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RESEARCH ARTICLE

Determinants of consistency of use of household water filters in emergencies: Insights from a protracted drought in Northern Kenya

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Abstract

The consistent use of household water treatment and storage (HWTS) technologies is necessary for human health. However, most HWTS options are designed for typical household use as opposed to emergency contexts, where use is less consistent. To investigate ways to improve the consistency of HWTS use in emergencies, we conducted in-person surveys with 108 households in northern Kenya and comparatively analyzed factors that influenced the use of household filters during a protracted drought. Findings showed that about 50% of respondents used their filter consistently over the course of the study. The main limitation to usability was that none of the filters were well-suited for the indoor living environment of the survey respondents. The factors associated with consistency of use varied by filter design. For one-bucket filters, consistent use was associated with ease of assembly, reported availability of spare parts, and peer approval of HWTS use. For two-bucket filters, consistent use was best explained by the certainty regarding when the filter was functioning or not. We suggest that filter manufacturers should reduce the number of parts to mitigate assembly difficulties and should develop flexible filter designs to improve compatibility across households in terms of space and height requirements. Those disseminating filters during protracted emergencies should conduct user training on the assembly and disassembly of unfamiliar filters and ensure affordable access to necessary replacement parts. Finally, to improve consistency of use of new types of filters, implementers should assess the peer approval of these HTWS options among the target population.

1. Introduction

About 2 billion people worldwide use a drinking water source affected by fecal contamination, which contributes to global child morbidity and mortality, among other negative health

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consequences [1–3]. To improve the quality of drinking water in areas lacking safely managed water supplies, it is necessary to deploy household water treatment and safe storage (HWTS) technologies at the point of use. These devices successfully reduce health risks related to drinking contaminated water, including instances of diarrhea associated with fecal contamination [4, 5]. Among the commonly available HWTS technology options, filters perform well in terms of preventing diarrheal diseases [4] and removing bacteria, viruses, and protozoa [6]. Despite these benefits, studies examining the effectiveness of HWTS technologies as compared to other water safety interventions have reported mixed results [7] and ultimately point to the need for consistent use to achieve the intended health benefits [5, 8, 9].

Consistent use is influenced by a mix of technical, psychological, and social factors. Sobsey, Stauber [10, 11], Dreibelbis, Winch [12], and Mosler [13] attribute inconsistent HWTS use to three categories. (i) technological factors, such as reservoir volume, aesthetic physical aspects of the filter, and mode of operation; (ii) psychosocial factors, such as user perceptions regarding the safety of local water supplies, perceived benefits, and knowledge of HWTS protocols; and (iii) contextual factors, such as the house structure, household environment, and user practices. Other studies have reported additional related factors, such as that by MacDonald, Juran [14] reporting that the households' perceived benefits of HWTS were significantly associated with consistency of use in Chennai. In low-income urban communities in Bangladesh, high levels of consistent use of household filters were associated with factors such as a positive attitude towards filter use and reporting boiling drinking water at baseline. Conversely, low consistency has been attributed to the consideration of filter use an additional task, filter breakage, and slow flow rates [12, 14–16]. Finally, users are also often concerned with the availability of a supply chain for spare filter parts [17].

Emergencies provide an additional complication, and a number of studies on HWTS effectiveness and their consistency of use have been conducted in varied emergency situations. For instance, Lantagne and Clasen [18] investigated the effectiveness of point-of-use chlorination or filter interventions in Nepal, Indonesia, Kenya, and Haiti during an acute emergency response. They observed that the effectiveness of HWTS programs was influenced by the provision of effective HWTS options, functional supply chains, training, and pre-emergency user familiarity with treatment methods. During a protracted emergency in Myanmar, 62% of households initially used ceramic water filters consistently, but use was eventually discontinued with reduced filtration rates or when the ceramic pots broke [19]. While a few comparative studies have been conducted on filters in emergency contexts (e.g., Rayner, Murray [20]), none have been conducted in the context of a protracted drought. The authors expect different results in such settings due to the increase in the precariousness of the residents' livelihoods. In addition, none of the studies has investigated whether filters with storage compartments are used more consistently than those without. This study comparatively analyzed the factors affecting the consistent use of filters at the household level based on their interface design during a protracted drought in Northern Kenya.

2. Materials and methods

2.1 Study site

This study was conducted in 2018 in Marsabit County in northern Kenya, which has been experiencing a protracted drought crisis since 2014. Marsabit County receives relatively low rainfall, averaging 760 mm annually [21]. As a result, the county has been characterized by high human morbidity, high livestock mortality and morbidity, resource conflicts, food insecurity, low livestock prices, and high food prices [22]. Complicating matters, more than half of the county's surface water sources are contaminated by fecal matter due to open defecation [23].

The people living in the study village are settled pastoralists, meaning men travel long distances in search of pastures while the women and children remain behind. Those left behind reside in temporary structures that are about two meters high and five to ten meters in diameter. Women perform most of the household chores, including ensuring the availability of household drinking water. Most households depend on contaminated surface water sources for their daily needs. In addition to the contamination risks, many of these local water sources are seasonal and rarely fulfill the required demand throughout the year.

2.2 The filters and filter groups

This study assessed the consistent use of filters that were supplied to improve the quality of water consumed in the village. In late 2017, a non-governmental organization that had previously provided water provision interventions in the area distributed four types of filters for free and at the same time to the residents. Each household received one type of filter.

The four filter types were grouped according to their design characterized by presence (two-bucket design) or lack (one-bucket design) of a water storage compartment, as shown in Fig 1. This differentiation was necessary for comparative purposes as well as for deriving a sufficiently large sample for statistical analysis. This differentiation was also based on physical differences in the filters that residents were able to easily spot when the filters were distributed and that the researchers hypothesized would influence consistent use.

The two-bucket group used two types of filters. The first comprised a black filter element made of carbonized coconut shells that employed gravity filtration. It was assembled using locally available buckets, one for raw water and the other for filtered water. The second filter in this group also used gravity filtration, instead employing a white ceramic filter cartridge between the compartments for the raw and filtered water. Both filters in this group had taps that were similar to those available in the local hardware shops.

The one-bucket group also used two types of filter. The first type had a single water compartment and relied on both gravity and suction force for filtration. Its filter element was made of diatomaceous earth treated with nano silver, and it contained activated carbon and a bromine-releasing cartridge. The filter element was connected via a hose to a rubber suction bulb and a tap. The second type of filter in this group also had a single compartment connected via a hose to a membrane filter that employed gravity filtration.

2.3 Variables and measurements

Combined with observations of the filter setup by the first author, the study also assessed the consistency of filter use via a structured questionnaire developed to assess the perceptions of economic, psychosocial, contextual, and design factors related to the filters, which were chosen based on the results of previous studies [9, 13, 15–17, 24–26]. The following paragraphs briefly describe the different variables and the measures used to assess them. The full questionnaire is available in the S2 Table.

2.3.1 Economic factors. To assess the economic perceptions of the filter, households rated the value of the filter, their willingness to pay for a similar filter, and the availability of spare parts. A four-point Likert scale of 1 = strongly agree, 2 = agree, 3 = disagree, and 4 = strongly disagree was used to evaluate these factors.

2.3.2 Behavior and psychosocial factors. Psychosocial factors and socio-psychological factors that may influence behavioral change as well as sustain a newly acquired behavior were assessed using the Ranas model as proposed by Mosler [13]. The model includes the following

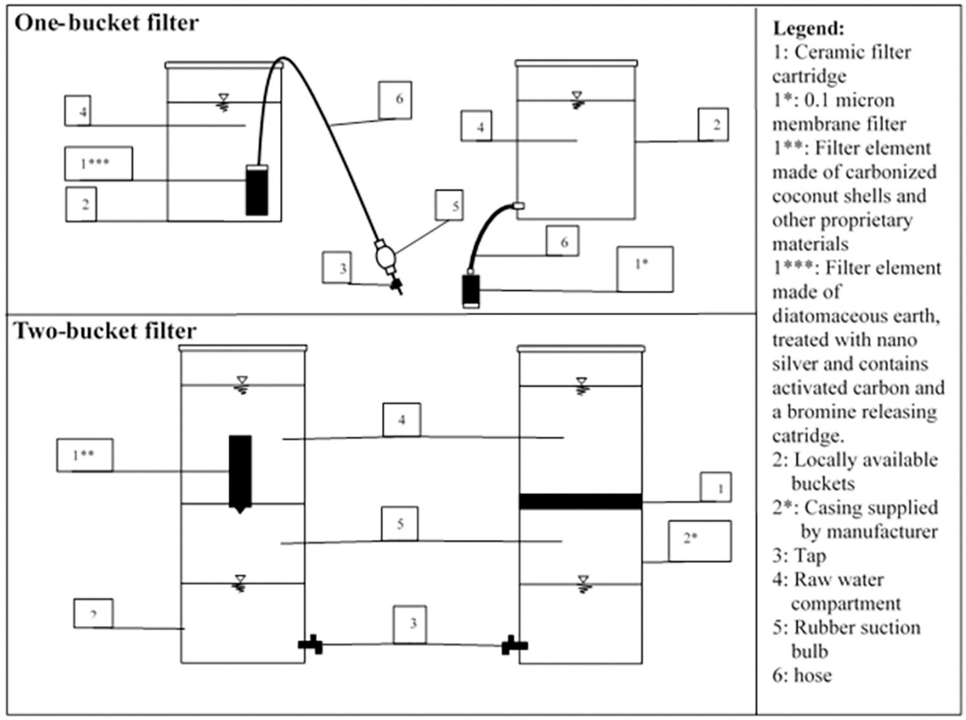

Fig 1. Illustration and characteristics of the filters included in the study.

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factors: perceptions of self-efficacy including general norms, the cost-benefits of filtering water, peer approval, intent to treat water, habit, planning, forgetfulness, and severity of the problems associated with consuming untreated water. Most of these factors were ranked according to a four-point Likert scale ranging from 1 = strongly agree to 4 = strongly disagree.

2.3.3 Factors relating to household environment and application process. The household environment and ease of application of the filter were also hypothesized to affect the consistent use of household filters. Questions about the household environment included the fit and application of the filter in the house, operation of the filters in low lighting, access to filtered water by children, time wasted during filter use, acceptability of flow rate, required cleaning time, and cultural prohibitions. All these factors were assessed using a four-point Likert scale ranging from 1 = strongly agree to 4 = strongly disagree.

2.3.4 Design factors. Design factors were assessed using questions about the comprehensibility of the initial setup, the space occupied by the filter and its dimensions, whether there was a visual indication of proper filter function, perceptions about disassembly during cleaning, tap accessibility for all members, and filter stability. Most questions were assessed using a four-point Likert scale (1 = strongly agree to 4 = strongly disagree), with the exception of the presence of an indicator of proper filter function, which was assessed using a dichotomous (yes or no) response.

2.3.5 Consistency of use. Consistency of filter use was assessed based on information gathered during the interview on self-reported filter use. Respondents were asked to give an estimate of how much water they consumed per day during the previous month and how much of it had been filtered. This ratio was then converted into a percentage, with 0% implying no filter use and 100% implying fully consistent use of their filter. The respondents reported these amounts in units of locally available containers of known capacities (5 liters, 10 liters, and 20 liters). To verify usage, the enumerators checked for water in the raw or filtered water compartment of the filter or for whether the compartments were moist, indicating recent or current use.

2.4 Participant enrollment and data collection

Data for this study were collected from March to May 2018 from one village with a population of approximately 5000 residents. The study village was chosen because residents were willing to participate and the location offered convenient access to a site comparable to other nomadic villages throughout Marsabit County, the bordering regions of the neighboring countries, and the North-eastern regions of Kenya in general in terms of electricity access, education levels, and livelihoods. The person in the household primarily responsible for the filter was invited to participate in the survey; a total of 108 households were enrolled. Questionnaires provided data that were analyzed quantitatively. In addition, unstructured observations were conducted on how the filters were used by the respondents, and the filters were visually checked for traces of recent use.

Oral informed consent was sought from all study participants before their enrollment. This study's protocol was approved by both the Swiss Federal Institute of Aquatic Sciences and Technology (Eawag) protocol ref: 16–09_04-10-2017 and Jomo Kenyatta University of Agriculture and Technology (JKUAT) Ethical Committee protocol ref: JKU/2/4/896B.

2.5 Data analysis

Quantitative data was analyzed using SPSS v.20 software (IBM Corp., Armonk, New York). These analyses included descriptive statistics and the association of each independent variable with the dependent variable via a Spearman Rho correlation. To model and identify factors that explain the consistency of filter use, we used multiple linear regression (ordinary least squares) based on the two filter groups. For the regression model, we included only those independent variables with sufficient variation in their scores and that were correlated with the consistency of use in at least one of the filter groups at the $\alpha = 0.05$ level during a univariate correlation analysis (See S1 Table).

3. Results

From the household survey data (N = 107), only one household datapoint was not used, as the questionnaire was not sufficiently completed. All the respondents were women in the reproductive age group with similar livelihoods of pastoralism. Additionally, all respondents were aware that drinking untreated water resulted in a variety of diseases, and 24% directly linked consuming untreated water with diarrhea. The average daily water consumption was 20 liters per household. Our observations indicated that most (85%) of the respondents had drinking water available in their households at the time of the visit. There was water in the raw water tank of the filter in 60% of the households, and the filters looked clean in 73% of the households. During the maintenance process, respondents concentrated on cleaning the outer casing of the filters. The containers for storing water did not have visible dirt or impurities on the inside in 63% of the households. The median consistency of use for both filter groups was 50%, indicating that half of the typical volume of consumed drinking water had been filtered daily over the past month. The interquartile ranges of the consistency of use for the one-bucket and two-bucket filter designs were 42% and 33%, respectively.

Table 1 presents some insights from the descriptive statistics for the factors included in the regression model. For instance, in terms of spare parts, 43% and 36% of the respondents thought that they would find spare parts for the one-bucket and two-bucket filter, respectively. More respondents remembered to filter their water in the week before data collection for the two-bucket filter (65%) as compared to the one-bucket filter (53%). The filters proved

Table 1. Descriptive statistics for factors that were included in the regression analysis.

Factor	Two-bucket filter					One-bucket filter					
	N	Range	Min.	Max.	Agreement %	N	Range	Min.	Max.	Agreement %	Intergroup differences (P value)
I would find spare parts to repair the filter easily.	58	3	1	4	36	49	3	1	4	43	0.966
People important to me disapprove filtering water.	58	3	1	4	28	49	3	1	4	37	0.624
In the last seven days, how often did it happen that you wanted to drink water, but you forgot to filter it in time?	58	2	2	4	65*	49	3	1	4	53*	0.47
It is possible to install this filter anywhere in my house.	58	1	1	2	0	49	2	1	3	2	<0.001
Does the product indicate when it is not filtering water properly?	58	1	0	1	15	49	1	0	1	12	0.334
The fitting parts can be incorrectly fitted.	58	3	1	4	44	49	3	1	4	27	0.096

Note

*Percentage that did not forget to filter water in the last seven days.

For all variables, 1 = strongly disagree, 2 = disagree, 3 = agree, 4 = strongly agree, unless otherwise specified.

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unwieldy, though, as the respondents unanimously agreed that it was not possible to place and use all of the filters in most parts of their house. Lastly, incorrectly fitting parts of the filters during reassembly was a concern for 27% and 44% of the respondents in the one-bucket and the two-bucket filters, respectively.

Table 2 details the results of regression analyses. For the one-bucket filter, consistency of use was significantly and positively associated with the perception of easy availability of spare parts, the possibility of placing the filter anywhere in the house, and the possibility of incorrectly fitting the parts of the filter. It negatively correlated with the disapproval of filter use by

Table 2. Multiple linear regression (ordinary least squares) model of consistent filter use for both filter groups individually and combined.

Predictor variables	Dependent Variable: Consistent Use (%)					
	Two-bucket filters		One-bucket filters		Both combined	
	B (SE)	*P* value	B (SE)	*P* value	B (SE)	*P* value
I would find spare parts to repair the filter easily.	0.839 (4.23)	0.844	**22.644 (4.79)**	**<0.001**	8.64	**0.012**
It is possible to situate and operate this filter anywhere in my house.	**21.554 (6.22)**	**0.001**	**21.118 (6.61)**	**0.003**	**20.367**	**<0.001**
In the last seven days, how often did it happen that you wanted to drink water, but you forgot to filter it in time? (1 = 0 times, 2 = 1–5 times, 3 = 6–10 times, 4 = more than 10 times)	-5.531 (4.76)	0.250	-3.652 (3.88)	0.352	1.040	0.739
The filter parts can be incorrectly fitted.	2.309 (5.21)	0.660	**13.192 (5.41)**	**0.019**	5.495	0.159
People who are important to me disapprove of if I filter my drinking water.	-0.610 (4.67)	0.896	**-11.092 (4.84)**	**0.027**	-5.092	0.143
Does the product indicate when it is not filtering water properly? (1 = Yes, 0 = No)	**-19.151 (7.27)**	**0.011**	-1.247 (8.57)	0.885	**13.385**	**0.022**
One- or two-bucket filter (dummy variable)	Not applicable		Not applicable		0.214	0.959
Constant	5.318 (26.27)		-36.17		143.17 (26.47)	
R^2	0.37		0.55		0.35	
Observations	58		49		107	

For all variables, 1 = strongly disagree, 2 = disagree, 3 = agree, 4 = strongly agree, unless otherwise specified.

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people that the respondents considered important, such as other family members and relatives. For the two-bucket filter, consistency of use was significantly associated with the possibility of placing the filter anywhere in the house and was negatively correlated with whether the filter indicated that it was working correctly or not.

The size and space requirements for operating the filters significantly influenced consistent use for both filter groups. The two-bucket filter required a larger space relative to all other items in the respondents' homes. Respondents that felt that the filter occupied too much space in their house were less likely to use it consistently. Conversely, the single-bucket filters required the bucket to be elevated for an acceptable flow rate, but this proved to be a challenge that prevented most users from filtering water inside their homes. Most opted to take their filters outside during the day to filter water.

Overall, the filters were generally accepted. Most households preferred to drink filtered water over their previously consumed water, acknowledged the benefit of filtering water, and intended to filter water in the future. There was also common knowledge of the link between contaminated water consumption and diarrheal diseases. However, none of these factors significantly correlated with consistent use.

In terms of statistics, the Shapiro-Wilk test for the regression model indicated that the residuals of the regression models were normally distributed for the two-bucket and one-bucket filters, with values of $P = 0.05$ and $P = 0.46$, respectively. This was upheld by the Lilliefors-corrected Kolmogorov-Smirnov test, with values of $P = 0.08$ and $P = 0.20$, respectively.

4. Discussion

The consistency of use for both one- and two-bucket filter users differed from other studies. For instance, Nusrat, Shaila [15] reported lower values (between 21% and 31%) in a non-emergency setting in Bangladesh for filters similar to one-bucket filters. Though they measured the consistency of use similarly to our study, the non-emergency setting could explain the lower reported use. Albert, Luoto [27] reported 62% filter usage in Kenya for households with poor quality water in non-emergency contexts. Though also a non-emergency setting, the available water in this location was very turbid such that households expressed a preference for filters over other point-of-use treatment methods. Otherwise, the observed discrepancies in the consistency of use between studies were likely due to the differences in the assessed predictors. In our study, the protracted emergency and the poor quality of available water increased the precariousness of the community and could have consequently prompted overall higher consistency as compared to some of the other previous studies. This is in line with reported findings for filter use in acute emergencies with similar outcomes (e.g. Rayner, Murray [20]).

The availability of spare parts impacted filter use. For instance, the more the users of one-bucket filters perceived that the spare parts of the filters would be available, the more consistently they used their filter. This contrasted with the two-bucket filter group wherein this association was absent, though the parts for these filters (especially the tap and local buckets) were readily available in local hardware shops. This agrees with the results of other studies that found that the lack of a supply chain was associated with a cessation of use of ceramic filters [10, 17] and further emphasizes the need to assure reliable access to spare parts. This is necessary especially for filters with parts that are unfamiliar to residents.

Peer approval was a significant psychosocial predictor of consistent use for the one-bucket filters, which were a relatively new type of filter to the residents as compared to the two-bucket filters. Thus residents were more confidence using them if they saw that people they trusted in the community, such as elders or relatives, were also using them. This was expected, with Rogers [28] explaining peer approval as a collective innovation decision whereby the decision to consistently use filters is influenced by immediate peers. Interestingly, injunctive norms, which represent behaviors one is expected to follow in social situations, representing the perceived social pressure towards filtering predicted consistent use for the one-bucket filter design but not for the two-bucket filter [29]. Freeman, Trinies [30] acknowledged the importance of peer influence in behavioral change interventions and recommend involving groups in HWTS sensitization campaigns to enhance the uptake and consistent use of water treatment at a household level.

The association between space requirements in the house and consistent filter use is congruent with the finding of PATH [31] on the challenges of siphon filters, which are similar to the one-bucket filter, because of the need for a higher height for efficient application, despite the advantages of their minimal footprint. The two-bucket group was also affected by the household setup, mainly due to their large footprint that requires balancing space requirements in the house while meeting the demand for a high filter capacity and effective water treatment. The perception of lack of spare parts and limited space requirements have been elicited in other studies [17, 20]. Our contribution is to confirm that they are still very relevant even in protracted drought emergencies.

The higher consistent use of one-bucket filters was associated with a simple initial assembly of filter parts. We therefore recommend targeting leaner designs with more compact parts that do not require assembly by users. Filters with many parts that need constant reassembly should be accompanied by proper training. In agreement with this, Ojomo, Elliott [17] emphasize the importance of training even when filter distributors view a particular HWTS technology or product as simple or intuitive to use. This is especially true for less common designs, such as the one-bucket filter, which required more training and were preferred less than two-bucket filters.

Another point of concern specific for users of two-bucket filters was the inability to determine whether a filter was functioning correctly or not. As none of the filters could indicate this, users had to guess if filters were still working properly from changes in the flow rates. We recommend that filter manufacturers include a real-time monitoring indicator to show the functional status of the filter so that the users are not left guessing and can receive assurance when the filters are properly installed and functioning.

The unexpected lack of correlation between consistent use and knowing that diarrhea can be caused by contaminated drinking water could imply that more sensitization on the importance of the filter may be necessary. This is especially true because several households either forgot to regularly filter water or perceived that their peers did not approve of the use of filters. Sensitization on filters could thus focus on ensuring peer approval.

The findings of this study have implications for policy and practice. It will be essential for the future distribution of new styles of filters to establish supply lines for spare parts. To ensure the selected filter is useful in the dwellings in the area, it is also essential to conduct early assessments of the types and nature of dwellings where the filter is likely to be used. Where possible, it would likely increase consistency of use to include a physical indicator for whether the filter was filtering as expected to assist users in assessing filter performance.

5. Conclusion

This study sought to understand and compare the factors that influence the consistency of use of household filters in a slow onset emergency of a protracted drought. Five conclusions can be drawn from this study; first, the largest predictor of consistency of use for both one- and two-bucket filters is whether the filter can be placed and operated with ease in the home. This relates to the physical accessibility and volume of the filter inside the house. Secondly, user perceptions of the availability of spare parts determines the consistent use of one-bucket but not two-bucket filter designs. In fact, for one-bucket filters, the more available the spare parts are perceived to be, the higher the chances of consistent use. Third, societal influence and peer approval determine the consistent use of one-bucket filters, with higher approval equating with a greater consistency of use. Fourth, user understanding of whether a filter is functioning or not and how the filter parts are assembled plays a role in consistent use. Users familiar with the physical features of the filters are more consistent in use, specifically for two-bucket filters. Fifth and finally, though both filter groups have the potential to be used consistently as well as improve drinking water quality, different factors influence how consistently they are used. We recommend more comparative studies of this nature in different contexts to ensure all barriers to use are known before employing the use of specific of filters.

6. Study strengths and limitations

Working within a community with similar characteristics was a strength of the research design, since it allowed us to compare the filter groups on a relatively stable framework that provided high internal reliability. However, these results should be interpreted bearing in mind that the study sampled women from one community served by similar water sources and possessing similar cultural beliefs and perceptions about their water services. Therefore, the results are likely not representative of the broader population of Marsabit county, though can be generalized to the many villages in Marsabit and beyond that have similar nomadic lifestyles, arid and semi-arid climates, and frequently face protracted droughts.

Additionally, consistency of use was self-reported and could not be measured directly over time due to time constraints. Other recommended methods of evaluating consistent use, such as having users record filtering times and amounts over time, were not possible due to the low literacy levels in the households. As in any research survey into health and hygiene behavior, an additional limitation of this study is the potential for social desirability bias, i.e., some participants might provide answers that do not reflect reality but are instead based on their perception of what the enumerator wishes or expects to hear, especially because the filters were provided for free. To manage this, we have attempted to interpret results with caution and made use of indirect measures for the purpose of triangulating hygiene. For example, consistency of use is not asked directly, but rather measured as a ratio of reported volume of water consumed to the volume of water filtered.

Supporting information

S1 Table. Spearman's rho correlation coefficients for factors affecting the consistency of use of household filters.
(DOCX)

S2 Table. Descriptive statistics for questionnaire items on households' perceptions of their filter.
(DOCX)

Author Contributions

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