maintenance. These households were visited over a period of six months during the dry season in Cambodia. The dry season was chosen for the study period because during this time households generally use water of poorer quality in their filters such as well water and surface water. These water sources generally contain more

contaminants than rainwater, which is considered a water of higher quality and is frequently used as source water for the filters during the rainy season.

### Collection of water samples and analysis

Treated and untreated water samples were collected in sterile autoclaved sample bottles and kept in coolers until transported to the Resource Development International Cambodia (RDIC) laboratory where they were analysed within 24 hours for total coliforms (TC), *E. coli*, pH, turbidity, colour, iron, manganese, fluoride, ammonia, nitrate and nitrite. Although arsenic is also prevalent in some Cambodian groundwaters, neither of these POU technologies has been proven consistently capable of removing arsenic from water supplies (Chiew *et al.* 2009). Therefore, this study did not examine arsenic removal. In addition, all well water sources were tested for arsenic to ensure households were not drinking water containing arsenic in concentrations exceeding the Cambodian guideline of 50 ppb arsenic.

Untreated water samples were collected from concrete household water storage containers, surface water sources near the household or directly from wells, depending on how the household collected the raw water to feed their filter. Treated water samples were collected from the spouts of the BioSand and ceramic filters

(Figures 1 and 2). In addition, water samples were collected from the treated water storage container for households using BioSand filters.

Total coliforms and *E. coli* were enumerated using the standard membrane filtration method as outlined in *Standard Methods* (2006). Samples were filtered aseptically through sterile 0.45- $\mu\text{m}$  filters using a vacuum aspirator. The filters were then transferred using sterile forceps onto pre-dried Oxoid differential coliform agar with BCIG (chromogen 5-bromo-4-chloro-3-indolyl-b-D-glucuronide, used for simultaneous detection of coliforms and *E. coli*) and incubated upside down for 18–24 hours at 37°C. At this time, all pink and blue colonies were enumerated as coliforms and those colonies that were blue were counted specifically as *E. coli*. All microbiological samples were processed using two serial dilutions and each dilution was processed in duplicate. Iron and manganese were measured using a HACH DR/2100 Spectrophotometer, using methods 8008, 8149 as specified in the HACH DR/2100 manual (HACH Company 2000). Fluoride, ammonia, nitrate and nitrite were measured using a HACH DR/2400 Spectrophotometer, using methods 8029, 8155, 8039, 8153, respectively, as specified in the HACH DR/2400 manual (HACH Company 2004). All chemical parameters were measured in triplicate and the average of the values was compiled.

### Ethics approval

Free and informed consent of the participants was obtained and the study protocol was approved by the Committee for the Protection of Human Subjects—Research Ethics Board at the University of Guelph, Ontario, Canada, Protocol #07OC007, approved 7 March 2008.

### Probability of exceedance analysis

A probability of exceedance analysis was performed to examine the probability that treated water from either technology would exceed WHO guidelines. For the analysis, measured values were organised from highest to lowest for each water quality parameter. For BioSand filters and ceramic filters, 220 and 169 data points were used in the analysis of each parameter, respectively. These values were

then ranked by number starting from the greatest value down to the lowest value observed. For example, the highest value was ranked as '1' and then the second highest value was ranked as '2' and so on until the lowest value observed was assigned a rank (220 or 169). Then a standard value was selected for each water quality parameter. In this analysis, the standard values used were the WHO guideline values for each parameter. The following equation was used to calculate the probability of exceedance:

$$\text{Rank}/(\text{total number of values observed} + 1) \\ = \text{Probability of exceedance}$$

In this equation, 'Rank' refers to the rank of the WHO guideline value in the data set. For example the WHO guideline for manganese is 0.4 mg l<sup>-1</sup>; hence, 0.4 mg l<sup>-1</sup> was selected from the data set and the corresponding rank was inputted into the above equation along with the total number of values observed.

## RESULTS AND DISCUSSION

The focus of this paper will be on part 2 of the research, the water quality survey of 40 households over six months. Results from the preliminary study (part 1) are presented separately in another publication. Twenty households using BioSand filters and 20 households using ceramic filters were monitored every two weeks for a period of six months. For the BioSand filters, 11 households used well water and nine used surface water as their water source. The source waters for the ceramic filters were as follows: ten households were using Mekong River water, four were using lake water, three were using deep well water (> 10 m) and three were using rainwater. The households that used rainwater initially told the senior author that they would normally switch to deep well water or lake water during the dry season (the study period); however, the rainy season lasted longer than usual and as a result, these households stored and used rainwater throughout the duration of the study.

During the six-month sampling period, 11 samples were collected from each household using a ceramic or BioSand filter. At the beginning of the sampling period, all BioSand filter households were using either well or surface water;

therefore 11 samples were used in the data set for each household. However, for the ceramic filters, not all households were using their dry season water source (well, lake or river) at the beginning of the sampling period. Many households were using stored rainwater and some continued to use rainwater for as many as two months into the sampling period. These rainwater data points are not included in the analysis. As a result, for any one ceramic filter household, between 6 and 11 samples make up the household's individual data set with the exception of one household using well water (C2), where only four samples

were included in the data set because they used rainwater for the majority of the study duration.

### pH, turbidity and *E. coli*

Average pH, turbidity and *E. coli* data are presented in Table 1 for untreated and treated water for each type of filter and water source. In general, both the BSF and ceramic filters reduced turbidity and microbiological contamination. Turbidity, on average, was decreased to below 0.5 and 0.9 NTU for ceramic and BioSand filters, respectively.

**Table 1** | Average pH, turbidity and *E. coli* concentrations in treated water from ceramic and BioSand filters

Filter type	Source water	Values	pH		Turbidity		<i>E. coli</i> (cfu/100 ml)	
			Untreated	Treated	Untreated	Treated	Untreated	Treated
Ceramic	River* (n = 82)	Avg	8.1	8.2	11.7	0.5	697	8
		SD	0.5	0.6	13.7	12.1	1,229	1,025
		Range	(6.7–9.0)	(7.3–9.2)	(0.5–51.5)	(0.1–12.0)	(0–5,800)	(0–710)
		GM	8.1	8.2	5.3	0.3	–	–
	Deep well† (n = 23)	Avg	8.0	8.3	11.0	0.5	571	5
		SD	0.5	0.2	7.8	0.4	1,161	13
		Range	(6.6–8.8)	(7.4–8.8)	(0.3–28.4)	(0.1–3.2)	(0–4,340)	(0–1,500)
		GM	8.0	8.3	7.8	0.3	–	–
	Surface water‡ (n = 34)	Avg	8.2	8.2	4.3	0.4	117	53
		SD	0.4	0.4	9.5	15.0	261	906
		Range	(7.1–9.1)	(7.2–9.4)	(0.2–44.2)	(0.10–1.3)	(0–1,400)	(0–894)
		GM	8.2	8.2	1.7	0.3	–	–
Rain§ (n = 30)	Avg	8.1	8.1	3.0	0.4	315	52	
	SD	0.6	0.5	5.0	11.2	784	961	
	Range	(6.5–9.6)	(7.0–8.8)	(0.2–25.4)	(0.1–1.2)	(0–3,760)	(3–980)	
	GM	8.1	8.0	1.5	0.3	–	–	
BioSand	Deep well† (n = 121)	Avg	7.1	7.4	10.3	0.2	67	13
		SD	0.8	0.3	13.9	0.1	404	46
		Range	(6.2–8.4)	(6.7–8.1)	(0.2–103.5)	(0.1–1.0)	(0–3,585)	(0–284)
		GM	7.0	7.4	4.8	0.2	–	–
	Surface water‡ (n = 99)	Avg	7.0	7.7	9.4	0.8	5,969	105
		SD	0.6	0.4	9.2	0.7	15,879	265
		Range	(6.2–9.0)	(6.9–8.6)	(0.1–52.3)	(0.1–5.5)	(2.5–122,000)	(0–1,990)
		GM	7.0	7.7	5.3	0.7	1,291	–

\*River water here refers to water specifically from the Mekong River.

†Deep well refers to households who use a tube well deeper than 10 m.

‡Surface water refers to households using lake or pond water.

§Rain refers to rainwater collected and stored in large concrete storage containers (often open to the environment).

Notes: Avg = average values observed; SD = standard deviation; Range = range of values observed; GM = geometric mean.

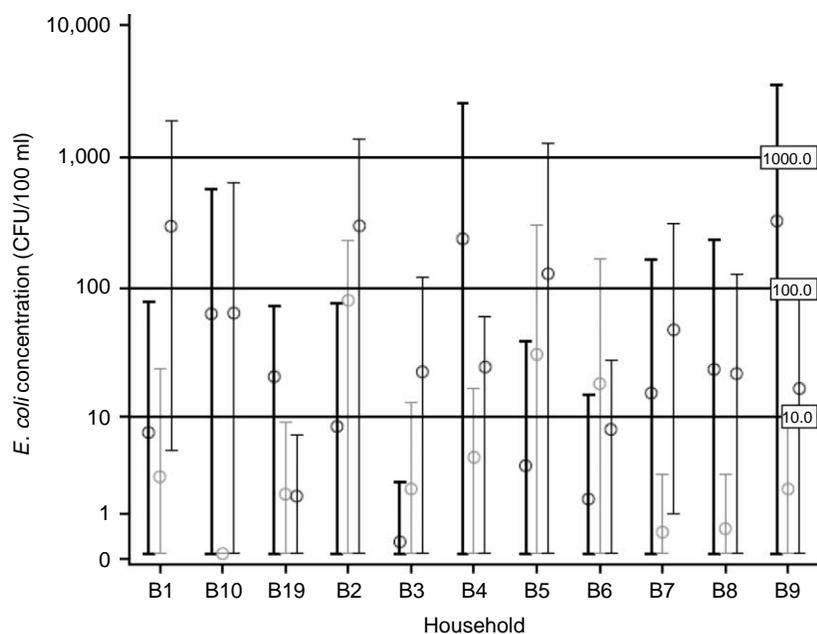
A pH increase from untreated to treated water was observed for the BSFs; this increase was attributed to calcium carbonate leaching from the concrete frame of the BSF. pH was fairly constant for the ceramic filters fed surface and rain water. A small pH increase was observed on average for ceramic filters that were fed river or deep well water.

In general, bacterial removal ranged from 0 to 99.99% for both technologies depending on the influent source water, which is consistent with the findings reported by others (Liang *et al.* in press; Duke *et al.* 2006; Stauber *et al.* 2006; Brown *et al.* 2009). Figures 4–7 illustrate the average *E. coli* concentrations in the influent (untreated water) and effluent (treated water) for both BSFs and ceramic filters. In addition, *E. coli* concentrations for the stored treated water for the BSFs are displayed in Figures 4 and 5. These figures are grouped by filter and water source. On each figure, WHO guidelines are represented by the 10, 100 and 1,000 lines. The low risk range for *E. coli* exposure as defined by the WHO is 0–10 CFU/100 ml, the medium risk range is 11–100 CFU/100 ml and the high risk range is 101–1,000 CFU/100 ml (WHO 2006).

Figure 4 shows the *E. coli* concentrations for BSFs fed well water for the duration of the study. On average, these

filters provided a range of treatment for *E. coli*, from zero removal up to 2 log removal. Instances of the low removal could be attributed to the fact that the initial source water was often relatively low in microbial contamination. Eight of 11 filters, on average, produced treated water in the low risk range. In four cases: B2, B3, B5 and B6, an increase in *E. coli* concentration was observed from influent to effluent. As a result, these four filters were introducing bacteria into the treated water, possibly through contaminated spouts or other filter elements. Based on field observations, cleaning practices and flow rate measurements, it seems as though the households using filters B2, B3, B5 and B6 cleaned their BSFs frequently and as a result may have been using improper cleaning practices such as: sticking a finger or hand deep into the top layer of sand and stirring it around, scooping out sand and cleaning it and then replacing it back inside the filter. In some cases, the households reported removing sand from their filter. Consequently, filter maintenance is an important aspect for ensuring the provision of safe water from the BSF.

The stored treated water quality was frequently worse than the treated water taken directly from the spouts of the BSF. In nine cases, on average, stored treated water was of



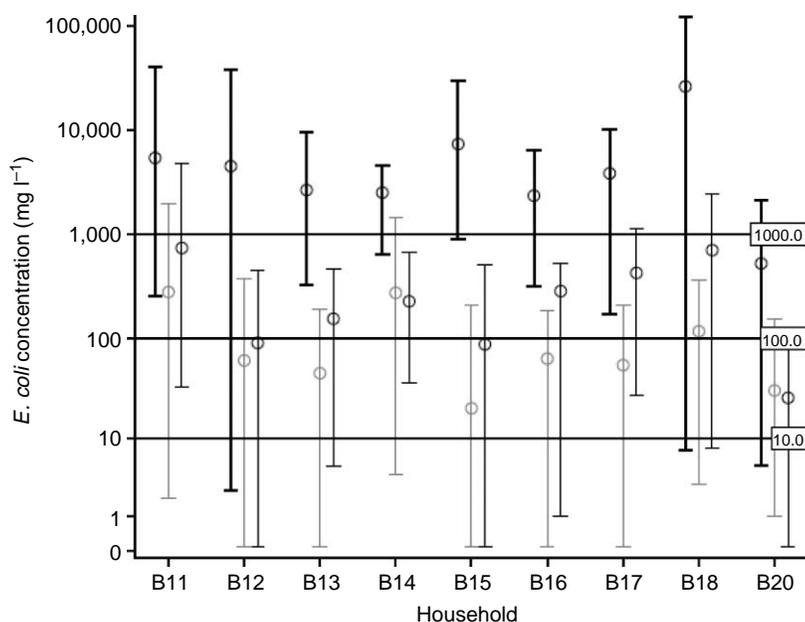
**Figure 4** | *E. coli* concentrations for BioSand filters fed well water (circles represent average values; bars represent high and low values observed during the study); 1st series of bars in each group (bolded) represent untreated water; 2nd series of bars (grey) represent treated water; 3rd series of bars (not bolded) represent stored treated water; number of samples for each household = 11.

worse quality than treated water collected directly from the spout. Two households had stored treated water in the low risk range, six in the medium risk range, and three were in the high risk range for *E. coli* exposure. In addition, five filters had stored treated water that contained higher concentrations of *E. coli* than the initial untreated well waters fed into the filters. Stored water containers, at most households, were not cleaned properly and at the time of visit were visibly dirty and some had considerable algae growth inside. Households used various types of storage container such as: an open 20-l bucket, open ceramic container, covered cylindrical cooler, or the plastic storage container provided by CGA at the time of filter installation. In addition, many households were using their treated water storage container to collect dirty untreated water to feed their BSF. This was a common occurrence and no matter how many times a household was informed that they should not use the same container to fill the filter as to collect the treated water, this practice tended to continue.

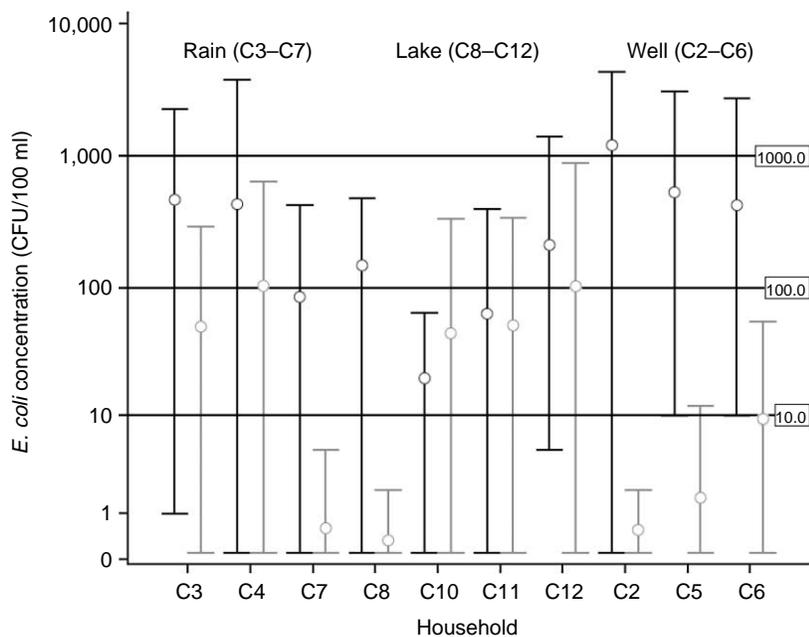
Figure 5 shows the *E. coli* concentrations for BSFs fed surface water sources for the duration of the study. None of the BSFs was consistently capable of providing treated water in the low risk range for *E. coli*. Given that the concentrations of *E. coli* in the raw surface water were extremely high, high

concentrations in treated water could be expected. On average, these filters were capable of achieving 1 to 2.5 log removal of *E. coli* when being fed surface water. In all cases, treated water was of better quality than the untreated water. Water produced from these filters ranged from medium risk up to extremely high risk (> 1,000 CFU/100 ml) on some occasions. Six and three filters, on average, produced water in the medium risk and high risk categories, respectively. For stored water, seven of nine households using surface water saw an increase in *E. coli* concentration from the treated water from the BSF to the treated water storage container. This demonstrates the importance of ensuring safe storage mechanisms are in place with the BSF.

*Escherichia coli* concentrations in untreated and treated water from the ceramic filters that were fed rain, lake or well water are illustrated in Figure 6. Households C3, C4 and C7 used rainwater as their source water. C8, C10, C11 and C12 used lake water. C2, C5 and C6 used deep well water. Average bacterial removals for households using rainwater, lake or well water were between 0.75 and 1.0 log removal, 0 and 2.0 log removal and 1.75 and 3.0 log removal, respectively. Treated waters from ceramic filters using rainwater were in the low risk category for one filter and medium risk category for the other two filters. For well



**Figure 5** | *E. coli* concentrations for BioSand filters fed surface water (circles represent average values; bars represent high and low values observed during the study); 1st series of bars in each group (bolded) represent untreated water; 2nd series of bars (grey) represent treated water; 3rd series of bars (not bolded) represent stored treated water; number of samples for each household = 11.



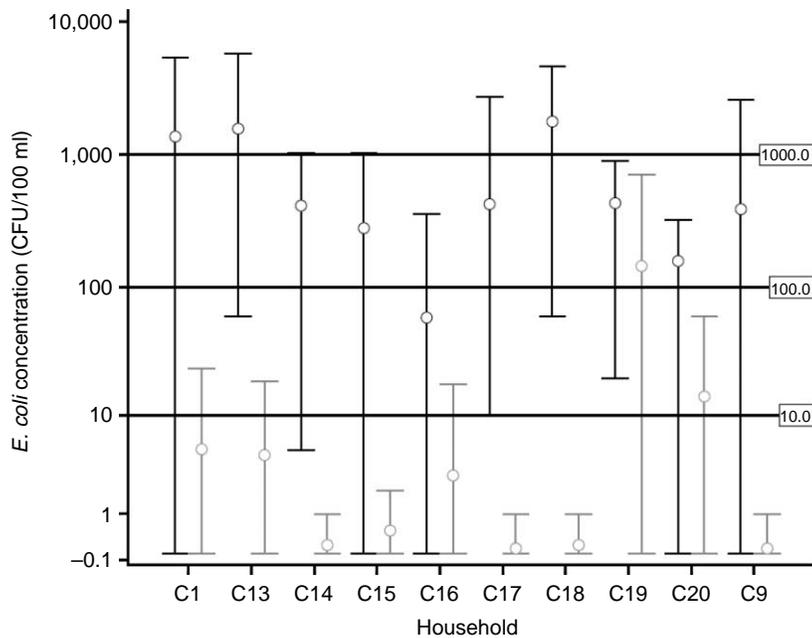
**Figure 6** | *E. coli* concentrations for ceramic filters fed rain, lake or well water (circles represent average values; bars represent high and low values observed during the study); 1st series of bars in each group (black) represent untreated water; 2nd series of bars (grey) represent treated water; number of samples ( $n$ ) for households: C4, C7 & C6  $n = 11$ ; for C12  $n = 10$ ; for C3, C8, C10 and C11  $n = 8$ ; and for C2  $n = 4$ .

water, all three filters produced treated water in the low risk category for exposure to *E. coli*. Treated lake waters were in the low and medium risk categories for one and three filters, correspondingly. In the case of C10, effluent *E. coli* concentrations exceeded influent lake water concentrations. One possible explanation for this is that the household frequently cleaned their filter, especially prior to our visit to their household. Although the filter element and plastic storage container never appeared visibly dirty, improper maintenance of the filter element (e.g. placing the filter on a dirty surface) and improper cleaning of the storage container (e.g. using a dirty cloth, dirty water, no soap) may have resulted in contamination of the stored treated water. This is consistent with findings from another study conducted by the senior author (Murphy *et al.* 2009). Filters were visually inspected at each household visit to see if there were any cracks in the ceramic filter elements. In addition, turbidity and colour were successfully reduced through the ceramic filter for C10; therefore, it is unlikely that there were any cracks in the filter element.

It is interesting that rainwater was more microbiologically contaminated than some of the lake water sources. This may be attributed to the fact that the rainwater would

have been stored for a longer period of time. In addition, rainwater storage jars are not always covered, and are frequently used for various things such as cleaning and bathing. Also, methods of water extraction from the water jars can contaminate the water source such as using a hand or a contaminated dipper.

In Figure 7, *E. coli* concentrations are displayed for untreated and treated water from the ceramic filters fed Mekong River water. Average bacterial removals for *E. coli* ranged from 0.5 to 2.5 log. All filters reduced *E. coli* concentrations to between 0 and 10 CFU/100 ml with the exception of filters C19 and C20. Both C19 and C20 removed turbidity and colour; therefore it is unlikely that there were cracks in the filter elements. In the case of C19, the household cleaned their filter frequently, like household C10 discussed previously, and, as a result, it is likely that improper cleaning practices may have contributed to the poor treated water quality. For C20, the plastic container for the filter often looked dirty inside, the spout was dirty and was broken by a small child, indicating that children had ready access to the filter and could have been tampering with it. The filter was located on a small shelf very close to the floor and therefore accessible to domestic



**Figure 7** | *E. coli* concentrations for ceramic filters fed river water (circles represent average values; bars represent high and low values observed during the study); 1st series of bars in each group (bolded) represent untreated water; 2nd series of bars (grey) represent treated water; number of samples (*n*) for households: C13 *n* = 11; for C17 & C9 *n* = 10; for C16 *n* = 9; for C19, C20 and C1 *n* = 8; and for C14, C15 & C18 *n* = 6.

animals such as cats that may have also been contaminating the filter spout.

### Nitrate and nitrite

Some of the most significant findings of this research were the results for nitrite ( $\text{NO}_2^-$ ) and nitrate ( $\text{NO}_3^-$ ). According to WHO, the guideline values for nitrite and nitrate in drinking water are as follows (WHO 2007a):

- (i) For short-term (acute) exposure to nitrate for bottle-fed infants, the value should not exceed  $50 \text{ mg l}^{-1} \text{ NO}_3^-$
- (ii) For short-term exposure to nitrite for bottle-fed infants, the value should not exceed  $3.0 \text{ mg l}^{-1} \text{ NO}_2^-$
- (iii) For long-term (chronic) exposure to nitrite for all those exposed to the water source, the nitrite value should not exceed  $0.2 \text{ mg l}^{-1} \text{ NO}_2^-$  (provisional guideline)
- (iv) The combined nitrate-nitrite guideline value should be  $\leq 1$ :

$$\frac{C_{\text{nitrate}}}{\text{GV}_{\text{nitrate}}} \oplus \frac{C_{\text{nitrite}}}{\text{GV}_{\text{nitrite}}} \leq 1$$

where *C* = concentration and *GV* = guideline value ( $50 \text{ mg l}^{-1}$  for nitrate;  $3.0 \text{ mg l}^{-1}$  for nitrite).

Nitrate ( $\text{NO}_3^-$ ) concentrations in both untreated and treated waters for the BSFs in this study never exceeded the  $50 \text{ mg l}^{-1}$  acute exposure guideline. For BSFs fed surface water, the average treated water concentrations for nitrate are displayed in Table 2. Eighteen of 20 BSFs monitored

**Table 2** | Average nitrate concentrations in treated water from the BioSand and ceramic filters

Water source	Average $\text{NO}_3^-$ concentrations ( $\text{mg l}^{-1}$ ) (standard deviation) (low-high values observed)	
	BioSand filters	Ceramic filters
Surface water (lake, pond)	3.8 (4.1)	5.0 (4.4)
BioSand <i>n</i> = 34	(0–20.3)	(0–22.9)
Ceramic <i>n</i> = 99		
Deep well (>10 m)	4.0 (3.3)	8.6 (5.6)
BioSand <i>n</i> = 121	(0–15.0)	(0.7–21.4)
Ceramic <i>n</i> = 23		
River (Mekong)	N/A	5.6 (6.7)
Ceramic <i>n</i> = 82		(0–47.8)
Rainwater	N/A	8.5 (5.5)
Ceramic <i>n</i> = 30		(0–24.5)

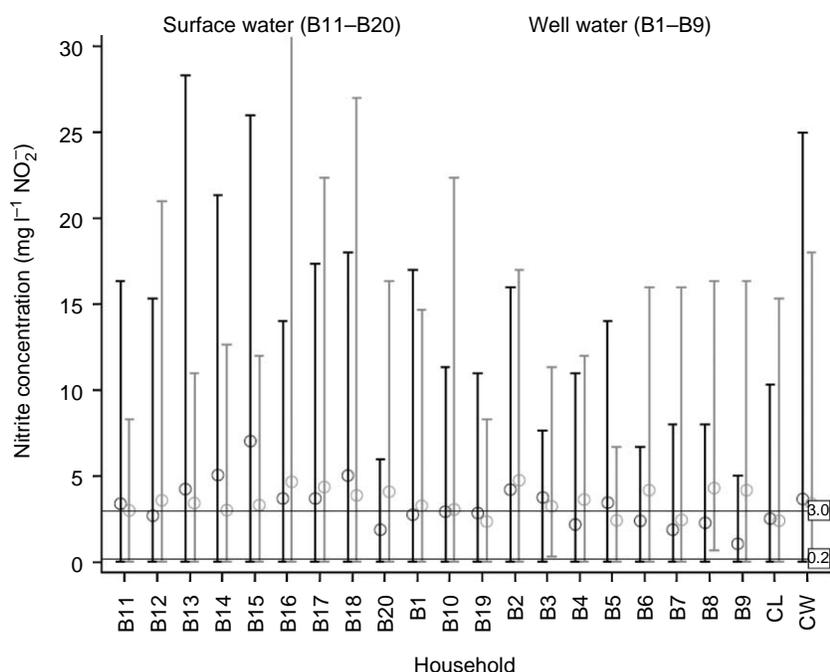
showed an average increase in nitrate from untreated to treated water independent of influent water source. In addition, the two control filters monitored at the RDIC laboratory showed an average increase in nitrate from influent to effluent water. One control filter was fed a local lake source and the other was fed a well water source on the RDIC property.

Treated water from the ceramic filters never exceeded the  $50\text{mg l}^{-1}$  acute exposure guideline for nitrate, with the exception of one of the control ceramic filters (fed well water), which exceeded the guideline on one occasion with a concentration of  $51.3\text{mg l}^{-1}\text{NO}_3^-$ . Average treated water concentrations for nitrate are shown in Table 2. Independent of water source, an average increase in nitrate was observed in 12 of the 20 household filters studied. In addition, an increase in nitrate was also observed in the two control ceramic filters run at the RDIC laboratory. Like the BSF controls, one was fed a lake water source and the other was fed a well water source.

Figure 8 illustrates the nitrite concentrations for influent and effluent water for the BSFs in the current study. From the figure, one can see that 17 of 20 filters on

average exceed or equal the acute guideline value of  $3.0\text{mg l}^{-1}$  for nitrite ( $\text{NO}_2^-$ ) in the treated water. All 20 filters exceed the chronic exposure guideline value of  $0.2\text{mg l}^{-1}\text{NO}_2^-$  in the treated water. Twelve of 20 BSFs see an average increase in nitrite from influent to effluent water. In addition, a matched paired *t*-test was conducted and an average increase of 0.4 and  $0.8\text{mg l}^{-1}\text{NO}_2^-$  was observed for BSFs fed well water and surface water, respectively. These results were significant at the 99.9% confidence interval level with *t* values of 11.51 and 8.98, respectively.

Nitrite was not measured for part 2 of the study for ceramic filters as, initially, it was not anticipated that nitrite concentrations would change substantially within the ceramic filters. However, nitrite was measured during the initial sampling period of the study (part 1), the initial survey of all ceramic filter households. In the initial study, water samples were collected from 56 households that were still using their ceramic filter on a regular basis. Seventeen out of 56 filters generated water that exceeded the  $3.0\text{mg l}^{-1}$  guideline value. Forty-two of 56 households exceeded the  $0.2\text{mg l}^{-1}$  guideline value. Concentrations of nitrite in treated water ranged from 0 to  $8.67\text{mg l}^{-1}$ .



**Figure 8** | Nitrite concentrations for BioSand filters fed surface water and well water (circles represent average values; bars represent high and low values observed during the study); 1st series of bars in each group (bolded) represent untreated water; 2nd series of bars (grey) represent treated water; number of samples (*n*) for all households *n* = 11.

**Table 3** | Average combined nitrate-nitrite guideline values for each household in treated water from the BSFs

Household code	Average combined nitrate-nitrite values	Household code	Average combined nitrate-nitrite values
B1	<b>1.17*</b>	B11	<b>1.06</b>
B2	<b>1.95</b>	B12	<b>1.26</b>
B3	<b>1.14</b>	B13	<b>1.23</b>
B4	<b>1.3</b>	B14	<b>1.05</b>
B5	0.87	B15	<b>1.18</b>
B6	<b>1.48</b>	B16	<b>1.63</b>
B7	0.91	B17	<b>1.52</b>
B8	<b>1.53</b>	B18	<b>1.39</b>
B9	<b>1.49</b>	B19	0.86
B10	<b>1.13</b>	B20	<b>1.47</b>

\*Numbers in bold indicate households that, on average, exceeded or equalled guideline values.

Table 3 presents the average results for the combined nitrate-nitrite guideline value for the 20 BSF filters studied. During the six-month study period, in the untreated source waters, on average, 11 households exceeded the combined nitrate-nitrite guideline value of 1; whereas after treatment an additional six filters, hence a total of 17, did not meet this guideline value. Given that nitrite concentrations were not measured for the ceramic filters for the ongoing study, combined nitrate-nitrite values are not available for the ceramic filters. However, these values were generated for the initial data set of 56 filters studied. Twenty-four of the 56 filters produced treated water that exceeded the combined guideline value of 1.

The discussion of nitrate and nitrite in drinking water supplies is significant as nitrite and nitrate may be harmful to infants, causing methaemoglobinaemia, also known as blue baby syndrome, a condition which occurs when nitrite oxidizes iron in the blood and limits the transport of oxygen around the body causing veins and skin to appear blue. Continued exposure to water exceeding the long term exposure guideline of  $0.2 \text{ mg l}^{-1}$  nitrite, can put people at risk for heart and lung complications as well as diuresis, a stomach condition that causes increased urination, starchy deposits and haemorrhaging of the spleen (USEPA 2006; WHO 2007a). In addition, some research suggests that brain tumours in children could be caused by prenatal exposure to nitrite as a result of pregnant women consuming water

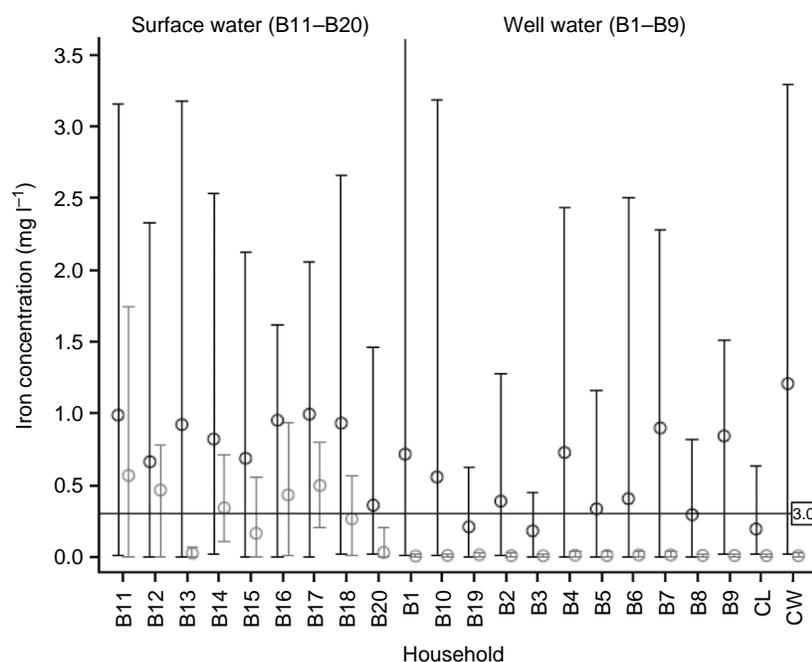
containing nitrite in excess of guideline values (Forman 2004). To date, little is known about the long-term effects associated with drinking water containing high concentrations of nitrite and nitrate.

A much more detailed analysis and discussion as to why nitrate and nitrite concentrations are increasing in the BioSand filter are presented in another paper. In summary, it is believed that combined nitrification, denitrification and ammonification may be occurring inside the BSFs, while nitrification may be occurring inside the ceramic filters.

### Iron and manganese

Although there is no significant health effects associated with iron in drinking water supplies, there are many aesthetic concerns such as taste and odour problems as well as the staining of laundry. The WHO aesthetic guideline for iron is  $0.3 \text{ mg l}^{-1}$ . In nearly all untreated water sources for the BSFs, total iron exceeded the  $0.3 \text{ mg l}^{-1}$  as shown in Figure 9.

Iron removal in sand filters occurs through two principal mechanisms: oxidation by aeration and adsorption of iron oxides onto the sand surfaces, or through microbial oxidation by iron-oxidizing bacteria followed by adsorption (Letterman 1999). For BSFs fed well water, >99% removal of iron was achieved by the BSFs and all filters produced water below the WHO guideline. For the BSFs fed surface water, iron removal varied from 40 to >99% removal. Four of nine filters fed surface water produced water below the WHO guideline. These results are somewhat surprising as they show that the iron is being removed more easily from well water sources than from surface water sources. The iron found in well waters is generally in the dissolved, more difficult to remove form ( $\text{Fe}^{2+}$ ) and in surface waters it is in the insoluble form ( $\text{Fe}^{3+}$ ). It is plausible that pumping of the well, transport to the BSF, and then pouring the water into the filter through the diffuser could aerate the well water enough to oxidize the iron to the more readily removed form,  $\text{Fe}^{3+}$ . At that point, the iron may have been adsorbed to the sand surface as it passes through the filter, thus explaining the high removal observed for the well water sources. Interestingly, this does not seem to be the case for all the surface water sources. Many households retrieved their



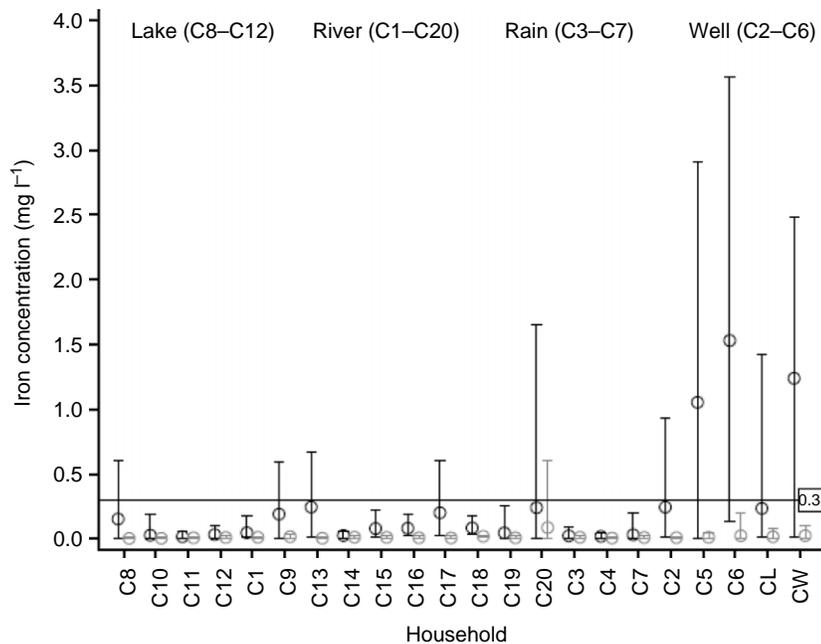
**Figure 9** | Total iron concentrations for untreated and treated water from BioSand filters (circles represent average values; bars represent high and low values observed during the study); 1st series of bars in each group (bolded) represent untreated water; 2nd series of bars (grey) represent treated water; CW is the control filter fed well water; CL is the control filter fed lake water; number of samples ( $n$ ) for all households  $n = 11$ .

source water directly from the surface water source prior to filling their filters; in other words, they did not store their surface water at their home. These waters were often very murky, stagnant and low in dissolved oxygen. It is possible that the form of iron in these waters was predominantly the reduced form ( $\text{Fe}^{2+}$ ) and there was not enough aeration between collection of the water and filling the BSF to convert the iron to  $\text{Fe}^{3+}$ , therefore explaining the low iron removal observed (Letterman 1999). In addition, if the iron in these surface waters was in the free metal form,  $\text{Fe}^{2+}$ , it was probably complexed to natural organic matter (NOM) which is often the case for surface waters, and consequently more difficult to remove from water supplies (Letterman 1999).

Although, neither total organic carbon nor dissolved organic carbon (DOC) were measured in this study, colour was documented and these waters had colour readings of between 44 and 558 Pt Co units with an average of 167 Pt Co units. Given that colour and DOC have a tendency to be correlated and indicators of NOM, one can assume that the surface waters in this study were relatively high in NOM which could have complexed the iron and thus led to poor removal through the filter (Rathnaweera *et al.* 1999).

In addition, iron removal may occur biologically by iron-oxidizing bacteria. These bacteria are prevalent in the environment such as in groundwater, swamps, ponds and wells (Pacini *et al.* 2005). It is possible that iron-oxidizing bacteria were more abundant in groundwater than the surface water in this study and thus increased iron removal in BSFs fed well water.

Figure 10 shows the iron concentrations observed in source water and treated water from ceramic filters. In general, the water sources were low in iron with the exception of the well waters. On average, all source waters except C5, C6 and the control well water (CW) were below the  $0.3 \text{ mg l}^{-1}$  guideline. For the three well water sources, the ceramic filters were consistently able to reduce the iron concentration to below the WHO guideline of  $0.3 \text{ mg l}^{-1}$  and achieved >99% removal of iron. These results are consistent with the results found by Low (2002) who reported greater than 90% removal of iron by ceramic filters. It is expected that the iron was oxidized from  $\text{Fe}^{2+}$  to  $\text{Fe}^{3+}$  during the pumping process and transport of water to the ceramic filters. The  $\text{Fe}^{3+}$  was subsequently removed by sedimentation in the ceramic filter as well as adsorption on the ceramic filter surface. Some biological



**Figure 10** | Total iron concentrations for untreated and treated water from ceramic filters (circles represent average values; bars represent high and low values observed during the study); 1st series of bars in each group (bolded) represent untreated water; 2nd series of bars (grey) represent treated water; CW is the control filter fed well water; CL is the control filter fed lake water; number of samples ( $n$ ) for households: C13, C4, C7 & C6  $n = 11$ ; for C17, C12 & C9  $n = 10$ ; for C16  $n = 9$ ; for C1, C3, C5, C8, C10, C11, C19 & C20  $n = 8$ ; for C14, C15 & C18  $n = 6$ ; and for C2  $n = 4$ .

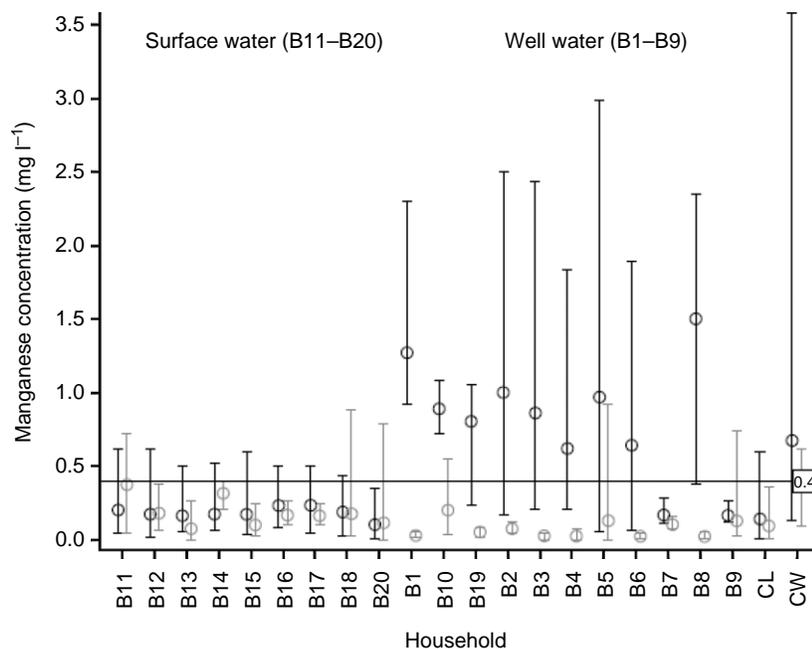
iron oxidation and subsequent removal may have also occurred at the ceramic filter surface, as a biofilm layer may exist if the ceramic filter is constantly filled with water and never left to dry out. Given that biofilms exist on all types of surface in contact with water, it is plausible that a biofilm exists inside the ceramic filter, especially since it has such a slow flow rate, and users often re-fill their filter before it has run dry (Marshall 1992). Further research would need to be conducted to confirm the nature of a biofilm within the ceramic filter.

The WHO health-related guideline for manganese in drinking water is  $0.4 \text{ mg l}^{-1}$ . The principal health concern associated with manganese (Mn) in drinking water is that extended exposure to high concentrations can lead to adverse neurological effects (Mergler 1999; WHO 2006). In a study conducted in Bangladesh on 142 ten-year-old children drinking water containing manganese with an average concentration of  $0.793 \text{ mg l}^{-1}$ , it was found that Mn was associated with neurotoxic effects resulting in poor intellectual function (Wasserman *et al.* 2006).

Figures 11 and 12 show the average influent and effluent concentrations of manganese observed for both

BSF and ceramic filters as well as high and low values observed during the sampling period. Manganese was below the WHO guideline for surface water sources used to feed the BSFs. Nine of 11 well waters exceeded the WHO guideline of  $0.4 \text{ mg l}^{-1}$  considerably. Manganese removal capabilities of the BSFs were  $>97\%$  for those fed well water.

Similar to iron, manganese must be in the more oxidative state,  $\text{Mn}^{4+}$ , in order to be easily removed in the BSF through adsorption. The manganese was probably oxidized in the same way as the iron through aeration from pumping, transporting and pouring of the well water through the diffuser into the BSF or through manganese-oxidizing bacteria followed by adsorption on the sand surface. For filters B7, B9 and CW, all fed a well water source, Mn removal efficiencies were notably lower. Given the small initial concentrations of Mn for B7 and B9, it would be expected that treated water concentrations would be closer to zero. In all three filter cases, ammonia ( $\text{NH}_3$ ) concentrations in effluent water samples ranged from 0.15 to  $12.58 \text{ mg l}^{-1}$ . Several authors have reported that manganese removal does not occur in sand filters until ammonia is



**Figure 11** | Total manganese concentrations for untreated and treated water from BioSand filters (circles represent average values; bars represent high and low values observed during the study); 1st series of bars in each group (bolded) represent untreated water; 2nd series of bars (grey) represent treated water; CW is the control filter fed well water; CL is the control filter fed lake water; number of samples ( $n$ ) for all households  $n = 11$ .

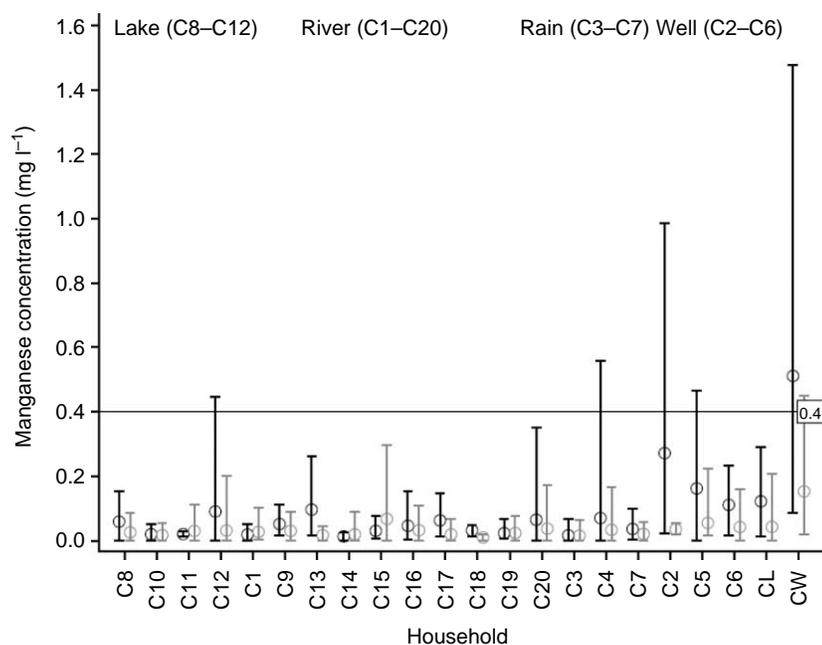
completely oxidized to nitrate ( $\text{NO}_3^-$ ) (Vandenabeele *et al.* 1995a,b). Tekerlekopoulou & Vayenas (2008, p. 219) reported that ‘ammonia and iron drastically affect manganese oxidation’. In addition to having relatively high concentrations of ammonia remaining in the effluent of the treated waters from filters B7, B9 and CW, Figure 9 shows they all have the highest influent concentrations of iron of all the filters fed well water. Consequently, it is probable that incomplete nitrification in these filters as well as high influent concentrations of iron contributed to poor manganese removal in these filters. This phenomenon may also apply to the BSFs fed surface water. All surface water sources for the BSFs had relatively high concentrations of iron, and treated water from all the surface water filters contained ammonia, with an average increase in ammonia of  $0.1 \text{ mg l}^{-1}$  from influent to effluent. This proved significant in a matched paired  $t$ -test at the 99.9% confidence interval with a  $t$ -value of 24.5.

Figure 12 illustrates that all household source waters for ceramic filters were, on average, below the WHO guideline for manganese. The control ceramic filter was fed well water with an average concentration of  $0.5 \text{ mg l}^{-1}$  of manganese. The manganese removal for this filter varied

from 0 to 97%. Filters C5 and C6 had manganese removal between 0 and 96%. Given that the well water sources for C5, C6 and CW also contained high concentrations of iron ( $>1.0 \text{ mg l}^{-1}$ ), the presence of iron was likely to be responsible for poor and inconsistent manganese removal in these filters. It is also plausible that the aeration prior to filtration through the ceramic filters was not enough to oxidize the manganese. Unlike the BSF, the ceramic filter does not contain a diffuser and, therefore, aeration through transport to the ceramic filter may not have been enough to oxidize the manganese from  $\text{Mn}^{2+}$  to  $\text{Mn}^{4+}$ , which means it remained in the dissolved form and passed through the filter. Filter C2, also fed well water, had initial iron concentrations on average below  $0.3 \text{ mg l}^{-1}$  and, as a result, had increased manganese removal over the other filters in the range of 37–95%.

### Fluoride

Fluoride is abundant in the Earth’s crust and is naturally occurring in drinking water. In low concentrations it can be beneficial for maintaining healthy teeth; however in high concentrations it can be lethal. In addition, elevated levels



**Figure 12** | Total manganese concentrations for untreated and treated water from ceramic filters (circles represent average values; bars represent high and low values observed during the study); 1st series of bars in each group (bolded) represent untreated water; 2nd series of bars (grey) represent treated water; CW is the control filter fed well water; CL is the control filter fed lake water; number of samples ( $n$ ) for households: C13, C4, C7 & C6  $n = 11$ ; for C17, C12 & C9  $n = 10$ ; for C16  $n = 9$ ; for C1, C3, C5, C8, C10, C11, C19 & C20  $n = 8$ ; for C14, C15 & C18  $n = 6$ ; and for C2  $n = 4$ .

of fluoride may cause dental fluorosis (teeth mottling) and may cause serious effects on skeletal tissues. The WHO guideline for fluoride in drinking water is  $1.5 \text{ mg l}^{-1}$  (WHO 2006). The fluoride levels measured for source water and treated water from both the ceramic filters and BSFs rarely exceeded the WHO guidelines; consequently, fluoride data will not be discussed in detail. The results regarding fluoride removal were somewhat inconclusive. In 12 of 22 BSFs (including controls) an average increase in fluoride was observed between influent sources and treated effluent from the BSFs. In a matched paired  $t$ -test, this increase was found to be mildly statistically significant at the 80% confidence level with a  $t$ -value of 1.39. In these cases, fluoride must be leaching from the sand or the concrete frame of the BSF. In the other 10 cases, some or no removal of fluoride was observed. All treated waters from the BSFs were well below the  $1.5 \text{ mg l}^{-1}$  guideline for fluoride with the exception of one sample.

In 18 of 22 ceramic filters (including controls) an increase in fluoride was observed from untreated to treated water sources. In a matched paired  $t$ -test, an average increase of  $0.11 \text{ mg l}^{-1}$  was found to be significant at the

99.9% confidence level with a  $t$ -value of 3.357. The other four filters provided some or no fluoride removal. In all cases, except for two data points, treated water values never came close to the WHO guideline value of  $1.5 \text{ mg l}^{-1}$ . In these two cases, influent water quality exceeded the  $1.5 \text{ mg l}^{-1}$  guideline. It appears there may be fluoride in the clay pot mixture that is being released into the treated water as it passes through the filter. These results were unexpected given that clay has been identified as a potential treatment for fluoride in water supplies (Hauge *et al.* 2007). It may be possible that removal may be only observed at higher fluoride concentrations; consequently in the current study removal was not observed, since fluoride concentrations in source waters were generally between 0 and  $0.75 \text{ mg l}^{-1}$ .

#### Probability of exceeding WHO guidelines

A probability of exceedance analysis was performed for nitrite, nitrate, iron, manganese, fluoride and *E. coli* for both BSFs and ceramic filters monitored in the field. The results are presented in Table 4. The probabilities of exceeding the 0.2 and  $3.0 \text{ mg l}^{-1}$  nitrite guidelines for both ceramic and

**Table 4** | Probability that treated water will exceed WHO guidelines

Parameter	Guideline value	Probability of exceedance (%)	
		BioSand filters (n = 220)	Ceramic filters (n = 169)
Nitrite (NO <sub>2</sub> <sup>-</sup> )	0.2 mg l <sup>-1</sup>	75	73 <sup>*</sup>
	3.0 mg l <sup>-1</sup>	33	30 <sup>*</sup>
Nitrate (NO <sub>3</sub> <sup>-</sup> )	50 mg l <sup>-1</sup>	<1	<1
Manganese (Mn)	0.4 mg l <sup>-1</sup>	4	1
Iron (Fe)	0.3 mg l <sup>-1</sup>	22	<1
Fluoride (F <sup>-</sup> )	1.5 mg l <sup>-1</sup>	<1	<1
<i>E. coli</i>	> 0 CFU/100 ml	56–67 <sup>†</sup>	30–40
	> 10 CFU/100 ml	37 <sup>†</sup>	15
	> 100 CFU/100 ml	14 <sup>†</sup>	6

\*These values were generated from the preliminary data set (part 1 of the study); as a result only 56 data points were included. The number of data points included for the BSF analysis was 220.

†These values were generated from the results from the treated water collected directly from the BSF spout, not from the treated water storage container.

BioSand filters were nearly the same. However, having said that, the analysis was only performed with 56 data points for the ceramic filters since nitrite was not measured for part 2 of the study. It would be interesting to see if these ceramic filter results would have been the same over a longer period of time into the dry season. The primary difference found between the BSFs and the ceramic filters is that there was a 22% probability of exceeding the iron water quality guideline in BioSand filters compared with ceramic filters. In addition, the ceramic filters had a higher probability of reaching the low risk guideline of between 0 and 10 CFU/100 ml for *E. coli*. This could be partly attributed to the fact that the surface water feeding the BSFs was of worse quality than many of the waters feeding the ceramic filters in this study. However, it is expected that the difference in probabilities would also be significantly higher if the probability of exceedance analysis was performed on the stored treated water from the BSFs instead of the water from the BSF spout. Given that the ceramic filter is enclosed within its storage container (Figure 2) and the storage container for the BSF is separate from the system, the treated water from the BSF is more likely to become contaminated in everyday use. Consequently, the treated water a BSF household would be drinking was often of lower quality than in those households using ceramic filters with enclosed containers.

## CONCLUSIONS/RECOMMENDATIONS

The findings indicated that ceramic and BioSand filters are not capable of consistently meeting WHO guidelines for drinking water. Both technologies fail to consistently treat water below the WHO guidelines for nitrite and provide water in the low risk category for *E. coli*. The probabilities of exceeding the WHO guidelines for nitrite in both types of filter were similar, ranging from 30 to 33% and 73 to 75% for the 0.2 and 3.0 mg l<sup>-1</sup> guidelines, respectively. Neither technology increased nitrate concentrations to above WHO guidelines, but nearly all filters saw an average increase in nitrate from influent to effluent. Both filters were capable of removing some manganese and iron depending on the influent water quality characteristics; however, manganese removal was not consistent. Fluoride results were inconclusive as to whether or not either technology can consistently treat for fluoride. The ceramic filters provided water in the low risk range for *E. coli* more frequently than BSFs. This might be attributed to the fact that the BSFs fed surface water had significantly higher concentrations of influent bacteria than the ceramic filters. Nevertheless, the water from the BSF treated water storage containers and, ultimately, the water a household would be using as their drinking water source, rarely met the low risk category guideline for *E. coli* of 0–10 CFU/100 ml. Only two of 20 households had treated stored water from their BSF that met these guidelines compared with 13 ceramic filters that produced stored treated water that met the low risk guideline.

The results indicate that more research should be conducted to establish the treatment capabilities of both of the POU technologies in a field setting. Removal mechanisms for manganese and iron in these systems are not well understood, fluoride removal results were inconclusive, and further analysis on nitrate-nitrite formation in these filters is still needed.

Until further research can be done, the following are a list of recommendations suggested for organizations looking to implement either of these technologies in the field:

1. Source water quality should be tested prior to use of either technology. If a filter implementation is to take place in an intensive agricultural area or in a location

where the presence of human and/or animal faecal waste could be contaminating water supplies, it is suggested that households use a water source that contains lower concentrations of nitrate and nitrite (if possible) to feed their filters.

2. In order to reduce the risk of blue baby syndrome in infants, it is recommended that an alternative source of treated water be used to make formula for bottle-fed infants, instead of relying on treated water from these systems. WHO recommends that water is boiled or heated to at least 70°C when preparing formula for infants (WHO 2007b).
3. Households who choose to boil their water after these filters should be cautioned, as boiling could concentrate the nitrate and nitrite to more harmful levels as found by Walton (1951) and Winton *et al.* (1971).
4. In the cases where concentrations of nitrite are high in treated water from BSFs or ceramic filters, the addition of chlorine or another oxidant may be useful to convert nitrite to the less harmful form of nitrate (Gerardi 2002, p. 92). This, however, will not always consistently reduce the combined nitrate-nitrite value to below the guideline value of 1. This value will be largely dependent on how much nitrate and nitrite is initially present in the treated water. Nevertheless, using an oxidant will help reduce the chronic and acute risks associated with high concentrations of nitrite in the water supply.
5. Education associated with appropriate maintenance and cleaning practices is crucial in order to protect treated water from microbiological contamination.
6. The addition of a secondary disinfectant such as chlorine may be useful in protecting treated water supplies in storage containers for both technologies.
7. Although this research suggests that POU filters can treat for iron and manganese, it is unknown whether these technologies will be capable of providing consistent treatment for either of these contaminants in the long term. The filters may provide treatment until all adsorption sites have been used up within the filter and at that point may start leaching iron and manganese into the treated water. It is expected that the media in the sand filter and the ceramic filter elements would need to be regenerated or replaced if metals removal was practised in the long term.
8. There is no consistent performance by either POU and therefore claims for removal of contaminants should be made with caution.
9. Household practices, as well as maintenance practices, in particular cleaning, can play an important role in the performance of these POU filters.

## ACKNOWLEDGEMENTS

This work was carried out with the aid of a grant from the International Development Research Centre, Ottawa, Canada, Canada Research Chair funding and student funding from The Natural Science and Engineering Research Council of Canada (NSERC). In addition, the Cambodian partners: Cambodia Global Action (CGA), Resource Development International Cambodia (RDIC) and the Samaritan's Purse Canada are acknowledged for their ongoing support throughout the research. The authors would like to acknowledge the late Dr Michael Sampson from RDIC for his support through the initial phases of the study in Cambodia. Finally, the authors wish to recognize the Bridge Students from RDIC for their hard work in the field and laboratory throughout the duration of the project work in Cambodia.

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First received 10 November 2009; accepted in revised form 11 January 2010. Available online 20 April 2010