Evaluation of use, acceptability, and effectiveness of household water filter systems in Honduras, 2016–2017

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Short Communication

Evaluation of use, acceptability, and effectiveness of household water filter systems in Honduras, 2016–2017

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ABSTRACT

We evaluated a household hollow fiber water filter program in 11 Honduran villages by assessing filter uptake and water quality. Filters were purchased by 90% of households; of these, 94% reported use within the past week. When comparing water treatment methods between baseline and follow-up, there were increases in the proportion of households reporting water treatment (74% vs. 93%, $p < 0.001$) and treatment by filtration (19% vs. 85%, $p < 0.001$), and decreased purchase of bottled water (44% vs 6%, $p < 0.001$), indicating acceptability of the water filtration systems. There was a significant decrease in the presence of *E. coli* in water samples taken from 35 households at baseline and follow-up in water filter systems ($p < 0.001$). As a result, 68% of samples met WHO water quality guidelines (no detectable *E. coli*) 6–12 months after program implementation. Observations of filter stands revealed a 6-inch gap between the top (reservoir) bucket and bottom (filtrate recipient) bucket that could have permitted animals, insects, hands, or other objects to touch filtered water. We recommend a redesign of filter stands to eliminate the gap between buckets, and a longer-term follow-up to assess filter durability and performance.

Key words | *E. coli*, hollow fiber water filter, Honduras, water quality

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INTRODUCTION

Approximately 884 million people worldwide lack access to basic drinking water sources (WHO/UNICEF 2017), and an estimated 1.8 billion drink unsafe water from contaminated sources (Onda *et al.* 2012), placing them at risk of enteric infections. Although global progress has been made in increasing access to basic water services in low- and middle-income countries since 2000 (United Nations 2015), many improved water supplies are not safe.

To address this problem, Sustainable Development Goal 6 aims to 'ensure availability and sustainable management of water and sanitation for all' by 2030 (United Nations 2017). However, achievement of universal coverage has been elusive because of population growth and movement, cost, technical challenges, and climate change (Diamant 1992; Moe & Rheingans 2006). Until universal coverage can be achieved, alternative methods for obtaining safe drinking water are important in order to protect the health of vulnerable populations lacking access to safe water. A number of field trials have provided evidence that simple, low-cost interventions at the household and community level are

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capable of improving the quality of water stored in the home (Clasen *et al.* 2007) and reducing the risk of diarrheal disease (Gundry *et al.* 2004). A number of point-of-use water treatment technologies, such as chemical and solar disinfection, ultraviolet processes, and use of ceramic filters, have been developed, field tested, and shown to reduce diarrhea risk by over 30% (Clasen *et al.* 2015). Despite evidence of the positive health impacts resulting from these technologies, household water treatment has been slow to scale up in the developing world, where need is greatest (Rosa & Clasen 2010). Additionally, sustained use of these technologies has proved challenging (Luby *et al.* 2008).

In Honduras, nearly 16% of the rural population lacked access to basic drinking water services in 2015 (WHO/UNICEF 2017). HOI, a non-governmental organization (NGO) located in the Agalta Valley of Honduras, initiated a program to address the lack of water access in 33 villages in 2016. Water tanks were installed in each village, and water was then piped to households, typically as standpipes in the yard. However, water sources of the piped water were typically unprotected springs or surface water. Because of uncertainty surrounding the water quality, some households elected to purchase bottled drinking water from shops, costing US$1.62 per 5-gallon (19 litre) bottle on average and lasting 1.5 days (L. Willing, HOI, personal communication). No data were available on bottled water quality. To ensure that the water supplies provided to these villages were safe, and to help families reduce the burden of paying for safe water, HOI initiated a program to create household access to two hollow fiber membrane filters (UZima or Sawyer). HOI selected the two filters based on recommendations by an environmental engineer who believed that their ease of use, low cost (retail price approximately US$30 per filter), filter lifespan, and effectiveness in improving water quality (from product websites) were desirable characteristics. Per HOI practice, in exchange for the filters, interested households contributed a small payment (usually $5–6) towards a community fund to help with other village projects.

HOI requested that the Centers for Disease Control and Prevention (CDC) conduct an independent evaluation of the filter program to determine the effectiveness and acceptability of the filters. We performed the evaluation 6–12 months after implementation to assess filter use and its impact on household drinking water quality.

METHODS

Baseline data collection

In January 2016, CDC, HOI, and the Universidad Nacional Autonoma de Honduras (UNAH) conducted a baseline survey on demographics, socioeconomic status (including income), and water treatment practices among heads of all 650 households in 11 villages in the Agalta Valley. All surveys were conducted in Spanish by students from UNAH.

For water testing, we assumed a 50% stored water contamination rate in households at baseline, a 20% rate of contamination at follow-up, power of 0.9, and 95% confidence intervals, yielding a sample of 52 households. A random numbers table was generated to select a sample of 48 households from the list of 650 households obtained in the census for baseline and follow-up drinking water quality testing. We collected 100-mL samples of source and stored water in Whirl-Pak™ bags (www.fishersci.com), and used compartment bag tests (CBT) (https://www.aquagenx.com/) according to manufacturer's instructions to test for presence of *Escherichia coli*, an indicator of microbiological water quality. We presented CBT data as a binary outcome ($\geq$1 MPN/100 mL or <1 MPN/100 mL) because of concerns about overlapping confidence limits between most probable number (MPN) categories used to interpret test results. To exclude the possibility that water was chlorinated, we collected 5 mL samples from drinking water sources and storage containers in test tubes and used the N, N-diethyl-phenylenediamine (DPD) colorimetric method (LaMotte, Chestertown, MD) to test for free and total chlorine.

Program implementation

Following the baseline survey, HOI offered hollow fiber filter systems (incorporating one of two filter types: UZima [http://UZimafilters.org/] or Sawyer [https://sawyer.com/products/type/water-filtration/]) for sale at subsidized prices (typically US$5–6), at which time community members were trained on filter use and maintenance by HOI at community meetings. Participating households had filter systems installed, including a wooden stand, a 5-gallon

(19 litre) reservoir bucket with a filter attached at the base to receive untreated water, a 5-gallon bucket with a tap to capture, store, and dispense filtered water, and a syringe to backflush the filter (Figure 1(a) and 1(b)).

Follow-up evaluation

For the follow-up evaluation, we calculated the sample size adequate to determine an assumed level of use of the hollow fiber filters by 70% of the population, with 80% power and 95% confidence intervals, which yielded a sample of 216 households in 11 villages. In January 2017, we conducted a follow-up evaluation that included interviews among a random sample of 227 heads of households selected from a total of 650 households in 11 project villages using a random numbers table, and repeated stored water testing in the 48-household sample chosen at baseline.

Statistical analysis

Although baseline data were collected in all households in 11 villages, we limited analysis to the 227 households selected for the follow-up evaluation in order to have paired data for comparison. For households lost to follow-up, a chi-square test for independence was used to determine whether they were similar to those included at follow-up. Baseline and follow-up survey and laboratory data were summarized and compared using McNemar's test for paired participant data.

Figure 1 | (a) UZima water filter system and (b) Sawyer water filter system installed in households for the HOI hollow fiber filter program, Honduras, 2016–2017.

Focus group discussions

Five focus group discussions (FGDs) were conducted from convenience samples in five villages, consisting of six to nine participants per group, to elucidate participants' opinions about the water filters. Each FGD was led by a local native speaker who followed a guide to elucidate participants' experience with drinking water access and water treatment technologies.

Ethical review

The Institutional Review Board representative at CDC determined that this evaluation was not research because we were evaluating public health practice. The Honduran Ministry of Health reviewed and approved the protocol. Verbal informed consent was obtained from all participants. Informed consent was obtained from heads of households at the time of the baseline and follow-up household visits, as well as for all FGDs.

RESULTS

Baseline

Of 227 households interviewed at baseline, 46 (20%) were excluded at follow-up, including 25 with no one home, five that refused to participate, four that had moved, and 12 for unknown reasons, leaving 181 (80%) households for paired baseline/follow-up data analysis.

At baseline, the median age of survey respondents was 49 years (range 20–92 years); 23% were female, 46% reported completing a primary education, and 43% reported having at least one child <5 years old in the home. Monthly income ranged from US$88 to US$351; 88% had electricity. There were no significant demographic differences between households included and excluded in the evaluation.

At baseline, 87% of 181 households reported having a piped water supply. The reported median monthly cost of water was US$1.49 (range US$0.53–8.53). Of 181 respondents, 161 (90%) reported storing drinking water in the home and 125 (84%) were observed to have covered storage containers.

Follow-up

A total of 162 (90%) respondents purchased hollow fiber filters from HOI (Table 1). Of these, 93 (58%) households purchased UZima filters and 67 (42%) purchased Sawyer filters; 152 (94%) households reported using their filters in the past week. Survey respondents reported using filtered water for drinking (94%), cooking (65%), and washing vegetables (37%). Three (2%) respondents reported that their water filters broke and 18 (11%) reported broken backwashing syringes, but none had been replaced. There were no differences between UZima and Sawyer filters in reported use or broken parts.

There were increases from baseline to follow-up in the percentage of households reporting any water treatment (74% vs. 93%, $p < 0.001$) and treatment by filtration (19% vs. 85%, $p < 0.001$), and decreases in purchase of bottled water (44% vs. 6%, $p < 0.001$) (Table 2).

Laboratory results

Of 48 households selected for water testing, we excluded 13 (27%) from the final analysis because two lacked baseline

Table 1 | Reported and observed filter use, backwashing frequency, and broken filter parts, by filter type ($N = 162$), Honduras, 2017

	Uzima (*N* = 94)	Sawyer (*N* = 68)	*p*-Value
Used filter in past week	88/94 (94.1%)	64/68 (94.1%)	1.0
Water in filter (*observed*)	47/86 (54.7%)	30/66 (45.5%)	0.26
Use filter for:			
Drinking	89/86 (96.7%)	65/66 (98.5%)	0.49
Cooking	56/86 (61.5%)	46/66 (69.7%)	0.29
Washing vegetables	29/86 (31.9%)	29/66 (43.9%)	0.12
Cleaning	6/86 (6.6%)	6/66 (9.1%)	0.56
Washing hands	9/86 (9.9%)	8/66 (12.1%)	0.66
Number of backwashes per week:			
0	5/86 (5.8%)	4/63 (6.4%)	–
1–2	37/86 (43.0%)	23/63 (36.6%)	–
3–4	30/86 (34.9%)	27/63 (42.9%)	–
≥ 5	9/86 (10.7%)	8/63 (12.7%)	–
Households with broken filter parts	1/91 (1.2%)	2/65 (3.1%)	0.44
Households with broken syringes	8/91 (8.5%)	10/65 (14.7%)	0.20

results, five had moved, and six were not home for the follow-up visit. No free chlorine was detected in any of the tested water samples. There was a significant decrease in the percentage of stored water samples yielding *E. coli* from baseline to follow-up (89% vs. 40%, McNemar test $p < 0.001$) (Table 2). At follow-up, 31 (89%) samples had been filtered and four (11%) were untreated. Ten (32%) filtered water samples yielded *E. coli*. Of 35 households sampled at baseline, 31 (89%) stored household drinking water samples were positive for *E. coli* contamination, while 10 (40%) were contaminated at follow-up ($p < 0.001$). We sampled stored water at follow-up from 16 UZima filters, 15 Sawyer filters, and four households without a water filter. Of these, 25% of samples taken from UZima filters ($n = 4$) and 40% from Sawyer filters ($n = 6$) were positive for *E. coli*. Among households that used water filters and stored water as their drinking water, there were statistically significant decreases in the number of households with *E. coli* in stored water treated with UZima ($p = 0.001$) and Sawyer ($p = 0.02$) water filters.

Focus group discussions

The majority of FGD participants were women. The main discussion themes included satisfaction with the filters, gratitude toward HOI, but also poor filter system construction, no access to replacement parts for broken filters or backwashing syringes, and slow filtration rates (Table 3). Observations of some filter systems revealed a 15-cm gap between the top (reservoir) bucket and bottom (filtrate recipient) bucket that could permit animals, insects, hands, or other objects to contaminate filtered water.

Table 2 | Drinking water treatment methods and presence of *E. coli* among households, 11 villages in HOI hollow fiber filter program, Honduras, 2016–2017

	N	Baseline, *N* (%)	Follow-up, *N* (%)	*p*-Value[a]
Water treatment method	**115**			
Filtration		22 (19.1)	98 (85.2)	<0.001
Purchasing bottled water (purified)		50 (43.5)	7 (6.1)	<0.001
Chlorination		6 (5.2)	5 (4.4)	1.00
Boiling		7 (6.1)	1 (0.9)	0.07
Straining[b,c]		–	2 (1.7)	–
None (not treated)		30 (26.1)	2 (1.7)	<0.001
***E. coli* presence**	**35**	**31 (89)**	**14 (40)**	**< 0.001**
UZima filter	16	15 (93.8)	4 (25.0)	0.001
Sawyer filter	15	13 (86.7)	6 (40.0)	0.02
Untreated water	4	3 (75.0)	4 (100)	–

[a]McNemar exact test.
[b]Straining drinking water through a cloth.
[c]Not measured at baseline.

DISCUSSION

Findings of this evaluation revealed that hollow fiber filter purchase and use were high and sustained in these communities. The substantial decrease in purchase of bottled water by households, presumably because of trust in filtered water quality, suggested that the filters may have an economic benefit over time. Although the increase in the percentage of water samples with no detectable *E. coli* from baseline to follow-up was likely attributable to filter use, about a third of filtered drinking water samples remained contaminated and did not meet WHO drinking water quality guidelines (WHO 2011). The findings of high filter use and modest impact on water quality are consistent with at least two previous hollow fiber filter studies (Boisson *et al.* 2010; Rayner *et al.* 2016).

There are several potential explanations for sub-optimal filter performance. First, the gap between top and bottom buckets observed in filter stands likely permitted post-filtration contamination of water to occur. Second, the filtrate storage bucket could have been contaminated. Because water samples were taken from storage buckets rather than directly from the filters, we were unable to directly assess the quality of filtrate. Several studies have demonstrated the need for safe storage and water management practices to avoid contamination of water stored in the home (Wright *et al.* 2004). Third, filter efficacy may have been impacted by biofilm growth (Geldreich *et al.* 1985; Daschner *et al.* 1996). Finally, enumerators could have contaminated water samples through improper handling.

Although filter acceptability appeared to be high, qualitative data suggested several problems with performance. The relatively short time period between implementation and follow-up raises a question about whether the problems

Table 3 | Common themes expressed in focus group discussion sessions among recipients of hollow fiber water filters, Honduras, 2017[a]

Focus group theme	Demonstrative quote
Filter acceptance within communities	'We would like for you to come more [often] because some people were not present when the filters were distributed … The filter is very good'
Filter system was designed poorly	'What we have not liked is that buckets don't fit well and there isn't enough water coming out. Same with the valve, which is a bit loose and leaks water.' 'The furniture [stand] is a bit wobbly … the little hose loosens up'
Syringes break easily	'I know that it broke the tip of the syringe' 'I broke the syringe […], but I wash it like this with water […] But it is needed to use the syringe. But there I am.'
No clear way to replace broken filter parts	'If it breaks there is no way to have them give you another one.' 'They told us that *when* we could not use the syringe, we should use a bottle of purified water for the young ones.'
Filter flow rate is too slow	'When you pour into the filter, that it is a struggle sometimes, it does not flow well, normal.' 'When it rains and the water is dirty, the filter is slower'
Gratitude for work of HOI in community	'It's a great benefit what the people who work at El Rancho [HOI] do because they have good intentions to help all neighborhoods … They have brought a lot of projects. We are thankful.' 'Everything. Those are things that not even the politicians give out. And El Rancho always looks out for the welfare of the communities, of the people.'

[a]Quotations are all translations from Spanish to English.

revealed in the FGDs would result in program participants reducing or discontinuing use of the filters over time. The cost advantage of the filters (US$5.00 compared with an estimated cost of US$394 per year for bottled water) could at least partially mitigate filter performance problems. Additional follow-up interviews could help shed light on the relative importance of these considerations.

This evaluation took place in communities with very high coverage of improved water supplies, which was the metric for achievement of the Millennium Development Goal for water (WHO/UNICEF 2012). However, high baseline levels of contamination in improved water supplies were not overly surprising, as water was piped from unprotected springs and surface water sources, highlighting the weakness of this metric. Sustainable Development Goal 6.1 attempts to address this problem by stressing the importance of drinking water being free from contamination (WHO/UNICEF 2017). It also recognizes the need for household drinking water treatment, even among households with access to improved water supplies, in settings where water supplies are likely to be contaminated (Heitzinger *et al.* 2015).

This evaluation had several important limitations. First, we were limited to a convenience sample of 11 participating villages, which was not representative of the general Honduran population. Second, the evaluation took place 6–12 months after filter distribution, a relatively short period over which to assess acceptability and effectiveness. A longer period until follow-up would permit a more complete assessment of filter durability, performance, and longevity. Third, because of logistical and financial constraints, an assessment of physical performance (e.g., flow rate) of the filters was beyond the scope of this evaluation. FGD results indicated that water flow through filters was already slow. At least one other study documented fouling of hollow fiber filters by inorganic metal oxides, organic material and biofouling, which can slow or completely block water flow through the filter (Murray *et al.* 2015). Fourth, because of financial constraints, we were limited to conducting only one follow-up visit. Additional visits could have revealed important information about practice habits. Finally, because the water testing budget was also limited, we elected to test water that participants actually drank, which was stored in the filter reservoir. By testing stored water rather than directly from the filter, we were unable to determine whether contamination occurred within the filter or in the storage container.

In conclusion, we observed a statistically significant improvement in stored quality in households using hollow fiber water filters, which, along with the acceptability of the filters to the local population, suggests that the filters could be a useful option for household water treatment in the developing world in settings where water is likely to be contaminated. The persistence of *E. coli* contamination in a third of samples tested highlights that technical challenges still need to be addressed. In particular, poor filter stand design, the absence of tests of water directly from the filter, and the relatively short post-implementation follow-up period limited our ability to evaluate filter performance and acceptability adequately. We recommend a redesign of filter stands to eliminate the gap between buckets (which HOI reports has been accomplished), and a longer follow-up period, to assess filter durability and performance.

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REFERENCES

Boisson, S., Kiyombo, M., Sthreshley, L., Tumba, S., Makambo, J. & Clasen, T. 2010 Field assessment of a novel household-based water filtration device: a randomised, placebo-controlled trial in the Democratic Republic of Congo. *PLoS One* **5** (9), e12613.

Clasen, T., Schmidt, W. P., Rabie, T., Roberts, I. & Cairncross, S. 2007 Interventions to improve water quality for preventing diarrhea: systematic review and meta-analysis. *BMJ* **334** (7597), 782.

Clasen, T. F., Alexander, K. T., Sinclair, D., Boisson, S., Peletz, R., Chang, H. H., Majorin, F. & Cairncross, S. 2015 Interventions to improve water quality for preventing diarrhoea. *Cochrane Database of Systematic Reviews* **3** (3), p.CD004794.

Daschner, F. D., Rüden, H., Simon, R. & Clotten, J. 1996 Microbiological contamination of drinking water in a commercial household water filter system. *European Journal of Clinical Microbiology & Infectious Diseases* **15** (3), 233–237.

Diamant, B. Z. 1992 Assessment and evaluation of the International Water Decade. *Journal of the Royal Society of Health* **112** (4), 183–188.

Geldreich, E. E., Taylor, R. H., Blannon, J. C. & Reasoner, D. J. 1985 Bacterial colonization of point-of-use water treatment devices. *Journal-American Water Works Association* **77** (2), 72–80.

Gundry, S., Wright, J. & Conroy, R. 2004 A systematic review of the health outcomes related to household water quality in developing countries. *Journal of Water and Health* **2** (1), 1–13.

Heitzinger, K., Rocha, C. A., Quick, R. E., Montano, S. M., Tilley Jr, D. H., Mock, C. N., Carrasco, A. J., Cabrera, R. M. & Hawes, S. E. 2015 'Improved' but not necessarily safe: an assessment of fecal contamination of household drinking water in rural Peru. *The American Journal of Tropical Medicine and Hygiene* **93** (3), 501–508.

Luby, S. P., Mendoza, C., Keswick, B. H., Chiller, T. M. & Hoekstra, R. M. 2008 Difficulties in bringing point-of-use water treatment to scale in rural Guatemala. *The American Journal of Tropical Medicine and Hygiene* **78** (3), 382–387.

Moe, C. & Rheingans, R. 2006 Global challenges in water, sanitation and health. *Journal of Water and Health* **4** (S1), 41–57.

Murray, A., Goeb, M., Stewart, B., Hopper, C., Peck, J., Meub, C., Asatekin, A. & Lantagne, D. 2015 Fouling in hollow fiber membrane microfilters used for household water treatment. *Journal of Water Sanitation and Hygiene for Development* **5** (2), 220–228.

Onda, K., Lobuglio, J. & Bartram, J. 2012 Global access to safe water: accounting for water quality and the resulting impact on MDG progress. *International Journal of Environmental Research and Public Health* **9** (3), 880–894.

Rayner, J., Murray, A., Joseph, M., Branz, A. & Lantagne, D. 2016 Evaluation of household drinking water filter distribution programs in Haiti. *Journal of Water, Sanitation and Hygiene for Development* **6** (1), 42–54.

Rosa, G. & Clasen, T. 2010 Estimating the scope of household water treatment in low- and medium-income countries. *The American Journal of Tropical Medicine and Hygiene* **82** (2), 289–300.

United Nations 2015 *The Millennium Development Goals Report 2015*. http://www.un.org/millenniumgoals/2015_MDG_Report/pdf/MDG%202015%20rev%20%28July%201%29.pdf (accessed 9 June 2018).

United Nations Department of Economic and Social Affairs 2017 *Sustainable Development Goal 6*. https://sustainabledevelopment.un.org/sdg6 (accessed 21 June 2018).

WHO. 2011 *Guidelines for Drinking-Water Quality*. World Health Organization, Geneva. http://apps.who.int/iris/bitstream/10665/44584/1/9789241548151_eng.pdf (accessed 26 May 2017).

WHO/UNICEF 2012 *Progress on Drinking Water and Sanitation: 2012 Update*. https://www.unicef.org/media/files/JMPreport2012.pdf (accessed 28 May 2017).

WHO/UNICEF. JMP 2017 *Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG Baselines*. http://www.who.int/mediacentre/news/releases/2017/launch-version-report-jmp-water-sanitation-hygiene.pdf (accessed 20 July 2018).

Wright, J., Gundry, S. & Conroy, R. 2004 Household drinking water in developing countries: a systematic review of microbiological contamination between source and point-of-use. *Tropical Medicine & International Health* **9** (1), 106–117.

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