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Research Paper

Evaluating filter functionality and user competence after a hollow fiber membrane filter intervention in Liberia

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ABSTRACT

In Liberia, access to safe water is not universal, and waterborne diseases like diarrhea run rampant. As part of a larger border-to-border clean water project in Liberia, hollow membrane fiber filters were distributed to households in remote and/or small villages across Liberia. While filter efficacy has been demonstrated in the laboratory, studies of filter efficacy in real-world settings yield more mixed results. Intervention efficacy in Liberia was evaluated by assessing (1) user ability to correctly filter and backwash and (2) filter functioning at follow-up visits approximately 2 and 8 weeks post-intervention. Ultimately, the results supported the efficacy of this intervention. At arrival of both follow-ups, over 95% of filters were functioning properly and the majority of issues were resolved during visits. This supported the short-term durability of the filters and the importance of follow-up visits for repairs. Furthermore, the vast majority of households were able to correctly demonstrate filtering and backwashing: 88.47% at the first follow-up and 91.79% at the second. This slight increase may indicate the value of follow-up visits as educational tools. The widescale distribution of point-of-use filters as a mechanism for clean water should include on-going education and affordable filter repair and replacement opportunities.

Key words: filtration, Liberia, point-of-use filters, water

HIGHLIGHTS

- Describes a border-to-border clean water filtration intervention in Liberia.
- Results demonstrate that point-of-use filters are easy to use.
- Results demonstrate high rates of filter durability in the short-term.

INTRODUCTION AND LITERATURE REVIEW

The UN General Assembly has recognized water as an essential human right, but 2.2 billion people, almost 30% of the world's population, still lack access to water that is clean, available, and located on premises, according to data from the World Health Organization (2019). Of these, 435 million use unprotected springs and wells, and 144 million rely on untreated water sources such as lakes and ponds (World Health Organization 2019). The World Health Organization (2019) estimates that over 800,000 deaths per year can be attributed to diarrhea due to issues with water, sanitation, and hygiene. Diarrheal diseases are particularly deadly for young children: they cause the deaths of 525,000 children under five each year (World Health Organization 2017). If WASH-related risk factors were addressed, about 300,000 lives under age five could be saved annually (World Health Organization 2019).

In Liberia, access to drinking water is certainly improving, from only 68% of the population having access in 2007 to 84% in 2019 (Liberia Institute of Statistics & Geo-Informational Services *et al.* 2021). According to the 2019–2020 Liberia Demographic and Health Survey (2021), 74% of the Liberian population have access to an improved water source within a

30-minute round trip, and an additional 10% have a round-trip collection time of over 30 min. Yet despite these improvements, there are still disparities between urban and rural areas: urban areas have 95% access, while rural areas have only 69% access (Liberia Institute of Statistics & Geo-Informational Services *et al.* 2021). Furthermore, access is markedly different between the lowest wealth quintile (48.6%) and the highest wealth quintile (87.2%) (2021). One quarter of Liberians use an appropriate water treatment method; of those, 2% use a water filter (2021). It is unsurprising, then, that waterborne diseases run rampant. The Institute for Health Metrics and Evaluation (2019) reports that diarrheal diseases are the second leading cause of death in Liberia. The 2019–2020 Liberia Demographic and Health Survey (2021) found 16% of Liberian children ages five and below were reported to have diarrhea in the 2-week period preceding the survey.

Much consideration has been given to how best to address clean water access, primarily whether to focus on piped water with centralized treatment or through point-of-use (POU) technology. While centralized treatment is often considered the gold standard, POU technology is frequently utilized for its cost-effectiveness and relative lack of barriers. Perhaps its primary advantage is economic: POU treatments are almost six times more cost-effective than centralized treatments (Ren *et al.* 2013). POU interventions require relatively little planning and construction in comparison with centralized treatments (Elimelech 2006), offer flexibility if population growth occurs (Elimelech 2006), and are more effective at reaching rural areas (Montgomery & Elimelech 2007; Peter-Varbanets *et al.* 2009). Although centralized treatment systems facilitate monitoring and enforcement of water quality standards, meeting such standards requires meticulous maintenance of the whole treatment and distribution infrastructure; if maintenance or public confidence is lacking, POU treatment may play a role (Wu *et al.* 2020). Furthermore, the use of POU technology may stimulate the local economy, as local economies in lower-income countries may have the capacity to produce the POU technology themselves (Montgomery & Elimelech 2007; Ren *et al.* 2013).

There are several options for POU technology, including solar disinfection, chlorination, and filtration (Pooi & Ng 2018). In a meta-analysis, Clasen *et al.* (2015) found that POU filtration systems tend to reduce diarrhea by about one-half across low- and middle-income settings, while POU disinfection treatments, such as chlorination, only reduce diarrhea by one-quarter. Similarly, Sobsey *et al.* (2008) found that filters have a greater potential for sustainability than other POU treatments, like solar disinfection and chlorination. Among filters, membrane filtration systems have been found to have higher and faster flow rates (Pérez-Vidal *et al.* 2016; Pooi & Ng 2018) and a longer lifespan than other filters (Pooi & Ng 2018).

The long-term sustainability of POU technology, however, is less certain. Over time, significant proportions of filters are no longer in use in follow-up studies of POU interventions (Goeb 2013; Sisson *et al.* 2013). In a follow-up study of a ceramic filter distribution project in Cambodia, Brown *et al.* (2009) found that among 500 households who received filters in the past 4 years, only 31% of households still used their filters regularly and results demonstrated declining use of filters over time.

Additionally, some questions have been raised regarding filter efficacy in the community setting compared with the laboratory. In a laboratory setting, Pérez-Vidal *et al.* (2016) tested four types of filters, including a hollow membrane filter, and found that each was highly effective in removing both turbidity and *E. coli* from spiked water. Similarly, Murray *et al.* (2017) found that filtrates from hollow fiber membrane filters had no or virtually no *E. coli* in laboratory or carefully controlled field tests; however, when tested in Honduran households, 1–3 years after receiving the filter, only 30% of the hollow membrane filtrate samples continued to comply with WHO water quality standards. These results were consistent with or better than field studies of other POU methods and were largely attributed to filter age and condition along with improper backwashing techniques. In the Honduran study, 29% of households failed to correctly demonstrate the backwashing procedure, an essential step for filter cleaning and maintenance (Murray *et al.* 2017). Other results surrounding user ability vary: in a series of follow-ups on hollow membrane filters distributed in South Sudan, Holding *et al.* (2019) reported that the vast majority of households, ranging from 97% to 100%, were able to demonstrate correct filter usage, while 96% to 100% were able to correctly clean their filters. Additionally, in follow-up visits between 6 weeks and 6 months after the distribution of the LifeStraw 2.0 filter in Rwanda, Barstow *et al.* (2016) found about 97% of households were able to demonstrate filter use at a level of 'sufficient' or better. However, Barstow *et al.* (2016) also reported that only about half of Rwandan households were able to correctly backwash their filters and safely dispose of the backwashed water, both of which are essential aspects of filter efficacy.

Investigating filter durability in community settings also yields mixed results. In the short term, POU filter functioning has been shown to be quite reliable: in follow-up visits following a hollow membrane filter distribution effort in Honduras, Fagerli *et al.* (2018) found only 3.1% of the filters had broken parts 6–12 months post-installation. However, nearly 15% of the filter syringes had broken in that time frame (2018). Similarly, in a 6-month follow-up of gravity-fed LifeStraw 2.0 filters in Rwanda, only 1.5% of the filters required repair (Barstow *et al.* 2016). However, as might be expected, filter functioning seems to decline over time. Kohlitz *et al.* (2013) investigated the distribution of hollow membrane filters up to 3 years earlier in Fiji. They found 22% of these filters were unusable due to broken filters or missing parts (2013). In a study of ceramic filter distribution in Cambodia, Brown *et al.* (2009) found only 31% of households were regularly using their filters after 12 years and, of those no longer using their filters, 65% attributed this to filter breakage. Similarly, Sisson *et al.* (2013) found that 47% of biosand filters distributed in Haiti were no longer in use after 4 years. Some common reasons for this included broken parts or clogged filters (Sisson *et al.* 2013).

Despite these limitations, there is evidence of filter efficacy in disease reduction (Hunter 2009; Clasen *et al.* 2015). For instance, when hollow membrane filters were distributed in Bolivia, the presence of a filter was associated with significantly lower rates of diarrhea than were observed in the control group (Lindquist *et al.* 2014). Likewise, when hollow membrane filters were distributed in Fiji (along with hand washing instructions), both diarrhea prevalence and severity decreased from baseline to follow-up (Tintle *et al.* 2019).

When evaluating clean water interventions using POU technology, it is imperative to understand both proper use and durability of the technology over time, as these are necessary to ensure on-going access to drinking water. This study evaluates these two components in a large-scale hollow membrane filter distribution project in Liberia. The study evaluates (1) the proportion of filters in proper working order at approximately 2 and 8 weeks post-intervention and (2) the proportion of households that could correctly use and properly backwash the filter.

METHODS

Research design and sample

This study was conducted throughout the country of Liberia in West Africa. The Last Well, a US-based nonprofit organization, completed a nationwide needs assessment of clean water needs. Wells were installed in larger villages without sufficient access to clean water, whereas villages with fewer than 200 households or larger rural villages which were too remote for well-drilling equipment received water filters. In these instances, each household in the village received a Sawyer PointOne hollow membrane water filter and a bucket with a tap installed for water collection purposes. The data for this study were collected between November 2017 and December 2020 and represent households receiving filters in 13 of the 15 Liberian counties. An adult over the age of 18 in each household receiving a filter was invited to participate in a survey at baseline, 2 weeks, and 8 weeks on behalf of the household. Thus, in a given area, the intervention and follow-up surveys occurred over a period of about 2 months, although the study as a whole lasted several years because filter distribution commenced at different times in different areas.

Measures

The survey questions were read to the household participants, and responses were recorded in real-time on a tablet and uploaded to cloud storage. Survey questions included questions on primary water source, number and ages of household members, diarrheal frequency for each family member in the past 2 weeks, missed days of work and school for each household member due to diarrhea, healthcare costs associated with diarrhea, and the amount of money spent on purchasing water in the past 2 weeks.

The follow-up surveys, administered 2 and 8 weeks later, included questions on water filter use and function. At the beginning of the visit, data collectors assessed the filter for the following potential issues: Filter was dirty, filter was clogged, air in the line, cracked bucket, syringe missing, damaged hose, rubber washers missing, bucket connector problem, white cap missing, clear cap missing, and cracked casing. Efforts would be made to address the issues with the filter during the visit. At the end of the visit, the surveyors would reassess the filter and note whether there were still problems or parts missing from the filter system and, if so, what parts were still missing or damaged. Surveyors also assessed if the family could demonstrate proper use of the filter system, using responses of 'no', 'yes filter water', 'yes back flush', and 'both filter and back flush'.

Filter technology

The Sawyer PointOne filter is a hollow fiber membrane filter (Figure 1; Sawyer 2022a). The filter's pores, measuring 0.1 μm or less, block a variety of harmful agents such as protozoa, microplastics, and bacteria, including *E. coli* and the diarrhea-causing parasite Giardia (Sawyer 2022b). It is advertised as simple to operate and relatively affordable, and it boasts a lifespan of 10 years (Sawyer 2022b).

Figure 1 | The Sawyer PointOne bucket filter system distributed to households in Liberia. Image used with permission from Sawyer (2022a).

Ethics

The study was approved by the Calvin University Institutional Review Board (IRB). The data were collected through the Last Well and partnering organizations. Field workers only distributed filters and collected data in villages in which the tribal chief had granted permission for the project. Community consent processes through the following of the village protocol and tribal chief permissions were utilized. The individual representing each household received a filter, was trained in its operation and use, and was asked verbally if they would additionally participate in the study. Every household in every village was surveyed and all households received a filter system.

Data analysis

Data were processed and analyzed using R and Rstudio statistical computing software (R Core Team 2021; RStudio Team 2021) using the package glmmTMB (Brooks *et al.* 2017). The analyzed dataset contained only households for which data on filter efficacy and use, as well as all necessary covariates (county, district, village, household filter ID, follow-up visit, partner organization, data collector's name, household size, water source, problems on arrival, problems on departure, user ability, and presence of filter instructions), were present for all three visits (filter installation and two follow-ups). User ability, though having four options on the survey, were coded as either 'yes' or 'no' for modeling purposes. User ability was only coded as 'yes' if the user could both filter water and backflush the filter. Two multivariable analyses were performed. Evidence of problems on departure was modeled using logistic mixed-effect regression models with fixed effects of evidence of problems on arrival, user ability, household size, county, water source, and follow-up (first or second), plus random effects of village nested within district, data collector's name nested within partner organization, and household filter ID. User ability was similarly modeled, with fixed effects of presence of filter instructions, evidence of problem on departure, household size, county, water source, and follow-up (first or second), plus random effects of village nested within district, data collector's name nested within partner organization, and household filter ID.

RESULTS

Sample characteristics

According to our dataset, in the course of the study, filters were distributed to 101,706 households, of which 30,154 had data that met eligibility criteria (30%). Eligible households required (1) data collected through a valid survey form ($n = 78{,}091$), (2) survey completions at filter installation (baseline), 2-week follow-up, and 8-week follow-up, with no duplicate visits ($n = 30{,}154$), and (3) included responses to the aforementioned variables necessary for modeling purposes ($n = 30{,}154$). Data were collected from 13 of the 15 counties across Liberia (Figure 2). Over three-quarters of households drew water from creeks; open wells were the second most common source (Table 1).

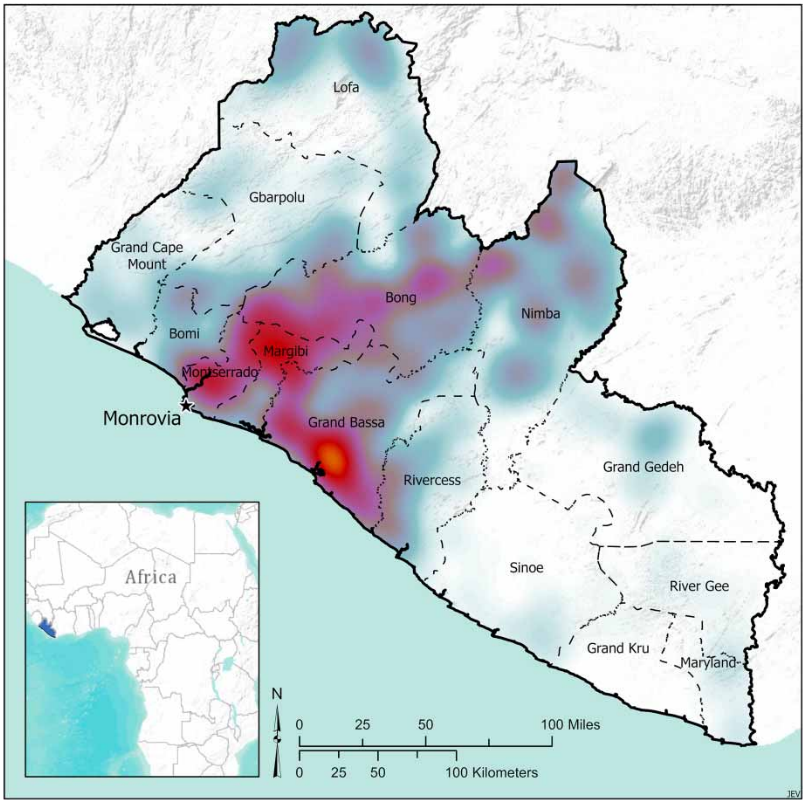

Figure 2 | Heat map of villages surveyed in Liberia.

Filter condition

Figure 3 shows changes in filter condition from 2 weeks (first follow-up) to 8 weeks (second follow-up) upon arrival and departure. While an overwhelming majority (>95%) of households did not report any missing parts or problems with filters, this percent was slightly higher at second follow-up (97.21) than first (95.31) on arrival. A similar small increase is seen at departure, with 99.23% of filters functioning properly at second follow-up, compared with 99.01% at first follow-up. According to the regression model, which also controlled for potential effects of location, season, water source, user ability, evidence of problems on arrival, and household size, probability of having a problem with the filter was most likely lower on the second follow-up than the first (OR 0.78, 95% CI 0.56–1.09). Households that had filter problems at arrival were more likely to still have problems at departure (OR 4.37, 95% CI 2.90–6.57).

Problems with the filters varied and most were able to be addressed during the visit (see Supplementary Table S1). The most commonly reported problem was a dirty filter, with 5.01% at the beginning of the first follow-up and 3.01% at the beginning of the final follow-up. This problem rarely, if ever, affects filter performance. Data on filter cleanliness were not collected at the end of the visits.

The second most commonly reported problem was a clogged filter due to improper or irregular backwashing. However, the data indicate that clogged filters were largely fixable over the course of the visit. At the beginning of the first follow-up, 2.1% of filters were clogged. This statistic decreased to 0.04% by the end of the visit, a percentage decrease of 98.1%. Similarly, at the beginning of the second follow-up, 0.97% of filters were clogged, but only 0.04% were clogged by the visit's conclusion (a 95.9% decrease). The difference in clogged filters at the beginning of the first and second follow-up visits (2.1% and 0.97%, respectively, a percentage decrease of 53.81%) may also indicate that these visits held the potential for user education.

The third most commonly reported problem was an air blockage problem due to air trapped in the line, with 0.71% at the beginning of both the first and second follow-ups. As data on air problems were not collected at the end of the visits, it is unknown how frequently this issue was resolved.

The fourth most commonly reported problem was missing syringes, which are used to backflush the filter. At the beginning of the first follow-up, 0.2% of filters were missing syringes, which decreased slightly to 0.18% by the visit's conclusion.

Table 1 | Participant characteristics

Variable	Participant characteristics Percent (number) at baseline ($n = 30,154$)	Percent (number) at first follow-up ($n = 30,154$)	Percent (number) at final follow-up ($n = 30,154$)
County			
Bomi	0% (1)	NA % (NA)	NA % (NA)
Bong	11.36% (3,425)	11.36% (3,424)	11.36% (3,426)
Gbarpolu	3.79% (1,144)	3.79% (1,142)	3.77% (1,138)
Grand Bassa	23.01% (6,938)	22.99% (6,931)	22.97% (6,927)
Grand Cape Mount	4.63% (1,395)	4.63% (1,396)	4.63% (1,395)
Grand Gedeh	0.74% (222)	0.75% (226)	0.76% (228)
Lofa	8% (2,412)	8.01% (2,415)	8% (2,413)
Margibi	14.89% (4,489)	14.9% (4,494)	14.91% (4,497)
Maryland	0.8% (240)	0.8% (240)	0.79% (238)
Montserrado	11.58% (3,491)	11.58% (3,491)	11.58% (3,492)
Nimba	8.16% (2,460)	8.17% (2,463)	8.17% (2,464)
River Gee	1.71% (517)	1.71% (516)	1.72% (518)
Rivercess	8.13% (2,452)	8.13% (2,452)	8.13% (2,453)
Sinoe	3.21% (968)	3.2% (964)	3.2% (965)
Water source			
Creek	78.51% (23,673)	81.42% (24,550)	83.3% (25,118)
Open Well	14.17% (4,272)	12.01% (3,622)	11.08% (3,342)
Other	4.55% (1,373)	4.62% (1,392)	3.92% (1,183)

Note: n denotes the number of filters/the number of households, not the number of individuals.

Likewise, at the beginning of the second follow-up, 0.15% of filters were missing syringes, which decreased slightly to 0.14% by the end of the visit indicating minimal replacements of syringes (Table 2).

User ability

Figure 4 shows user ability to operate filters at first and second follow-ups. Demonstration of only one function (either filtering or backwashing) was considered incomplete and thus classified as a failure to demonstrate proper use. As Table 3 shows, user ability, from first to second follow-up, to perform both functions increased from 88.47% to 91.79%. Regression results confirm this trend, indicating a high probability of a user being able to demonstrate proper use of their household filter at second

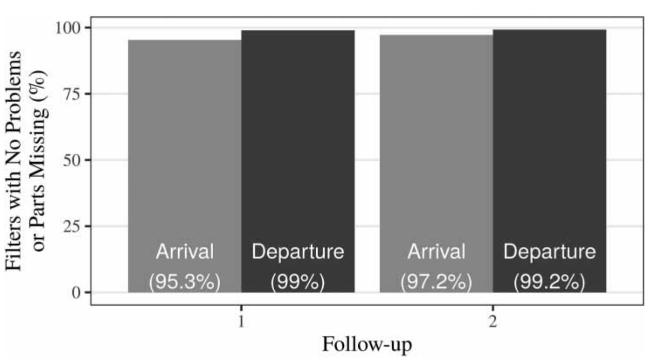

Figure 3 | Filter condition on arrival and at departure at first and second follow-ups.

Table 2 | Filter functionality and household characteristics

	Has problem at departure		
Predictors	**Odds ratios**	**CI (95%)**	***p***
Intercept	0.000054	0.000012–0.000236	<0.001
Has problem at arrival (TRUE)	4.37	2.90–6.57	<0.001
Proper use (No)	14.48	9.03–23.24	<0.001
Household size	1.03	0.98–1.08	0.240
County (Gbarpolu)	0.90	0.06–13.01	0.937
County (Grand Bassa)	2.47	0.58–10.56	0.222
County (Grand Cape Mount)	0.15	0.01–2.79	0.204
County (Grand Gedeh)	69.90	4.29–1,137.83	0.003
County (Lofa)	2.87	0.44–18.59	0.270
County (Margibi)	4.53	0.70–29.15	0.112
County (Maryland)	13.62	0.82–225.18	0.068
County (Montserrado)	13.09	1.93–89.06	0.009
County (Nimba)	2.04	0.36–11.44	0.417
County (River Gee)	2.57	0.20–33.93	0.473
County (Rivercess)	0.67	0.11–4.23	0.672
County (Sinoe)	2.14	0.25–18.59	0.491
Water source (Open Well)	0.72	0.40–1.31	0.286
Water source (Other)	0.87	0.34–2.20	0.763
Follow-up (2)	0.78	0.56–1.09	0.147
Residual and random effects variances (number of groups in parentheses)			
σ^2 (residuals)	3.29		
Collector name	11.05 (714 groups)		
Partner organization	0.00 (10 groups)		
Village	3.56 (4,350 groups)		
District	0.72 (109 groups)		
Filter ID	0.00 (30,098 groups)		

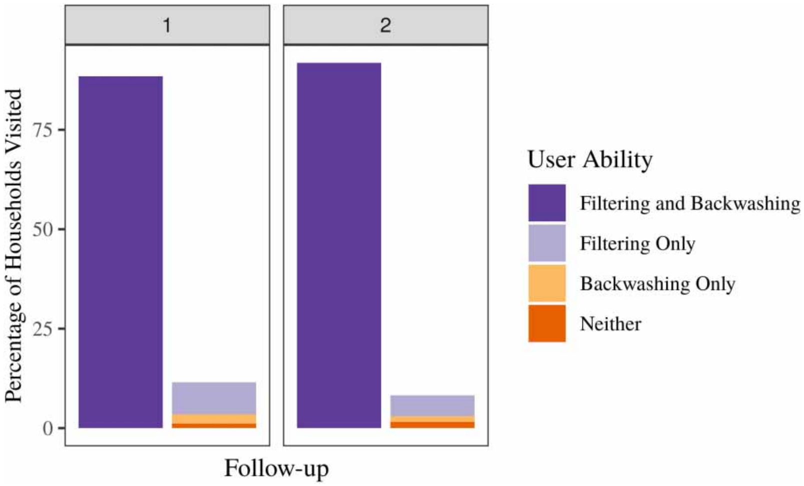

Figure 4 | User ability to operate filter at first and second follow-ups.

Table 3 | Ability to demonstrate proper filter use and household characteristics: Summary of regression model results

	Demonstrated proper use		
Predictors	**Odds ratios**	**CI (95%)**	***p***
Intercept	912.22	205.98–4,040.00	<0.001
Household size	1.05	1.03–1.07	<0.001
County (Gbarpolu)	0.29	0.04–2.08	0.218
County (Grand Bassa)	0.28	0.06–1.32	0.107
County (Grand Cape Mount)	41.33	5.65–302.17	<0.001
County (Grand Gedeh)	0.20	0.01–5.22	0.331
County (Lofa)	2.47	0.32–19.13	0.387
County (Margibi)	1.29	0.18–9.45	0.804
County (Maryland)	0.24	0.01–5.80	0.381
County (Montserrado)	3.37	0.46–24.78	0.232
County (Nimba)	1.01	0.20–5.18	0.994
County (River Gee)	2.81	0.07–111.99	0.583
County (Rivercess)	0.00	0.00–0.00	<0.001
County (Sinoe)	1.93	0.24–15.71	0.539
Water source (Open Well)	0.94	0.71–1.24	0.664
Water source (Other)	0.65	0.39–1.08	0.098
Follow-up (2)	4.29	3.68–4.99	<0.001
Filter instructions (Yes)	2.70	1.64–4.44	<0.001
Has problem at departure (TRUE)	0.05	0.03–0.08	<0.001
Residual and random effects variances (number of groups in parentheses)			
σ^2 (residuals)	3.29		
Collector Name	37.81 (714 groups)		
Partner Organization	0.00 (10 groups)		
Village	1.76 (4,349 groups)		
District	1.23 (109 groups)		
Filter ID	0.00 (30,099 groups)		

follow-up (OR 4.29, 95% CI 3.68–4.99). The presence of filter instructions was also associated with a high probability of user ability (OR 2.70, 95% CI 1.64–4.44).

DISCUSSION

This study sought to understand the sustainability of a POU filter intervention in terms of filter functionality and user ability. A short-term follow-up supports intervention sustainability in these areas, with the majority (over 95%) of filters functioning properly and the majority of households (over 90%) properly demonstrating filtering and backwashing after 8 weeks.

POU filter interventions continue to be promising as a mechanism to deliver clean water to households, particularly as they provide ease of use. Our study results indicate high levels of proper filter operation, both in filtering water and backwashing the filter after use. These results are mirrored by many others, which show that the vast majority of households receiving POU water filters are able to demonstrate how to correctly filter water (Barstow *et al.* 2016; Holding *et al.* 2019). Many studies, including ours, suggest slightly lower rates of user ability in terms of properly cleaning filters (Goeb 2013; Barstow *et al.* 2016; Murray *et al.* 2017). Furthermore, even if users are able to properly operate filters, some research indicates that consistent use of filters decreases over time, thus decreasing the benefits of the intervention (Brown *et al.* 2009; Barstow *et al.* 2016; Kirby *et al.* 2019).

One strategy to both ensure filter functionality and consistent and proper use of the filter is to engage in regular follow-up visits. Our results suggested minor improvements in both functioning and user ability to properly filter water and backwash the filter between the first and second follow-ups. The follow-up visits provided the teams an opportunity for household members to demonstrate proper use and cleaning of the filters as well as the opportunity to re-educate household members as necessary. On-going education and follow-up has been identified as a major contributor to the sustainability of POU filter interventions (Ogunyoku *et al.* 2011; Wu *et al.* 2020). Furthermore, self-efficacy among filter users plays a significant role in clean water practices (Lilje & Mosler 2017). Interestingly, the large estimated random-effect variance associated with data-collector field-worker identity in this study might suggest that some individuals were better (or worse) at delivering this education.

Despite an advertised lifespan of 10 years, this level of filter sustainability may not always be seen in the field. The results of our study suggest high levels of proper filter functioning in the short-term, mirroring other similar studies (Barstow *et al.* 2016; Fagerli *et al.* 2018). However, we began to see indications consistent with studies researching long-term functioning in the field. Many studies have shown POU filter technology has not held up as well over multiple years in community settings, with high proportions of filters out of use due to disrepair or missing parts (Brown *et al.* 2009; Kohlitz *et al.* 2013; Sisson *et al.* 2013). This points to the need for accessible and affordable repairs and/or replacements of filters, whether through in-country manufacturing of filters and parts or promoting local distribution of replacement parts and repairs (Lantagne *et al.* 2006; Ren *et al.* 2013) – there is currently no such situation for the Sawyer PointOne filter in Liberia.

This study has several limitations. Due to the large-scale nature of the project and remoteness of many of the villages, the timing of the first and second follow-ups varied. Additionally, the results may not be representative of the entire country of Liberia as the filter intervention was primarily delivered to rural and/or remote villages. Finally, the study focused on filter functionality and whether filter owners could demonstrate proper use; no assessment of microbiological water quality was included in this work.

This is a unique study in that it demonstrates how POU technology can be distributed successfully on a larger scale. Data around functionality and use of the filters were not based on self-report but rather on examination of the filter and observation of household members filtering water and backwashing the filter. This method of data collection not only contributed to the accuracy of the data but also provided an opportunity to promote user self-efficacy, encourage use of the filter, and provide re-education and repair or replacement of the filter as necessary – particularly since every household received follow-up visits.

CONCLUSION

Our findings inform future efforts to promote the use of filters as a viable option for clean water access, particularly in remote areas where infrastructure for centralized water systems may not be available. We demonstrate the ease-of-use of hollow membrane filters as well as functionality of the filters over time, up to about 8 weeks. Furthermore, the results reinforce the importance of on-going education and reinforcement to ensure filter functionality and correct use.

Future interventions should focus on ways to reinforce ongoing use of the filters through the involvement of communities. Local communities can be an important driver of sustainability, through the production and distribution of replacement parts and filters as well as through the provision of education regarding clean water and maintenance of POU filter technologies. Future efforts should focus on how best to integrate these technologies into the economic and social fabric of communities.

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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