

## The Chulli Water Purifier: Acceptability and Effectiveness of an Innovative Strategy for Household Water Treatment in Bangladesh

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**Abstract.** To evaluate the effectiveness of the chulli water purifier, a new household water treatment strategy in Bangladesh that relies on passing water through a stove, we interviewed persons who had this water purifier. From households using it regularly, we tested untreated water, sand-filtered water without heat pasteurization, sand-filtered and heat pasteurized water, and household stored, treated water. Reasons for discontinuing use among 80 of 101 persons included mechanical problems (49%), inconvenience (35%), and high cost (10%). Only four households were regularly using the purifier. Three (19%) of 16 heat-treated samples were positive for *Escherichia coli*. The median log reduction from source water was > 5. Nine (56%) stored water samples were positive for *E. coli*, indicating recontamination. Poor durability, inconvenience, high cost, and post-treatment contamination limit the usefulness of the purifier. These issues, which are relevant for other household water treatment strategies, should be resolved before further implementation.

### BACKGROUND

Diarrheal disease kills approximately 23,000 children in Bangladesh annually.<sup>1,2</sup> These deaths peak during Bangladesh's annual rainy season from June to September, when widespread flooding predictably amplifies microbial contamination of surface water.<sup>3</sup> Although most of the population has access to tubewell water that is less contaminated than surface water, approximately one-fifth of these tubewells contain unacceptable levels of arsenic, which slowly poisons those who consume it.<sup>4</sup> Water and health experts have been challenged to find ways to enable access to water free of microbes and arsenic. Water quality advocacy groups are increasingly promoting arsenic-free options, such as rainwater, deep tubewells, and surface water, treated either at the point of collection or at the household level.

Unlike water supply improvement strategies, household water treatment strategies avoid the recognized problem of increasing levels of water contamination during transport of water from the source to the home.<sup>5,6</sup> Their efficacy has also repeatedly been shown; a recent meta-analysis of 31 studies found a pooled risk reduction of diarrhea ranging from 31% to 63% for different household water treatment strategies.<sup>7</sup> The research agenda has now shifted to investigating the acceptability, field effectiveness, scalability, and sustainability of such strategies.<sup>8,9</sup>

**Chulli water purifier.** The chulli water purifier was designed to treat contaminated surface water and provide an alternative to arsenic-affected tubewell water.<sup>10,11</sup> The Integrated Approach to Community Development (IACD), a Bangladeshi non-governmental organization, introduced the chulli water purifier in 2003. With the support of the Department of Public Health Engineering and the United Nations Children's Fund, almost 3,000 chulli water purifiers have been installed in homes in Bangladesh.

The chulli is the traditional clay cooking stove used in Bangladesh. Wood or cow dung is burned to produce thermal energy for cooking, but most of this energy is wasted to the atmo-

sphere. The chulli water purifier uses both sand filtration and heat pasteurization to eliminate microbes from water (Figure 1). Water flows through the system by gravity, and the user controls flow by the use of a tap at the output end. All of the chulli water purifier components are made from locally available materials.

Water is poured into a 25-liter bucket that sits at the height of 3 feet on top of a stand. The bucket contains 12 kilograms of sand on top of which sits a layer of foam rubber. The foam diffuses the force of water being poured into the bucket, and the sand filters the water of organic and inorganic particles. The bucket is connected to a plastic tube, which attaches to a hollow aluminum coil that enters the clay walls of the chulli. This coil spirals inside the chulli, and after exiting, connects to another plastic tube, which ends in a tap that is placed on a stand 1 foot off the ground. When a fire is present, heat is transmitted through the clay to the aluminum coil. Users are instructed to collect the water when copious steam is visible or the water is too hot to touch (approximately 60–70°C). The water is usually collected in an aluminum kolshi, a commonly used storage vessel, where it is cooled and transferred to another container for storage in the home. The maximum flow rate is 500 mL/minute and is determined by the internal diameter of the aluminum coil and the height difference between the bucket and tap. The chulli water purifier costs \$6 to produce.

The IACD typically installed the chulli water purifier together with a second chulli just next to the household's original chulli. Users were instructed to not use the chulli water purifier to cook with the tap closed, and instead use their original chulli, because having a fire burning with the tap closed would generate pressure in a closed space, and possibly damage the aluminum or plastic tubing.

Beginning in 2003, in Homna subdistrict, in southeastern Bangladesh, chulli water purifiers were installed in 114 households where testing by IACD had shown drinking water supplies were contaminated with arsenic. Residents purchased chulli water purifiers for a subsidized price; those who could not pay at the time of purchase needed to pay in installments to keep their chulli water purifier. Until December 2004, users could request repairs by contacting the IACD office in Homna town. We conducted the first independent evaluation

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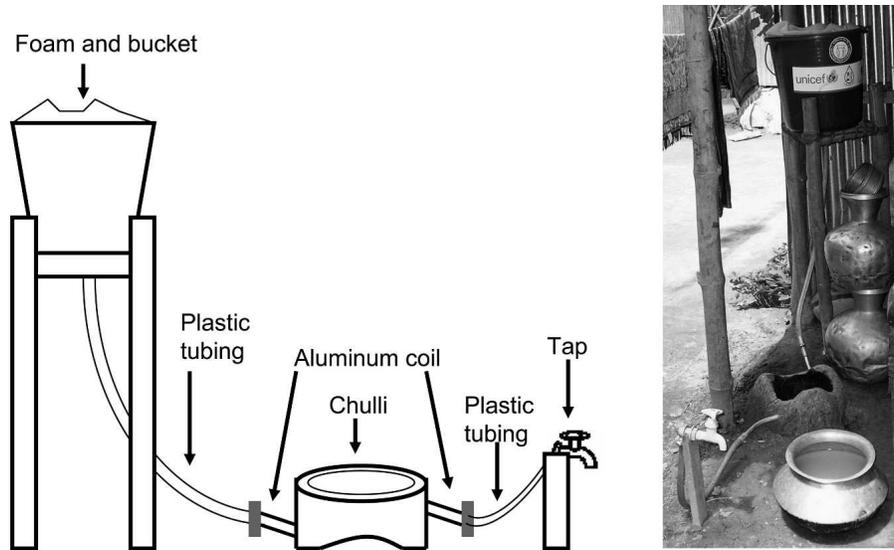


FIGURE 1. Chulli water purifier.

of the chulli water purifier to learn more about its microbiologic effectiveness and its acceptability to the end user.

#### MATERIALS AND METHODS

From September 18 to 28, 2005, a trained female survey team attempted to interview all 114 households in Homna subdistrict where a chulli water purifier had been installed. From each household, one female household member responsible for water handling and cooking was interviewed about water, hygiene, and sanitation practices. Univariate analyses were performed to examine associations between household characteristics and use of the chulli water purifier.

Within 2 weeks after surveys were completed, a trained laboratory team returned to each household that reported regularly using the chulli water purifier. On each of four separate visits to each household, water samples were collected using aseptic technique at four points between collection and consumption: untreated water; sand-filtered water pasteurized by the chulli water purifier; sand-filtered water that was not pasteurized by the chulli water purifier; and water stored in the household that had been sand-filtered and pasteurized by the chulli water purifier. For each individual household visit, a single bucket of source water provided water samples for the first three points, and the sample of stored and treated household water was from water previously collected by a household member.

Water samples were tested for *Escherichia coli*, an established indicator of fecal contamination, using a standard membrane filtration technique.<sup>12</sup> One hundred milliliters of the water sample was filtered through a 0.22- $\mu$ m Millipore (Billerica, MA) membrane filter. The filter paper was then placed on modified thermotolerant *E. coli* agar medium and incubated at 35°C for 2 hours, followed by further incubation at 44.5°C for 22–24 hours. Red and magenta colonies were counted as *E. coli*.<sup>13</sup> The output water temperature and time necessary to collect 500 mL of treated water were also measured.

Informed consent was obtained from all participants before

conducting interviews and again before taking water samples. The study protocol was reviewed and approved by the Ethics Review Committee and the Research Review Committee of the International Center for Diarrheal Diseases Research, Bangladesh, ICDDR,B.

#### RESULTS

Members of 101 (88%) of 114 households were interviewed; 11 households could not be identified and 2 persons declined to be interviewed. A median of six persons (range = 1–12) including a median child less than five years of age (range = 0–5) lived in each household. Sixty-four (63%) male and 41 (41%) female heads of household were literate (defined as ability to read a newspaper).

Forty-five percent of 101 respondents personally knew of someone with arsenic poisoning. However, only 21% believed that water sometimes made their family ill. Using a latrine for defecation was reported by 90%, and the same proportion was observed to have soap in the home. Sixty percent of 99 respondents were observed to have a hand washing station with soap and water.

The water sources in the study area were tubewells, rainwater, and surface water. The frequency of tubewell use was lower at the time of the interview (73%) compared with reported practice before installation of the chulli water purifier (91%), but the frequency of reported rainwater use was the same (27%). Use of alum potash, boiling, and filtration were also lower (Table 1).

Chulli water purifiers were installed a median of 12 months (range = 1–24 months) before the interview. Eighty-nine (88%) respondents paid for their chulli water purifier. The median amount paid was \$3 (range = \$1.50–\$6); 83 (82%) decided to obtain a chulli water purifier because of direct promotion by an IACD representative, and 16 (16%) actively contacted IACD to have one installed after hearing about it from others. Only thirty-four (41%) of 83 respondents stated that they would pay for a new chulli water purifier if it were stolen. Of these 34, the median price they would pay was

TABLE 1

Reported use of improved water sources and household water treatment strategies before installation of the chulli water purifier and at the time of the interview (n = 101)\*

Water source	Reported practice before chulli water purifier installed		Reported practice at time of interview	
	No.	%	No.	%
Use of improved water sources				
Tubewell	86†	91	74	73
Rainwater	25†	27	27	27
Any improved source	92†	98	27	86
Use of household water treatment strategies				
Alum phosphate	15	15	7	7
Boiling	13	13	1	1
Filtration	4	4	3	3
Chulli water purifier	NA	NA	21	21
Any water treatment	30	30	33	33

\* NA = not applicable.  
 † n = 94.

\$1.50 (range = \$0.75–\$7.50). Twenty-one (21%) respondents reported regularly using their chulli water purifier.

**Factors affecting the selection of water sources and water treatment options.** The principal benefits reported for tubewells, among 74 users, and for rainwater, among 27 users, were convenience and perceived water safety (Table 2). Rainwater was used during the entire year by only 7 (26%) rainwater users.

Two main benefits of the chulli water purifier were reported among 101 respondents: availability of hot water, by 65 persons, and availability of safe water, by 48 persons; convenience was not mentioned as a benefit. Eleven (18%) of 62 respondents incorrectly believed that the chulli water purifier reduced or eliminated arsenic from tubewell water. Hot water was used for a variety of purposes, especially in the winter months: cooking and mixing with flour, washing and bathing children, giving to cows and washing hands before prayer. Three persons reported using their chulli water purifier to treat water for their neighbors.

Among 80 persons not using the chulli water purifier regularly, the most common reasons reported were mechanical problems, complexity or inconvenience, and inability to pay the installment (Table 3). Types of inconvenience reported included time and energy required to collect and transport surface water, make safe water and transfer, store and cool treated water.

Of 64 (63%) respondents who cited mechanical problems as a barrier for continued use of the chulli water purifier, the specific problems reported were breakage of the aluminum coil (14, 22%), leakage of water (23, 37%), breakage of the plastic tubing (14, 22%), sand in the system (29, 46%), and air in the system (23, 37%). Fifty-five (55%) of 100 individual mechanical problems were repaired, and this was done by a

TABLE 2

Reported reasons for using tubewell water and rainwater (n = 101)

Reported reason	Tubewell users (n = 74), no. (%)	Rainwater users (n = 27), no. (%)
Able to obtain water on demand	49 (66)	8 (30)
Access to water believed to be free of microbes or arsenic	34 (46)	16 (60)
No need to go far to collect water	22 (30)	14 (52)

TABLE 3

Acceptability: reported reasons for not using the chulli water purifier (n = 80)

Reported reason	No. (%)
Mechanical problems or breakage	39 (49)
Complexity or inconvenience	28 (35)
Inability to pay the installment	8 (10)
Problems with installation	4 (5)
Increased fuel requirement	3 (4)
Bad water taste	3 (4)
Theft	2 (3)
No perceived need for the chulli water purifier	2 (3)
Use exclusively during the winter months	2 (3)

non-governmental organization technician in 41 (75%) instances. Although respondents could not clearly know the cause of such problems, they suspected that some of the following occurrences may have resulted in damage: use with the tap closed and fire on; use with an empty bucket and no water; damage during installation; damage during cyclones, floods, rain, or fire; damage during moving the chulli water purifier from one location to another; careless use; overuse; loose joints; and children opening the tap when there was no water in the system.

Having a belief that contaminated water can cause illness (risk ratio [RR] = 2.6, 95% confidence interval [CI] = 1.3–5.3) was associated with reporting use of the chulli water purifier (Table 4). Members of households with a literate female head of household (RR = 2.0, 95% CI = 0.9–4.2), and persons who treated their drinking water before obtaining the chulli water purifier (RR = 1.6, 95% CI = 0.8–3.4) were also more likely to report using it, although these factors were not statistically significant. Other characteristics associated with reporting chulli water purifier use included not having rainwater available (RR = 3.0, 95% CI = 1.1–8.3), having the chulli water purifier for < 12 months (RR = 2.5, 95% CI = 1.2–5.2), and obtaining the chulli water purifier through one's own initiative as opposed to direct promotion by IACD (RR = 3.9, 95% CI = 2.0–7.7).

Twenty (95%) respondents reported transferring water collected from the chulli water purifier to a second water container for cooling and storing, and the same proportion reported keeping the storage container covered with a metal or plastic cover. The median length of time reported for water to cool enough for drinking was 120 minutes (range = 10–720 minutes).

**Chulli water purifier microbiologic effectiveness.** When initially asked by the interviewers, 21 respondents reported using the chulli water purifier regularly; however, when the laboratory team returned to test water samples, 17 households reported irregular or inappropriate use. Of these 17 households, 15 were either collecting water without a fire burning or without waiting for the water to become hot. Further reasons reported for not using the chulli water purifier regularly included water leakage from the coil, irritating noises from the chulli water purifier, preference to use a double burner stove for improved cooking efficiency, and availability of a gas connection. Water testing was only conducted in the four remaining households with confirmed regular and appropriate use.

Untreated water, which was to be treated using the chulli water purifier, was collected on four occasions in each of

TABLE 4  
Relationship of selected characteristics to self-reported use of the chulli water purifier (n = 101)

Characteristic	% (no. positive/no. tested)	Use of chulli water purifier when characteristic present, %	Use of chulli water purifier when characteristic absent, %	Risk ratio (95% confidence interval)
Literate male head of household	63 (64/101)	22	19	1.2 (0.5–2.6)
Literate female head of household	41 (41/101)	29	15	2.0 (0.9–4.2)
Believed that water can make family ill	22 (21/94)	43	16	2.6 (1.3–5.3)
Believed that arsenic is a concern in tubewell water	83 (74/89)	24	20	1.2 (0.4–3.6)
Knew of someone with arsenic toxicity	45 (45/99)	20	20	1.0 (0.5–2.2)
Treated drinking water before obtaining chulli water purifier	32 (30/94)	30	19	1.6 (0.8–3.4)
Did not have rainwater available	58 (59/101)	29	10	3.0 (1.1–8.3)
Did not have tubewell water available	3 (3/101)	33	20	1.6 (0.3–8.5)
Had purifier for less than 12 months	20 (20/101)	40	16	2.5 (1.2–5.2)
Obtained chulli water purifier after hearing about it, as opposed to through direct promotion from non-overmental organization	16 (16/99)	56	14	3.9 (2.0–7.7)

these four households. Of 16 samples tested, 13 (81%) were from surface water and 3 (19%) were from rainwater. All 16 were positive for *E. coli*; the median *E. coli* count was 5,000 colony-forming units (CFU)/100 mL (range = 1,000–110,000 CFU/mL). The same water was sand-filtered, run through the chulli water purifier without pasteurization, and tested. Again, all 16 samples were positive for *E. coli*. However, the median *E. coli* count was 950 CFU/100 mL (range = 300–22,000 CFU/mL), and the median log reduction in *E. coli* counts caused by sand filtration was 0.4 (range = 0.1–1.8).

The untreated water was then run through the chulli water purifier with both sand-filtration and heat pasteurization. The median temperature of water tested immediately after collection was 62°C (range = 50–80°C). Of 16 samples, 5 (31%) were measured to be less than 60°C, the minimum recommended output water temperature. The median water flow was 230 mL/minute (range = 90–600 mL/minute); only 1 (6%) of 16 was faster than the maximum recommended flow rate of 500 mL/minute. Faster flow rates appeared to be associated with colder water (Pearson correlation =  $-0.45$ ,  $P = 0.07$ ), although this relationship was not statistically significant (Figure 2).

Three (19%) of 16 samples that had been fully treated by the chulli water purifier were positive for *E. coli*, with counts of 200, 500, and 13,000 CFU/100 mL. These samples had water temperatures below the median (50°C, 55°C, and 50°C, respectively) and were from three different households. The overall median log reduction in *E. coli* caused by sand filtration and pasteurization was  $> 5$  (range = 0.4 to  $> 5$ ).

Of 16 household stored water samples tested, all had previously undergone treatment by the chulli water purifier. Ten (63%) samples had been treated at least 24 hours before testing. Nine (56%) of the 16 were positive for *E. coli*; the median count was 100 CFU/100 mL (range = 0–190,000 CFU/100 mL). The median log decrease in *E. coli* between untreated and stored water in the 16 samples was 2.4 (range =  $-1.7$  to  $> 5$ ). Four (25%) samples from two households had more *E. coli* in stored water than in the corresponding untreated water, and seven (44%) had more *E. coli* than the corresponding treated water. Eleven (69%) of the storage vessels were covered and 12 (75%) had a narrow mouth, defined as small enough to prevent entry of a hand. The number of samples was too few to measure difference in contamination associ-

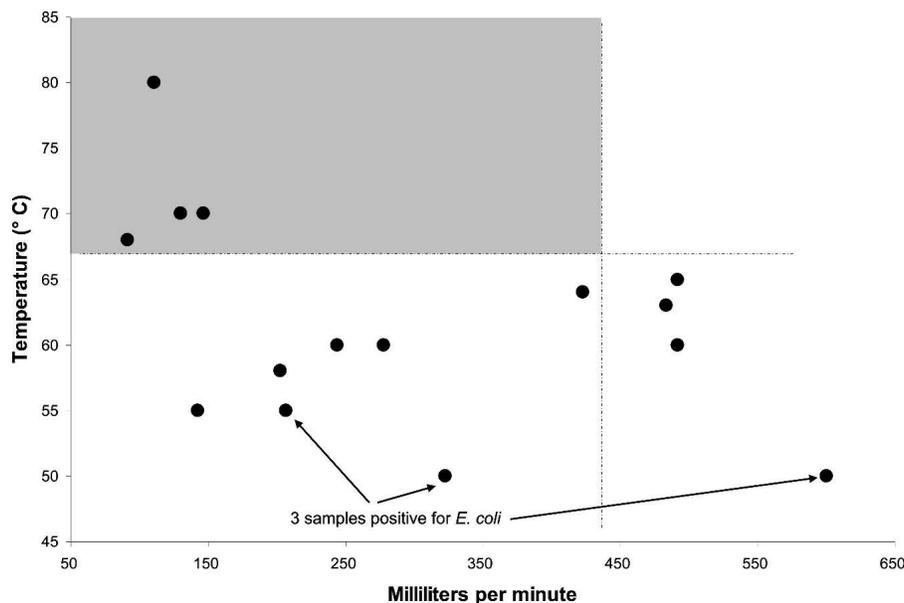


FIGURE 2. Scatter plot of flow rate and temperature of chulli water purifier output water (n = 16). Shaded area indicates recommended temperature and flow rate.

ated with the use of covered vessels, the use of narrow mouth vessels, or the length of time water was stored before testing.

## DISCUSSION

The chulli water purifier was regularly used by only a small proportion of households in which it was installed. The principal reasons cited for this low rate of adoption were poor durability and inconvenience. Although the chulli water purifier can eliminate microbes, this effect was reduced by inadequate heating of water and by recontamination of stored water. Recontamination of stored water is a common problem with household water treatment options, such as boiling.<sup>5</sup> End users may go through considerable effort and expense to treat their water only to have it recontaminated before consumption. Without a chemical barrier in the form of chlorine or iodine, or a safe storage container, the microbiologic benefits of treating water are often reduced or lost.<sup>14</sup>

Durability of the chulli water purifier is a major problem, and many different types of mechanical problems were reported. Engineering changes that improve reliability are essential to support more consistent use.

Inconvenience is also a major factor limiting use. The work of collecting and transporting surface water, treating it using the chulli water purifier, and then storing it is substantial when fresh, clear, cool tubewell water or rainwater is immediately available and does not require separate storage. The chulli water purifier, as well as other household water treatment options, may be less useful strategies for persons with access to rainwater or arsenic-free tubewell water. However, this study was conducted during the rainy season, and results may have been different if conducted in the winter, when rainwater is generally not available, and because hot water from the chulli water purifier was attractive to most respondents.

Concern about arsenic toxicity also did not appear sufficient to cause persons to change their water source. More persons did express concern about arsenic contamination than about diarrheal diseases from drinking unsafe water. However, the belief that arsenic is a concern and the knowledge of someone with arsenic toxicity were not associated with chulli water purifier use (Table 4). This finding is consistent with findings that most persons, despite being aware of the risks of arsenic exposure, will not adopt household water treatment strategies<sup>15,16</sup> or adaptive behaviors such as switching wells<sup>17</sup> if considered inconvenient.

The cost of the chulli water purifier was also a substantial barrier to use, and respondents did not report a willingness to pay the full cost if theirs was stolen. There was a markedly higher proportion of reported users among those persons who actively sought out chulli water purifiers than in those who accepted one during household visits by non-governmental organization field staff. Those who reported using the chulli water purifier regularly were educated, had a pre-existing habit of treating water in the household, or were highly motivated. This group represents a small minority of chulli water purifier purchasers and an even smaller proportion of the general population. These findings suggest that in its current form the chulli water purifier is unlikely to be used by a substantial proportion of the population in Bangladesh.

This study was limited by a cross-sectional design. Baseline data were not available for this population, and the evaluation team could not ascertain how initial promotion and

implementation may have affected acceptability. However, durability and convenience should not be affected by these factors. Relative risks were not adjusted for potential confounders and should be interpreted cautiously; however, the significant associations found are all plausible and consistent with reasons reported for using the chulli water purifier. Also, it is unknown if there were unusual characteristics of Homna subdistrict where this evaluation was conducted that affected acceptance. Finally, the water testing component of this study was limited by low numbers of confirmed regular chulli water purifier users. However, the striking difference found between reported and confirmed use of the chulli water purifier illustrates the unreliability of self-reported use of household water treatment strategies, and the need to confirm regular and appropriate use of such strategies.

This study has implications for the development and evaluation of household water treatment strategies in general. Our findings highlight the unreliability of self report of water use practices, and the importance of direct observation and laboratory confirmation in evaluations of household water treatment strategies. Efficacy trials of different strategies, including filtration, chlorination, solar disinfection and flocculant disinfection, consistently show a reduction in microbial contamination,<sup>7,18</sup> and direct promotion of novel technologies may result in an initially high level of adoption. However, other considerations that are important to the consumer, such as convenience<sup>16,19</sup>; durability<sup>20</sup>; aesthetics, including taste, temperature and smell<sup>16,21</sup>; and cost of the technology<sup>20</sup> may eventually determine if a strategy is widely accepted. Careful consideration of the consumer perspective, including sociocultural, economic, and logistical factors, is necessary when introducing household water treatment interventions.<sup>22</sup> Community-driven implementation strategies may also help by increasing community involvement in selecting new technologies and investment in sustaining their use.<sup>23</sup>

Further research of household water treatment systems should focus on alternative strategies for sustained and widespread use.<sup>9</sup> Two recent systematic reviews of the health impact of water quality improvement strategies<sup>7,18</sup> discuss the critical need for studies assessing their acceptability, use and longer-term effectiveness. The World Health Organization Household Water Treatment and Safe Storage Network draft research agenda<sup>8</sup> further divides this into numerous sub-topics, including cultural views of water, sensory perceptions of water, valuation measures, alternative business models, long-term compliance, understanding of waterborne diseases, and existing local water transportation, storage and use patterns. However, there appear to be few such studies in the scientific literature.

In the case of the chulli water purifier, the United Nations Children's Fund and IACD invested in this independent evaluation of a novel strategy before scale up. Although the results are not optimal, they illustrate the necessity of evaluating acceptability, use, and effectiveness of household water treatment strategies beyond the initial implementation phase. Only by continuing to support and publish these types of evaluations will it be possible to address barriers to the established use of effective household water treatment strategies into households that need them.

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