Assessing reported use and microbiological performance of a point-of-use household water filter in rural Fiji
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ABSTRACT
A non-governmental organisation has distributed point-of-use water filtering units in the Western Division of Fiji. We sought to understand filter utilisation and water quality: both water flowing directly out of filters and stored water. We surveyed 270 households and 6 schools on filter use and performed hydrogen sulphide bacterial indicator testing on 24 water samples directly from filters and 37 stored water samples. Our response rate was 95%. Of these, only half (52%) reported consistently filtering their drinking water. Very few (8%) reported consistent use when preparing kava, a traditional drink. Factors associated with limited filter use included lost or broken filter parts (22%) ($p < 0.05$) and perception of source water quality as 44% of respondents who believed their source water was safe to drink reported consistent filter use compared to 68% of respondents who did not ($p < 0.01$). Bacterial indicator testing using hydrogen sulphide paper-strips showed that most water samples directly from the filter (71%) and from storage vessels (76%) were contaminated. Limited levels of use and high levels of contamination in both water directly from the filter and stored water raise serious questions as to the benefit of the filter even as an interim water quality solution in this setting.

Key words | drinking water, Fiji, hydrogen sulphide test, point-of-use, sustainability, water filter

ABBREVIATIONS
GCW Give Clean Water
H$_2$S Hydrogen sulphide
HWT Household water treatment
MOH Fiji Ministry of Health
NGO Non-governmental organisation
SODIS Solar disinfection
SOPAC Applied Geoscience and Technology Division
SPC Secretariat of the Pacific Community
WAF Water Authority of Fiji
WHO World Health Organization

INTRODUCTION
Unsafe drinking water, along with inadequate hygiene and sanitation are leading causes of diarrhoeal disease worldwide (Pruss-Unstun et al. 2008). Most of the transmission of diarrhoeal disease takes place at the household level (Curtis et al. 2000) and can occur through many different pathways, including through drinking water. Point-of-use water treatment at the household level or household water treatment (HWT) is a method by which individuals can treat their water in their households in settings lacking an adequate supply of safe drinking water (Clasen et al. 2007). HWT techniques other than boiling water include slow-sand filtration, membrane filtration, chlorination, solar disinfection (SODIS) and flocculation-coagulation and have had varying degrees of success in the field and reported effectiveness may be the result of bias (Schmidt & Cairncross 2009; Cairncross et al. 2010).

Filtration, SODIS and other HWT techniques are not nearly as common as boiling water (Rosa & Clasen 2010).
There are published trials and evaluations of HWT options in most regions where their use may be of benefit, including in Latin America (Mäusezahl et al. 2009), Africa (Crump et al. 2005; Boisson et al. 2009), and Asia (Gupta et al. 2008). To the best of our knowledge, the available literature lacks evidence on the use or effectiveness of HWT in the Pacific region.

Beginning in October 2008, an American based non-profit non-governmental organisation (NGO) Give Clean Water, Inc. (GCW) (http://www.givecleanwater.org), set up operations in Fiji and from that time to April 2011 donated approximately 1,970 personal water filtering units to rural communities and schools in the Western Division of Fiji (Dip Chand, Fiji Ministry of Health Divisional Health Inspector Western, personal communication, 26 April 2011). Sawyer® Products Inc. manufactures the filters and GCW has distributed them to individual households and schools. The manufacturer states this particular water filter has a functional lifetime guarantee, a 73.5 litres/hour flow-rate from a full 19 litre bucket with a 91 cm hose attachment, ease of operation and maintenance, and ability to decrease the turbidity of the water (Sawyer® 2008) over some other common methods of HWT (Lantagne et al. 2006). In a laboratory setting, the filter achieves a removal rate greater than 5 log and 6 log for protozoan parasites and bacteria respectively (Sawyer® 2005). The filter is too large to remove viruses. We found no data on this filter’s field effectiveness.

In April 2011, the Fiji Ministry of Health (MOH) requested the Applied Geoscience and Technology Division (SOPAC) of the Secretariat of the Pacific Community (SPC) and the World Health Organization (WHO) South Pacific Office to evaluate the efficacy of the Sawyer® filters being used in the country. Specifically, our objectives were to understand the frequency of filter use and the quality of filter effluent. This research aims to contribute to understanding how HWT options are used in the field and add to international literature on one example of HWT use in the Pacific region.

**METHODS**

**Study location**

The Fiji Islands (pop. 850,000) are located in the South Pacific Ocean and Nadi, where the country’s primary international airport is located, sits at approximately 17°S and 177°E, 2,000 km north of New Zealand, and 3,500 km east of Townsville, Australia.

This study investigated communities and schools in the western region of Viti Levu, the largest island in Fiji, where the NGO that provided the water filters was operating as of April 2011 (Figure 1).

**Filter**

The NGO provided households with The Sawyer Point One™ Filter Bucket Adapter Kit (http://www.sawyerpointonefilters.com) and two plastic buckets. This kit has multiple components, including a 0.1 micron hollow fibre membrane filter, a 91 cm long hose, a hole cutter tool, a hanger, a syringe, and fittings. Once assembled, gravity allows water that is poured into the first bucket to flow down through the hose and the filter and into a second storage bucket. To ‘turn off’ the filter, a hanger that connects to the top of the first bucket is used to hang the filter above the water level in the first bucket thus stopping the flow when not in use. The NGO demonstrated the assembly of units and backwashing the filters and left contact information to request replacement parts and technical assistance. Users are expected to clean the filter once flow-rate has noticeably slowed by backwashing using a syringe to force clean water backwards through the filter.

**Initial visits**

A team consisting of two SOPAC staff members and an MOH Environmental Health Inspector visited all study sites. During these visits the team met with at least one representative of each community or school to verify they had been visited by the NGO, obtain information on when and how many filters their community or school was given, and record the number of houses in the community and the school roll.

**Selection of villages and schools**

We acquired, from MOH, a list of 32 villages or settlements, 14 schools, and one orphanage where the NGO installed filtering units as of 11 April, 2011. We then mapped out
these locations to gain an understanding of the geographic area of distribution (Figure 1).

We selected nine villages and six schools for this study. We randomly selected these sites to represent three distinct geographical areas (Ba, Nadi, and Sigatoka), different filter installation years (2008, 2009, and 2010), and varying ethnic composition (Indigenous Fijian and Indo-Fijian). We invited a systematic random sample of half of the households that received filtering units at each selected site to participate; a total of 284 households. Of these, 270 agreed to participate, yielding a response rate of 95%, a sample representing roughly 14% of the total recipient households. This sample is estimated to provide a 95% confidence level with a ±6.0% confidence interval and 80% power to detect a 15% difference between groups at \( p = 0.05 \). The interviewing team made all site visits between 20 June and 2 July 2011.

**Survey**

We developed separate questionnaires for households and schools to determine demographic information, water sources, and knowledge and perceptions of drinking water-related diseases and water treatment. We also asked study participants how frequently they filtered their water for drinking and for kava preparation. Kava is a non-alcoholic traditional Fijian drink with sedative properties that is made by mixing water with the pounded root of the *Piper methysticum* plant and plays an important social and ceremonial role in the Western Pacific, including in Fijian culture (Lebot *et al.* 1997). Both men and women, but not children, regularly consume kava in rural Fiji. Survey questions had coded responses and were pre-tested during initial site visits. All study participants spoke at least one of Fiji’s three national languages: English, Fijian or Hindi. Questionnaires were written in English and bilingual interviewers were trained with the survey prior to site visits.

**Survey visits**

A group of two SOPAC staff members and one or two MOH officials made unannounced site visits to conduct surveys. The group split into two teams of one or two and began...
surveying at opposite ends of the village. Each team surveyed alternating households resulting in a survey of 50% of the households in the site. In the case of schools, the team interviewed the principal and/or senior management staff. All interviews were conducted orally in the preferred language of the study participant: Fijian, Hindi, or English. Following the interview, the teams asked the male or female head of household to show their filtering unit. We asked every tenth householder to demonstrate how they filtered their water and how to backwash the filter. We also observed the state of the filtering unit, the apparent cleanliness of the unit and its surroundings and whether or not the individual demonstrated proper filtration or backwashing techniques.

To understand knowledge of the dangers of contaminated water and possible motivations for using a filter we asked participants: ‘what are the diseases or health problems you can get when you drink water that is contaminated or dirty?’ and asked if they agreed or disagreed with the statements ‘Can people die from drinking dirty water’ and ‘Does filtering make dirty/contaminated water clean to drink?’

**Water sampling**

During the survey visits to communities, we also collected water samples directly from drinking water sources or, in cases where the source was under the Water Authority of Fiji (WAF), directly from a tap. Initially the teams targeted every fifth house in each village for collecting samples from filters and storage containers holding filtered water. However, because households infrequently had water in their filtering bucket or storage container at the time of the visits, we took samples whenever it was possible to do so as a convenience sample. At each site we took negative control samples using bottled water.

**Microbiological water testing**

We tested water samples from source water, filter effluent and storage containers holding filtered water using the hydrogen sulphide (H$_2$S) paper-strip test (Mosley & Sharp 2005). The H$_2$S test detects hydrogen sulphide gas producing bacteria which have a reasonable correlation (100, 84 and 89% with the Eijkman test, Membrane Filter Technique and Most Probable Number test, respectively) with faecal contamination and can be used to assess water contamination (Mosley & Sharp 2005; Tambekar et al. 2007). The H$_2$S test is a simple presence/absence test whereby ‘low’, ‘medium’ or ‘high’ contamination is indicated by a colour change to varying shades of black. We chose this test because it does not require electricity, refrigeration, or a cold chain and is therefore ideal for remote and isolated rural communities in the Pacific because of its ease, simplicity and low cost (Mosley & Sharp 2005).

**Statistical analyses**

Data were entered into Excel and analyses conducted using Stata 11 (StataCorp 2009). Households sampled were clustered into villages, therefore analyses were adjusted for clustering at the village level. The mean difference between frequency of filter use for drinking water and kava was calculated and chi-squared tests were used to explore associations between frequency of filter use and three other variables: proportion of dysfunctional parts, age of the filter and perceptions regarding the quality of source water. Two-sided p-values of 0.05 were considered statistically significant in all cases.

**RESULTS AND DISCUSSION**

**Demographic information**

We targeted 284 households to survey and successfully completed 270 of them. Demographic characteristics of the study population are described in Table 1.

| Study population, (N – 1399) n (%) |
| Age |
| Under 5 years | 174 (12.4) |
| 5–60 years | 1,110 (79.3) |
| > 60 years | 115 (8.2) |

| Gender |
| Women | 698 (49.9) |
| Men | 701 (50.1) |
Source water contamination

Drinking water sources at the sites we surveyed included boreholes, wells, surface water, rainwater catchments, and WAF. Some sites had two or more separate sources of water. H2S testing indicated that most water sources were contaminated at time of sampling (Table 2).

Under normal circumstances, households utilised the same primary source throughout the year for drinking and other general purpose uses. All wells we observed were hand-dug and uncovered. WAF treats its water by clarification, pressure filtration and chlorination before delivery.

At the time of sampling, 55% of all samples we took from both primary and secondary water sources were indicated by H2S testing as having bacterial contamination. A higher proportion of village water sources were contaminated (78%) than school water sources (22%) (chi-squared p < 0.05). Although it was highly likely that village water sources were contaminated at the time of visit, over half (59%) of study participants believed they were safe, suggesting a lack of awareness amongst study participants about their source water quality. This may in turn affect their willingness to take preventative action towards waterborne diseases.

Filter use in villages

Overall, only about half (52%) of respondents reported consistently (always or most of the time) filtering water for drinking (Table 3). The frequency of consistent filter use for drinking water (52%) was higher than for kava (8%) (p < 0.01).

The proportion of filters consistently used by households in this study population varied considerably over different villages, from 9 to 90%. There was no difference in filter use by year of installation (chi-squared p = 0.25).

Barriers to filter use

Some (22%) study participants indicated they were not able to use the filtering units at all due to broken or missing parts. Sites that received their filters in earlier years had higher proportions of dysfunctional units, (chi-squared p < 0.05). At sites where filters were received in 2008 (n = 77), 32% were dysfunctional. In 2009 (n = 116) this was 25% and in 2010 (n = 77) this was 6%.

Overall, more than half (59%) of respondents believed their community’s water source was safe to drink without being treated. Amongst those who believed that their water was safe to drink, 44% still reported consistent filter use, less than those who believed their water to be unsafe (68%), p < 0.01. This indicates that some belief of source water contamination may contribute to more consistent use of a HWT device.

Required maintenance practices for keeping the filtering unit operational also likely had an effect on usage. While in the field, the interviewing teams observed householders having difficulty backwashing their filters properly. The backwash syringe is a small, separate unit and is easily lost. Infrequent or improper backwashing can lead to a drastic reduction or complete interruption of filter flow.

### Table 2 | Primary water source types and quality as indicated by H2S testing at the time of sampling

<table>
<thead>
<tr>
<th>Primary water source</th>
<th>Study households, N = 270 n (%)</th>
<th>Schools, N = 6 n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface water</td>
<td>128 (47)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>WAF</td>
<td>82 (30)</td>
<td>5 (83)</td>
</tr>
<tr>
<td>Borehole</td>
<td>50 (19)</td>
<td>1 (17)</td>
</tr>
<tr>
<td>Well</td>
<td>10 (3)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>High contamination at time of sampling</td>
<td>197 (73)</td>
<td>1 (17)</td>
</tr>
<tr>
<td>Medium contamination at time of sampling</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Low contamination at time of sampling</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
</tbody>
</table>

### Table 3 | Frequency of household filter use

<table>
<thead>
<tr>
<th></th>
<th>Drinking water, N = 270 n (%)</th>
<th>Drinking water in kava, N = 251 n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filtered water is used</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Always</td>
<td>81 (30)*</td>
<td>12 (5)*</td>
</tr>
<tr>
<td>Most of the time</td>
<td>59 (22)</td>
<td>7 (3)</td>
</tr>
<tr>
<td>Half the time</td>
<td>20 (7)</td>
<td>11 (4)</td>
</tr>
<tr>
<td>Rarely</td>
<td>25 (9)</td>
<td>10 (4)</td>
</tr>
<tr>
<td>Never</td>
<td>85 (31)</td>
<td>211 (84)</td>
</tr>
</tbody>
</table>

*Frequency of consistent filter use is higher for water than kava, p < 0.01.
Filter use in schools

Two of the six schools were using the filters to treat their water before drinking on a regular basis. One of these schools gave students the option of drinking the filtered water or drinking directly from a WAF source tap while the other school required students to take drinking water from the filter. Two other schools used the filters only a few times per year when water from the tap appeared turbid or if they needed to drink from rainwater catchments during times of government supply water shortages. The remaining two schools no longer had possession of their water filters, purportedly due to staffing issues.

This study has found inconsistent filter use, but this does not differ from many settings where point-of-use water treatment has been introduced. There are other examples of inconsistent use in the time period following the intervention, raising questions about the sustainability of point-of-use interventions (Luby et al. 2008; Sobsey et al. 2008; Schmidt & Cairncross 2009; Boisson et al. 2010).

Perception of waterborne illness

Study participants most commonly identified contaminated water (80%) as a cause for members of their community getting diarrhoea while fewer identified contaminated food (25%) and an unhygienic living environment (10%) as a cause. Very few (9%) were unable to identify a cause of diarrhoea. The apparent lack of awareness of the study participants on the importance of hygiene is of concern because of the potential for recontamination of the treated water or alternative transmission routes for diarrheal disease (Cairncross et al. 2010).

Respondents identified diarrhoea (52%), stomach aches (25%), typhoid fever (13%), headaches (6%) and vomiting (5%), while 8% were unable to identify a consequence to drinking contaminated water. Most (87%) study participants agreed with the statement ‘People can die from drinking dirty water’ and nearly all (96%) agreed ‘Filtering makes dirty/contaminated water clean to drink’.

Microbiological performance of the filter in the field

A total of 24 water samples directly from the filters and 37 samples from storage containers holding filtered water were tested for contamination using H2S testing. H2S levels, correlated to contamination levels (Tambekar et al. 2007), showed that most samples indicated some level of bacterial contamination (Table 4).

The high proportion (71%) of samples indicating the presence of contamination directly from the filters is a concern that must be addressed if this filter should even be considered an interim solution to water quality issues in this setting. It is not clear from this study why filter effluent was so frequently contaminated. It is possible that the filter does not perform in the field as claimed by the manufacturer. Another explanation may be related to backwashing practices. According to the Sawyer Point One Filter™ instruction sheet (Sawyer® 2009), if the filter is backwashed with contaminated water, the first litre to pass through it after backwashing may be unsafe to drink. More than half (61%) of respondents reported using water from an untreated source for backwashing. Some householders were observed improperly backwashing their filters, and it is possible that repeated practices of improper backwashing may affect the filter’s capability to treat contaminated water. Either explanation raises serious concerns over the practicality of using this particular filter in this or similar settings.

More than three-quarters of the samples taken from storage containers were contaminated, and most of these (70% overall) were highly contaminated (Table 4). Since the filtering units do not provide any residual disinfectant,

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### Table 4 | Microbiological contamination of water directly from filters and stored filtered water in households, measured by H2S testing

<table>
<thead>
<tr>
<th>Water samples directly from filter, N = 24 n (%)</th>
<th>Water samples stored at the household level, N = 37 n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water contamination free</td>
<td></td>
</tr>
<tr>
<td>Water contaminated</td>
<td></td>
</tr>
<tr>
<td>H2S test reading</td>
<td></td>
</tr>
<tr>
<td>+     a</td>
<td>7 (29)</td>
</tr>
<tr>
<td>++ b</td>
<td>17 (71)</td>
</tr>
<tr>
<td>+++ c</td>
<td>13 (54)</td>
</tr>
</tbody>
</table>

* a, b, c indicate low, moderate and high contamination respectively.
the collected water even if initially clean is vulnerable to recontamination (Wright et al. 2004). The NGO provided households with a bucket and lid for storage but the interviewing team often observed storage buckets that were uncovered and/or sitting on the floor where children and animals could contaminate them. Many households obtained drinking water by dipping a cup of questionable cleanliness into the bucket, which also risks recontamination (Swedlow et al. 1997; Psutka et al. 2011).

Study limitations

This study is limited in several ways. It may not represent all Fijians, Pacific peoples or others using this filter, although we believe our combination of random and systematic sampling means that it should be fairly representative of people in rural, western Fiji. A larger sample size may have added power to our analysis but personnel, financial and logistical resource constraints prevented a larger study. Householders may have over-reported consistent filter use, as there is some evidence that household survey respondents over-report healthy practices including HWT (Rosa & Clasen 2010). Although we took care to explain to householders that the study, regardless of responses given, was not linked to any consequences, we commonly observed filtering units that appeared to have not been recently used covered in dust and householders frequently did not know the location of their filter despite reporting consistent use. This indicates some inconsistency between reported usage figures and their actual usage, which may have had an effect on the accuracy of the reported figures. Microbiological performance of the filters was tested with H2S tests in the field. While the H2S test is effective as a simple presence/absence test, with potential semi-quantitative properties, it does not indicate a specific type of bacterial contamination, or guarantee that contamination would cause illness if consumed because water sources that H2S tests indicate as being highly contaminated are not necessarily contaminated with harmful pathogens. The test has a reasonable, but not perfect, correlation with faecal contamination (Mosley & Sharp 2005). H2S testing also does not indicate viral contamination which may be of concern for this filter because the 0.1 micron filtration material (Sawyer® 2008) is not fine enough to block waterborne viruses from passing through. Unfortunately, the sample size from filters and storage containers was small (24 from filters, 37 from storage containers) compared to the study population (270 households) because of the lack of opportunities to collect samples during the study, which may further indicate low filter use. Finally, while this study has investigated motivations for the use of filters in one setting, no burden of disease data, which may be the focus of a future study, was collected to investigate any health impact.

As far as we are aware, no data exists on the health impact of this filter in any Pacific island nation. Subject to this study's limitations, there is little evidence here to suggest a health impact given the performance of the filter: (i) indicator testing with H2S showed that most water samples taken directly from filters were highly contaminated; (ii) although it cannot be guaranteed, it is highly likely that this contamination included some harmful pathogens; (iii) not only are the filters inconsistently used for water, but they are almost never used for kava preparation; (iv) willingness-to-please bias may have resulted in over-reporting, evidenced by households not knowing the location of the filter yet reporting consistent use; and (v) water found in open storage containers was more contaminated than water from filters indicating that, despite filtration efficacy, recontamination occurs in the household setting.

CONCLUSION

This study has shown that consistent use of a HWT device, a filter, for drinking water in selected communities was limited. The majority of the water samples tested directly from the filters and from household storage vessels showed highly compromised water quality. Further, use of the filters for kava preparation was very low. Improvements to the implementation process and the approach taken are needed if stakeholders could consider the filter as a sustainable, long term HWT option in rural areas of Fiji. Issues with reliability, utilisation and maintenance by recipient households and the filter’s performance need to be addressed.

Involvement of local government scan be an important factor in the success of water quality interventions (Barnes et al. 2011). In this case, increased inclusion of MOH during installation and monitoring may improve the
sustainability of this intervention and others like it. Other HWT interventions have declined to low compliance perhaps due to a lack of community ownership, and/or real or perceived effectiveness (Luby et al. 2008; Sobsey et al. 2008; Schmidt & Cairncross 2009; Boisson et al. 2010).

H₂S testing results showed that at the time of sampling, performance of the filters in the field was unsatisfactory overall. If improper backwashing is responsible for the high percentage of bacterially contaminated water samples then improved training of community members on backwashing practices, or less arduous backwashing practices, may improve the quality of filter effluent. Training on safe storage and handling to prevent recontamination in the household may improve the quality of water in storage vessels (Nath et al. 2006), but only if filter effluent is initially clean.

Some sites received their drinking water from a WAF supply which is already treated before delivery. In such cases where the source water is already treated and safe it may be more useful to ensure that the water supplier is implementing drinking water safety planning to ensure consistent supply of safe drinking water (Khatri et al. 2011) than household level interventions.

Nearly a third (32%) of respondents that received their filtering units in 2008 reported they could not use them due to broken or missing parts. Replacement parts are not available locally, so users in rural areas are reliant on others and international transport for replacements. This inaccessibility to parts may have the greatest impact on the sustainability of household water filters such as this one and may be one of the most difficult issues to address (Lantagne et al. 2009).

A study including health impacts of typical filter use in these communities would contribute to a better understanding of the potential effects of HWT and storage in the Pacific region.

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